Journal of Brilliant Engineering 2 (2023) 4822
Brilliant Engineering
journal home: www.acapublishing.com/journals/4/ben
Research Article

Analysis of Niger's Renewable Energy Potential

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Keywords

Energy analysis,
Energy potential of Niger,
Renewable energy in Niger, Solar and wind power plant simulation,
HOMER PRO,
Renewable energy.

Abstract

In this study, we conduct an analysis of Niger's energy potential and electricity production capacity. We are interested in the potential of renewable energies in order to see if an electric production using renewable energies, more precisely solar and wind energies, are viable for Niger. In order to achieve results that are closer to reality, we used the HOMER PRO program, which allows us to simulate the energy production of several types of power plants while having the possibility of changing the wind speed parameters as well as solar radiation, and also to introduce the installation, maintenance and operation costs in order to establish a better economic and optimal energy analysis. We have therefore proceeded to the simulation of different scenarios of photovoltaic and wind power plants for the city of NIAMEY where the highest human density of Niger is located. According to our results and based on installation and maintenance costs only we note that the solar electric potential is much higher than that of the wind energy for the city of Niamey. The energy cost of the solar photovoltaic power plant is lower than that of the wind power plant although the initial investment of the PV is higher than the wind power plant. In the same way, solar panels have a better electrical output under the climatic conditions of Niger than wind turbines because of a good solar irradiation in the city of Niamey.

1. Introduction

Electricity is the main factor for social, economic and industrial development. In the generation of electric energy, a generation can be possible in two ways renewable and non-renewable energy types that depend upon generation resources. Renewable energy sources are replenished automatically time to time means they may be natural and cannot be replaced as fast as they are being consumed [1]. Quality energy production, more economical and ecological consumption are among the great challenges that most of the world's superpowers are facing in order to reach the Paris climate goals (net-zero carbon neutrality). Although considerable efforts have been made to reach the Paris Agreement goals, the high energy consumption due to the resumption of activities due to the end of the covid restrictions and the drama of the Ukraine conflict have led to an increase in the production of electricity by primary fossil fuels and thus to an increase in carbon emissions with an increase of nearly 10% in 2021 compared to the previous year. In 2021, an increase of nearly 6% was observed reversing the sharp decline in energy consumption in 2020 [2]. But developing countries, aware of the importance of energy sufficiency and stability at the economic and social level, face the challenge of achieving self-sufficiency in electricity generation or meeting their energy needs through energy imports. This stability is all the more important for these countries when, according to several statistics, 50% of the population in these regions still does not have access to electricity, causing dramatic repercussions on health, education, poverty reduction and sustainable development [3].

Energy self-sufficiency is also one of Niger's major challenges, despite its vast natural resources, which are suitable for electricity generation from fossil fuels such as coal, uranium and oil, or from renewable sources. Energy stability is even more desirable in Niger as the population has grown rapidly in recent years and is increasingly dependent on electricity for the operation of medical and electrical infrastructure, water distribution, public lighting, etc.

Due to climate change caused largely by greenhouse gas emissions from power generation, industrial expansion and livestock farms (mainly cattle ranches), the trend is towards a shift from fossil fuel-based power generation to renewable energy. In recent years, Niger has started to adopt a more flexible policy of integrating renewable energy into its power generation system, with the construction of a solar power plant in the town of Malbaza and other similar renewable energy projects. The integration of renewable energy into the power generation system is further supported by the country's integration into various international organizations aimed at promoting renewable energy. Thus, Niger has joined the Sustainable Energy for All initiative, SE for ALL, launched by the UN Secretary General and the World Bank in 2011 with the objective for Niger to facilitate universal access to energy, double the overall rate of improvement in energy efficiency and increase to 40% the share of renewable energy in the energy mix [4].

This study analyzes Niger's current electricity generation as well as its fossil and renewable energy potential. We then use Homer software to estimate the economic costs, performance and energy production of a hybrid power plant in Niamey city.

