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Evaluation Of The Cost Of The Energy Mix Of The West African Power Pool Interconnected Network By 2032

Journal of Electrical Systems

Abstract: - Matching electricity supply and demand in the countries of West Africa is a key issue for the energy independence of the sub-region. To this end, the West African Power Pool has drawn up a master plan which includes a supply forecast for 2032. This electricity production forecast, which includes 20% of intermittent renewable energies, shows that there will be an overproduction of energy if all the forecast projects are implemented. This will result in very high net energy costs for the population. This calls for rigorous scientific work to balance supply and demand in the long term, in order to avoid the disadvantages associated with overproduction. The objective of this work is to make use of heuristic methods, in particular the combination of Taboo and Cuckoo research, to determine the optimal energy mix at peak times of the day and night. The results showed that at the daytime point, the optimal mix for the interconnected network of the Economic Community of West African States (ECOWAS) is made up of 81.5% solar and wind power and 18.5% hydropower. The night-time peak is dominated by hydroelectricity (88%), followed by wind power, biomass and gas. The annual energy mix is distributed between hydroelectricity (70.7%), solar PV (19.7%), wind (4.1%), gas (5.1%) and biomass. We note a reduction in the proportion of gas by more than 60% compared with 2022. The average cost to 2032 is $86.83/MWh.

Keywords: Overproduction; optimization; electrical energy; energy mix; Peak.

I. INTRODUCTION

The states of West Africa united as a community aim to meet the energy challenges of the sub-region through the West African Power Pool (WAPP). One attribute of this institution is to ensure the balance between supply and demand at an affordable cost. WAPP therefore adopted since 2012, a master plan that includes all the existing sources of production and the one in project. For uniform network and energy market for all states, the region is divided into power zones as shown in figure 1. In order to meet the Paris COP 21 agreement to limit global warming to 2°C by 2050 [1] and the commitments made by the heads of state of West Africa, there is massive integration of renewable intermittent energy. Thus, WAPP has decided to update its master plan in order to ensure an environmentally friendly mix.

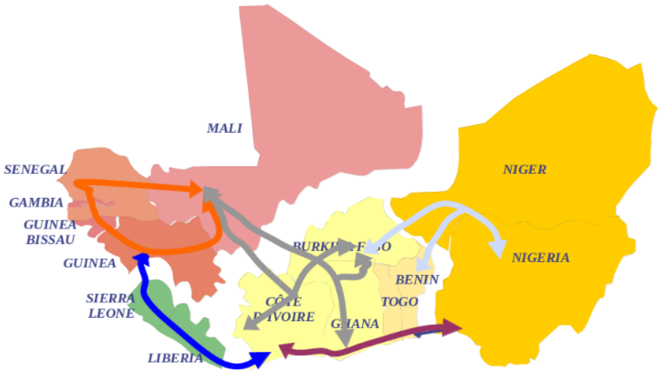

Figure 1. Composition of WAPP with interconnection lines [3]

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This system is made up of 5 control zones with zone managers whose roles are to ensure the balance between supply and demand and to ensure energy transfers outside the zone. The scientific work carried out by [2] has shown that the peak of electrical demand and the consumption of electrical energy in the West African Zone are correlated with social, economic and climatic parameters such as temperature, gross domestic product (GDP) and population size. Likewise he found that the ARIMA model corresponds to the forecast of energy while the Prophet model corresponds to the forecast of peak electricity demand. Thus in 2026 and 2032 they respectively estimated the point of electricity demand at 12.29GW, 13.6GW and energy consumption at 86.14TWh and 96.85TWh

From the updated plan for the projection of 2018 means of production [3] the long-term mix in 2032 will consist of 36% the production of renewable energy, i.e. 18% for hydroelectric power plants, 17% for photovoltaic power plants and 1% for wind power plants With an installed power of 36GW for solar PV. For thermal power plants, they will be dominated by gas at 62%, coal at 2% and the rest between biomass and HFO in small quantities. The figure 2 shows the distribution of the energy mix in the long term

