[*Sustainability Assessment for West Africa's Interconnected Electricity Network.*]

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Overview

Increasing electricity access is a necessity for the sustainable development of any country. Hence providing reliable and affordable electricity to people without access to electricity by 2030 is one of the targets of the Sustainable Development Goal (SDG) 7 and Sustainable Energy for All (SEforAll) initiative. In order to achieve this ambitious target for the 171 million people in West Africa without access to electricity, the ECOWAS (Economic Community of West African States) Renewable Energy Policy (EREP) was defined in 2015 with several targets for 2030. First, increase electricity access in all member states to 100%. Second, 75% of the ECOWAS population will be connected to the grid, with the remaining 25% connected to mini-grids and stand-alone systems. Third, increasing grid connected renewable energy installed capacity to 48%. Fourth, reduce greenhouse gas (GHG) emissions in the energy sector (no specific benchmark was set). Furthermore, a few of the member states of ECOWAS have set national RE policies to increase electricity generation from renewable energy sources (RES) with the targets varying between the countries. In line with the EREP targets, the West African Power Pool in 2015 set additional targets for the region. These targets include interconnecting the electricity grid of all fourteen member states, establishing a single regional electricity market and developing large regional RE power plants by 2025. Despite political cooperation between member states and increasing research on RE potentials in the region, lack of well-defined national RE policies and increasing oil and coal power plant developments to meet rapidly growing demand continue to hinder the success of the aforementioned targets. These new fossil fuel power plants will consequently increase the GHG emissions from the electricity sector. Given the continuous conflicting implementation of national and regional projects, there is need for a consensus on an optimum electricity mix and interconnection expansion policy which will consider technical, economic and environmental aspects of each country. Therefore, the objective of this study is to answer the research question "What is the sustainability assessment of the proposed national and regional generation and interconnection plans for each West African country".

Methods

PLEXOS Integrated Energy Modelling tool is used in this study and is developed by Energy Exemplar for the planning, simulation and optimization of electricity systems. The model developed in PLEXOS for the West African region has a temporal resolution of 1 hour in 2025 and a spatial resolution of 33 sub-regions, with each sub-region's location equivalent to the interconnection point in each of the 14 countries under this study. By dividing the entire West African region into 33 sub-regions, we account for the hourly intermittent characteristics of the RES in various sites in each country, and also aggregate the power plants in each country based on their fuel type and sub-regions. The power plants in each country are aggregated based on their type of technology and their proximity to their closest region. We modelled the existing and planned 25 interconnection lines between the 14 countries by their maximum flow capacity.

In order to quantify the technical and economic impact of increasing cross-border electricity trade and high RES integration, we examined four scenarios. In the *Business as Usual(BAU)* scenario, we assume all national and regional power plants currently in planning phase are fully operational. On the other hand, interconnection capacities remain the same as in 2019 with only 9 countries interconnected (2.5GW). The *Renewable* scenario has the same interconnection capacity as the BAU scenario and seeks to utilize the unexploited hydro resources in the West African region. We assume potential run-of-the-river hydro power plants (5GW) are in operation in addition to the BAU scenario installed capacities. Additionally, we identified pumped hydro energy storage (PHES) in the region (1GW). Additionally, for the *Renewable* scenario we assume solar PV capacities (38 GW) in order to meet the EREP's objective of increasing grid connected renewable energy installed capacity to 48%. This additional solar PV capacities in the Renewable scenario, are then divided equally between the different regions in each country in order to represent the intermittent characteristics of solar resources in different locations. In the *BAU NewLines* and *Renewable NewLines* scenario we assume the plans for WAPP to interconnect all 14 west African countries is successful. Therefore, all the twenty-five existing and proposed interconnections fully operational.

In this study, we have identified 8 sustainability criteria which have been grouped into 3 categories: technical, economic and environmental. The technical criteria reflect the ability of the grid to continuously meet electricity demand at all times and they include: system reliability, electricity import independence and peak demand response.