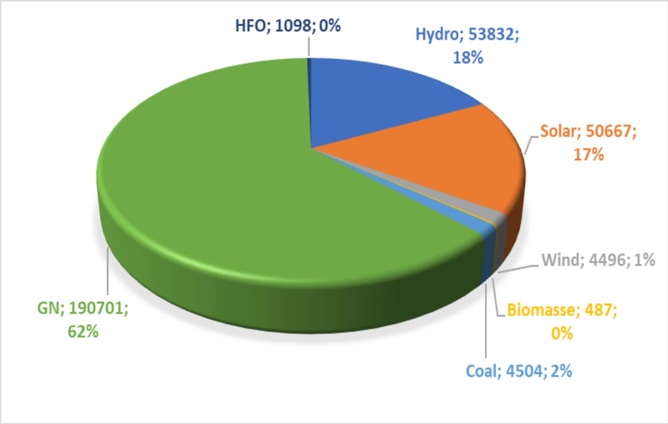

Figure 2. Long-term energy mix [3]

In 2022, an update of installed capacity with the demobilization of leased and idle power plants yielded the results shown on figure 3 and figure 4 for 2026 and 2032 respectively in terms of installed capacity by zone and total.

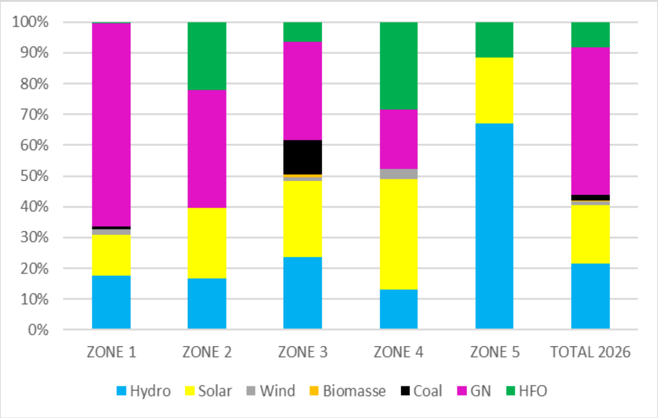

Figure 3. Install mix by zone and source in 2026

In 2026, the global installed capacity of 51.97 GW, with gas predominating in general, although this predominance varies in the different zones. For example, in Zone 5 we have hydro and in Zone 4 we have solar. In 2032, this trend would result in an installed capacity of 68.87 MW, with the same predominance. Figure 4 shows the installed mix.

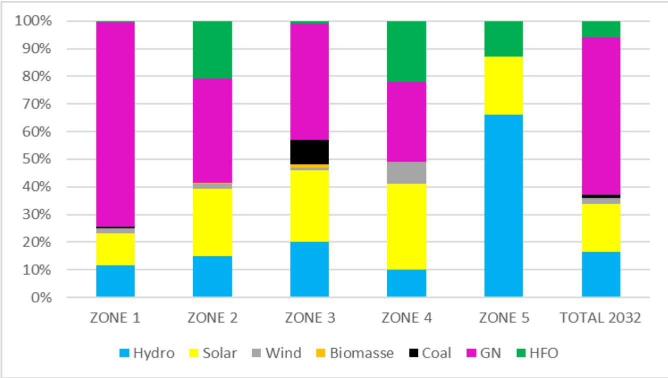

Figure 4. Install mix by zone and source in 2032

Thus a comparison of the peak values and the installed power capacity shows that if all the power plants should operate, the demand will not be in the rang of overall power produced. There will be overproduction and the cost of energy will be affected. Hence, there is need to optimize the system in order to meet the demand at low cost and avoid overproduction and in the sale way reduce environmental pollution. In the literature, several authors have addressed these questions. The author [4] who proposed an optimization of renewable energy sources in the city of Perugia in Italy in order to reduce the cost of production and the environmental impact.[5] to use the genetic algorithm for the optimization of an isolated hybrid energy system composed of solar PV, wind, hydroelectricity, diesel groups and the battery. Also, the author [6] used the coyote algorithm for the engagement of production units in an electrical system and noted a considerable reduction in operating costs. [7] to integrate distributed energy resources into their unitary commitment and came to the conclusion that these sources constitute a significant challenge for the operation of the system. Siyuan et al worked on the introduction of the uncertainty of variable renewable energies in the placement of sources with the flexibility resources with the algorithm in L. he contributed to the improvement of the cost of the system by determining the power of the sources of flexibility to be integrated [8]. In the same idea [9] to use variable energy sources with storage in an electrical system they came to the conclusion that the insertion of storage reduces the cost of the risk of losing a solar or wind power plant. [10] [11] made a review on the different approaches, techniques and methods for solving unit commitment problems and the algorithms to use.[12] to use the monarch butterfly optimization algorithm to minimize the cost of the unit commitment and to find the performance of the program on the reduction of the operating cost and the execution time compared to other techniques used. To solve the same problem [13] to use the whale optimization algorithm for cost reduction and to find which is efficient on the 29 reference functions. [14] used the Gradient Based Optimization (GBO) algorithm for unit commitment. he concluded its effectiveness compared to other optimization algorithms used in unit commitment such as: the bacterial food search algorithm, differential evolution, the improved genetic algorithm, the genetic algorithm, the gray wolf algorithm, optimization of direct particle swarms by ionic bonding, and Lagrangian relaxation. The author [15] hybridized the particle swarm optimization algorithm with a random search for the placement of sources in an electrical system and found that this method was effective than the traditional method for obtaining optimal solutions. The author in this work compared several algorithms such as simulated annealing, taboo search, artificial immune system, ant colonies, artificial bee colonies and hybridization of cuckoo and taboo search in the application of the placement of sources and to recommend the use of cuckoo and taboo hybridization by its effectiveness in optimizing the cost [16].

II. METHODS

The method used is based on the cuckoo search and taboo search hybridization algorithm.

A. CUCKOO SEARCH

Cuckoo research is based on three idealized principles [17]:

- All the cuckoos lay an egg (one solution) and place it in a nest chosen randomly from the fixed number of nests available;
- The best nest containing the best egg quality (best solution) is kept for the next resolution;

- The number of nests to lay the egg is fixed, and the host bird comes to discover the egg laid with the best solution with a probability in the interval [0,1]. In this case he may reject the egg or abandon the nest for the construction of a new (new solution).

According to the authors [18] the cuckoo search algorithm is efficient for optimization problems and the results from its comparison with algorithms such as particle swarms (PSO), differential evolution (DE) algorithm, annealing simulated (SA), ant and bee algorithms show that it outperforms in terms of convergence speed and computational efficiency.

B. TABU SEARCH

The principle of Tabu search is based on a method of moving in the space of solutions by constantly seeking to improve the current best solution and maintaining a list of those previously moved, thus directing the search outside the area of previous movements. It is based on:

- Flexible memory structures (short term, medium term, long term), the evaluation criteria as well as the search history can be fully explored.
- A control process established on the alternation between requirements which restricts (taboo limits) and releases (desire criteria) the development of research.
- Integrate so-called research intensification and diversification strategies:
  - Reinforcement strategies using medium-term memory can help improve research on the best solutions recently discovered in the field.
  - Various strategies using long-term memory can help guide research into new areas.

C. TABU SEARCH AND CUCKOO SEARCH HYBRIDIZATION

The combination of cuckoo search (CS) with tabu search (TS) abbreviated as (CS-TS), is an efficient exploration process thanks to CS and its ability to efficiently navigate the local search space through the use of TS. Among all the optimization methods discussed above, only CS stands out for its unique ability to integrate a very efficient global search mechanism. In simpler terms, this mechanism allows for optimal study of the research area, as well as improved use for optimal gains. The TS algorithm demonstrated its superiority in the search space, particularly in local search. The algorithm provides an illustration of the proposed CS-TS approach to solve the UC problem.

D. PROBLEM FORMULATION

The installed power in West Africa being greater than demand, we will have to minimize the cost of production by the optimal placement of the different power plants.