These 3 technical criteria are beneficial criteria which means that a higher value is better. The economic criteria are average marginal cost and annual electricity generation cost, which reflect the ability to provide affordable electricity to consumers and consequently encourage competition among suppliers in the electricity sector. These 2 economic criteria are non-beneficial criteria which means that a lower value is better. The environmental criteria include CO_2, NO_x, and SO_2 emissions and reflect the total amount of GHG emissions generated by each country in each scenario. Furthermore, they give an indication on the impact of RES in replacing electricity generated from fossil fuel plants. Similar to the economic criteria, the 3 environmental criteria are non-beneficial. We assume 5 weighing outlooks to assess the sensitivity of the planning scenarios' ranking when the criteria categories are given equal importance, or when one or more of the categories is assigned a higher relative importance. In all the 5 weighing outlooks, the weight assigned to a criteria category is divided equally among its respective criteria. The first outlook is the Equal Weight where all the 3 categories are assumed to be equally important , and the second outlook is the Technical Priority which assumes the technical reliability of the grid is the most important criteria. The third outlook is the Economic Priority which has a business focus orientation and economic criteria are considered the most important. The Techno-economic Priority is a more realistic outlook where providing reliable and affordable electricity to consumers is considered the most important criteria. Finally, the Environmental Priority considers the GHG emission impact on the environment to be the most important criteria. PROMETHEE II, a Multi Criteria Decision Analysis (MCDA) method is applied to rank the above-mentioned scenarios using pair-wise comparison, while considering the 8 defined criteria.

Results

The results from the optimization model showed that with the current generation and interconnection capacity plans (national and regional), only Guinea can meet 100% of its grid connected demand by 2030. Thus, leading to continued unexpected electricity outages and load shedding. Additionally, generation costs in most West African countries will still be relatively high, with average marginal cost ranging from an estimated $27/MWh to $140/MWh. This is due to the reliance of electricity generation on imported diesel and heavy fuel to meet national electricity demand and electricity export obligations. On the other hand, by increasing interconnections between countries and the share of RES in the system through solar PV and hydro power plants, reliability in all the countries can be increased to 100%. The presence of additional interconnections in the region provides the opportunity for some countries to import electricity generated from these RES in neighbouring countries. However, countries like Benin, Burkina Faso, Gambia, Guinea Bissua, Senegal and Togo could be dependent on other countries for up to 40% of their electricity supply. With the integration of high shares of RES and additional interconnections in the West African electricity system, average marginal cost could reduce significantly ranging from $1/MWh to $38/MWh. However, in this scenario diesel and heavy fuel are still maintained as reserves, which leaves them susceptible to global price fluctuations. Finally, fossil fuel capacities could account for only 37% in the generation mix in the *Renewable Newlines* scenario, resulting in GHG emissions decreasing by 44% in the region.

The performance of each country based on the 8 sustainability criteria, in the 4 planning scenarios are presented in this study. The results highlight the conflicting relationship between the technical, economic and environmental criteria for each country. For eleven countries (Benin, Burkina Faso, Gambia, Ghana, Guinea, Guinea Bissua, Liberia, Mali, Senegal, Sierra Leone and Togo) the results were stable across all the five weighing outlooks, with the same scenario (*Renewable NewLines*) having the top rank as the most sustainable scenario despite the varying importance of the different criteria categories. This is as a result of diversifying the electricity generation mix with the integration of RES , and the additional interconnection lines in comparison to the *BAU* scenario. The *BAU* and *BAU NewLines* scenarios performed poorly in most of the criteria, and were ranked as the least sustainable scenarios for all the countries. This is due to these 2 scenarios characterized by insufficient generation capacities to meet demand, low share of RES in the electricity generation mix and relatively high utilization of expensive fossil fuel power plants to meet demand in neighbouring countries.

Conclusions

Selecting a long-term generation and interconnection capacity planning scenario can be a complicated task, as it requires simultaneously considering the impacts of sometimes conflicting technical, economic and environmental indicators. This study has applied optimization modelling and MCDA in evaluating future electricity planning pathways for West African countries. ECOWAS has set targets to provide affordable and reliable electricity in all 14 West African countries, thereby improving economic growth in the region. Results from this study show that cross-border electricity trading is a feasible option to achieve affordable electricity in the region, provided that there is an increase in grid connected hydro and solar power plants. The scenarios presented in our study show that investments in unexplored hydro and solar resources can achieve the aim of WAPP to reduce the supply-demand gap and GHG emissions in the region. The MCDA analysis of the generation and interconnection scenarios was useful in the sustainable assessment and ranking of future scenarios for West Africa's interconnected electricity network. This study has presented policy recommendations in achieving the multi-dimension objectives of ECOWAS in providing reliable and affordable electricity in a low-carbon system.