The objective function allowing to solve the problem is given by equation 1[19], [20]:

$$X\left(Y_j^t, U_{j,t}\right) = \sum_{t=1}^{T} \sum_{j=1}^{N} [X_j\left(Y_j^t\right) + ST_{j,t}\left(1 - U_{j,t-1}\right)]U_{j,t} \quad (1)$$

The quantities used to solve the problem are:

N: Plant number;

T: Number of hours;

Y_j^t : The power produced by unit i at a time t

ST_j: Restart cost of the unit i

$U_{j,t}$: The on/off state of unit i at a time t, $U_{j,t}$=0 if off and $U_{j,t}$=1 if on;

And is subject to the following constraints:

- Rotating reserve

$$P_{Load}^t + R^t - \sum P_{j,max} U_{j,t} \leq 0 \quad (2)$$

P_{Load}^{t}: The electrical demand at a time t (MW);
R^{t}: The rotating reserve at one hour t (MW);
$P_{j,min}$: The minimum power produced by the unit i (MW);

In the Wapp operations manual [21] the rotating reserve is the sum of power of the large central Nigeria group of Egbin (220MW) and that of the large group of Ghana-Ivory Coast-Togo-Burkina Faso of the Akosombo power plant (170MW) and the secondary reserve R_{s}^{t} is given by the formula

$$R_{s}^{t} \geq (a * P_{Load}^{t} + b^{2})^{\frac{1}{2}} - b \tag{3}$$

With a and b constants respectively equal to 20 and 150

- Balance between supply and demand

$$P_{Load}^{t} - \sum Y_{j}^{t}\, U_{j,t} = 0 \tag{4}$$

- Production limit

$$P_{j,min}U_{j,t} \leq Y_{j}^{t} \leq P_{j,max}U_{j,t} \qquad j = 1,2, \dots N \tag{5}$$

$P_{j,max}$: The maximum power produced by the unit j (MW);

- Start-up cost

$$P_{j,min}ST_{j,t} = \begin{cases} HST_{j}, Si\ T_{j,down} \leq T_{j,off} \leq T_{j,cold} + T_{j,down} \\ CST_{j}, Si\ T_{j,off} > T_{j,cold} + T_{j,down} \end{cases} \tag{6}$$

HST_{j}: Hot restart cost of the unit j (\$USD);
CST_{j}: Cold restart cost of unit j (\$USD); negligible
$T_{j,down}$: Minimum unit downtime (hours);
$T_{j,off}$: Continuous stop time of the unit j (hours);
$T_{j,cold}$: Cold start time of the unit j (hours);

The cost of fuel used to produce P at a time t is generally a quadratic polynomial function:

$$X_{j}(Y_{j}^{t}) = d_{j} + e_{j}P_{j}^{t} + f_{j}(Y_{j}^{t})^{2} \tag{7}$$

d_{j} , e_{j} , f_{j} : coefficient of running cost of unit j

- Operating constraint

For the variable renewable energy plant their production is used instantly

$$P_{RE}(t) = P_{output}(t) \qquad 0 \leq t \leq 24 \tag{8}$$

III. RESULT AND DISCUTION

Two scenarios were carried out assuming that peak electricity demand is obtained during the day and the other at night:

- During the day: the peak is obtained when the solar power plants produce their peak.

We see that in 2026 at the annual peak of 12.29 GW the mix at the peak is only renewable energy of 68.8% solar PV, 2.4% wind and 28.8% hydroelectricity. The figure 5 below shows the mix graph in 2032

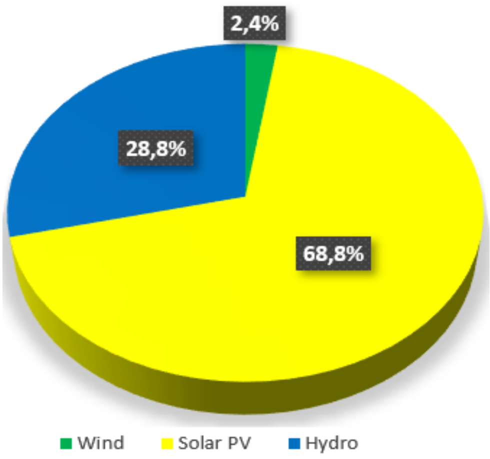

Figure 5. Peak daytime mix in 2026

In 2032 we observed the same phenomenon at the annual peak of 13.6GW and that the share of solar and wind power increased in favor of hydroelectricity. The figure 6 below shows the mix in 2032

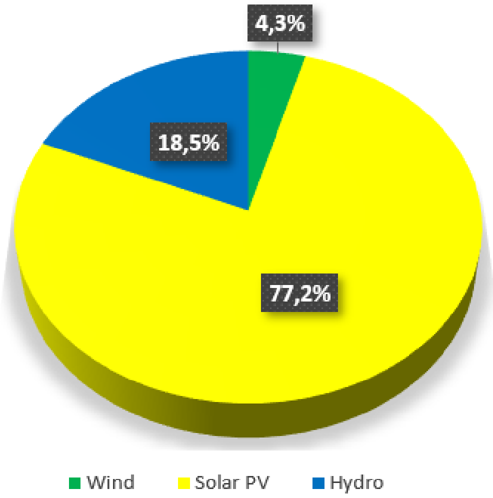

Figure 6. Peak daytime mix in 2032

- The peak is obtained at night: Solar production is zero

We see at night that the mix at the peak of 2026 is made up of hydroelectricity production at 93%, biomass at 0.5%, gas at 3% and wind power at 3.5%. The figure opposite shows mix at peak in 2026 at night.

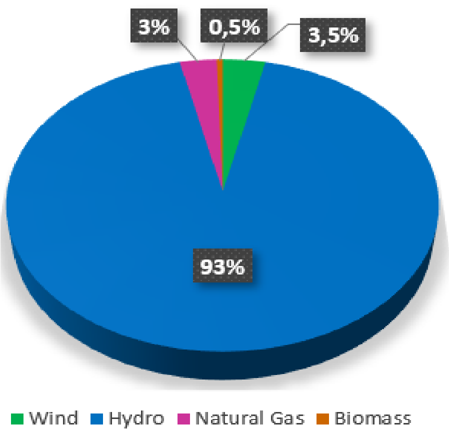

Figure 7. mix at night peak in 2026

In 2032 we see the same mix except that hydroelectric production declines in favor of gas and wind power. The figure opposite shows the mix at night peak.

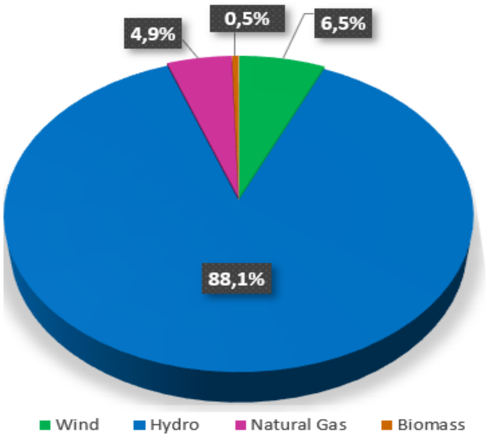

Figure 8. mix at night peak in 2032

Thus we notice that during the day the variable renewable sources occupy more than 70% of the mix which brings us in the load trough to more than 100% intermittent on the network where the system must think about the installation of the flexibility systems and review are planning plan for production works.

Cost optimization made it possible to determine the annual energy mix in 2026 and 2032. In 2026. Thus the production cost is high at $83.92/MWh and the energy mix obtained is largely made up of hydroelectric production and solar PV which follows. Other sources of production complement this. The figure below shows the annual mix in 2026.

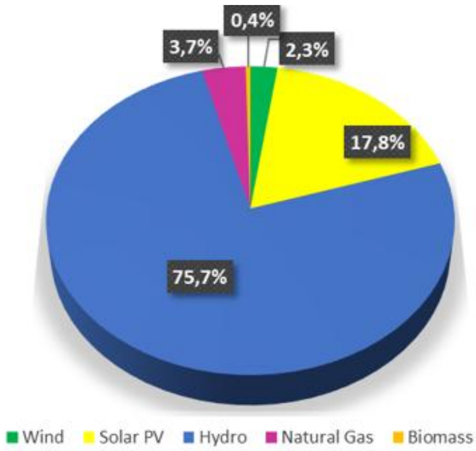

Figure 9. annual energy mix in 2026

Likewise at the annual energy of 96.85TWh in 2032 the average cost of energy is 86.83$/MWh with an identical mix in 2036 with an increase in the share of gas, wind, and solar to the benefit hydroelectricity. The figure below shows the mix obtained after cost optimization.

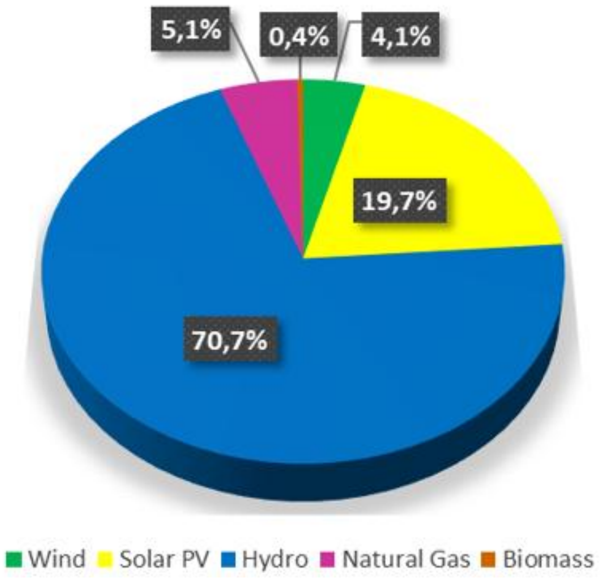

Figure 10. annual energy mix in 2032

From these different developments we note that the share of renewables is significant in the electricity mix. So a great ambition for ECOWAS countries whose mix consists of more than 70% thermal in 2021.

A sensitivity of the mix was carried out on the rate of completion of the different projects in 2032 Thus the figure below shows the evolution of the mix in 2032

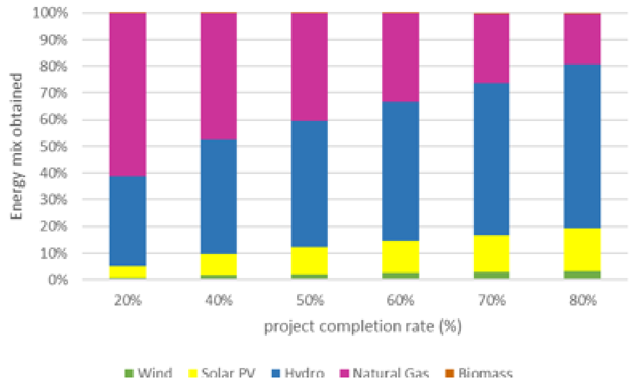

Figure 11. Energy mix with variation in the rate of project completion in 2032

From this sensitivity, gas has been gradually replaced by hydroelectricity and solar power. The costs obtained for the different scenarios are presented in the figure below.

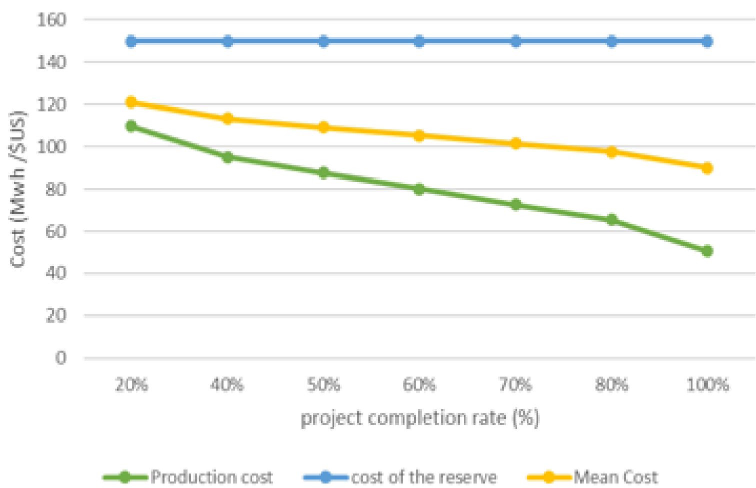

Figure 12. Cost of the energy mix with variation in the project completion rate in 2032

It appears from this graph that the reserve is provided by thermal power plants with a constant cost while the production cost decreases as renewable energy power plants are introduced.

IV. CONCLUSION

The results obtained from this study show that Wapp must provide sources of flexibility and review the means of production in relation to demand so as not to increase the cost of electricity production. We also notice that the energy mix will be more than 90% renewable if all the projects are carried out. There will be no more load shedding due to lack of supply sources. However, it is recommended to establish and make operational the common electricity market and the construction of interconnection lines throughout the sub-region to initiate sustainable development.

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