Homer is a software developed by the National Energy Laboratory with a library containing various information on quantities, load data, renewable resources data allowing to perform a real economic and comparative analysis of generation and distribution systems while listing the systems according to their current costs. Thus, with the results of the economic analysis, it is generally found that the installation costs of a system can be amortized over the long term even if the initial installation costs are high. The Homer program can also perform a sensitivity analysis with the possibility of modifying

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Received 13 Apr 2023; Revised 18 May 2023; Accepted 18 May 2023
https://doi.org/10.36937/ben.2023.4822
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environmental factors, the electrical characteristics of the system components to be studied as well as the prices and yields of the system components in order to achieve the most realistic results possible and thus determine the effects of the energy cost of the system studied. The software is based on a simple logic Optimization and Sensitivity in order not to increase the complexity and speed up the calculations. Homer is also more flexible in terms of the variety of systems that can be met. Although the program can only model systems beyond one hour, the hourly data listed in the system is sufficient for system analysis [5].

Using the HOMER program, it is therefore easy to establish a thorough analysis of a normal or hybrid renewable energy production system regardless of where the plant is to be installed.

Niger's energy potential is enormous, both in terms of fossil fuels and renewable energy. In Niger, wood, coal and oil are the most used sources for domestic needs and electricity generation. Niger's electricity mix is dominated by petroleum products (70%), followed by coal (28%) and solar energy (2%). Wood is the most widely used domestic energy source, far ahead of all other sources, and causes major ecological problems for the country's environment and biomass, especially since more than half of the country's territory is desert.

The purpose of our study is to analyze the energy sources and more precisely the renewable resources available in Niger in order to evaluate the feasibility of using these renewable energy sources in the country's electricity production. We seek to establish through this study if it is economically and technically strategic for the country to initiate an integration of renewable energy in the energy mix. Thus, it is by basing itself more on the simulation of a solar and wind power plant that we want to determine the capacity of electric production that can reach a solar and wind power plant and thus deduce by the result obtained if Niger must really be interested and invest more on the renewable energy. In view of the growing interest of Niger for the self-sufficiency in energy and also for the solar energy whose total power installed is more and more growing; it is question in this article to make a comparison between the solar and the other type of energy to see if the country should be interested in the other type of energy as much as the solar energy.

2. Methodology

We first proceeded to an analysis of the different literature dealing with the energy assets of Niger in order to have an overview of the energies that the country currently uses for its electrical production as well as to be able to establish the electrical profile of Niger. Once the electrical profile of the country is established, we have made other literary analysis in the fields of solar and wind energy to be able to proceed to simulations that are closer to reality. For the simulation of our different scenarios we used the program developed by the National Renewable Energy Laboratory (NREL) named HOMER (Hybrid Optimization Model for Electric Renewables) which allowed us to have results based on the environmental and economic criteria that we have previously defined during the simulations. We finished by analyzing the results obtained from the HOMER program in order to determine the most optimal source of energy studied according to the electrical production and according to the installation costs for the different simulations.

2.1. Difficulty

The major difficulty encountered in writing this article is the lack of documentation and accurate information on the production and consumption of electricity in Niger throughout its history. Most of the documents found only give abstract figures of electricity production between 2015 and 2021 and little information on the years 2000 to 2015, too much detail on the production by region or by cities as well as the lack of graphs of monitoring the evolution of production and consumption of electricity in hours, days, months or years. We had therefore difficulty in establishing with precision the electrical profile of the city of Niamey for which we wanted to make the simulation. Following this situation, we preferred to establish an artificial profile of consumption for which we had carried out the tests. The second difficulty is also a lack of article and technical or scientific documentation on tests or simulation of power plants using renewable energies concerning Niger which would have allowed us to make a discussion and a comparison of our respective results.

3. Fossil Energy

3.1. Coal

Coal has been mined for decades by SONICHAR, which also produces electricity for consumption by the city of Arlit in the north of the country. The field's reserves were estimated at around 6 million tons in 2009, i.e. 40 years of consumption at the current rate. In the town of Salkadamna in Azawak, also in the north of the country, a reserve of 30 million tons has been discovered that could facilitate the construction of a 200 MW thermal power plant and the production of 100,000 tons of charcoal for domestic use per year.

Even if it is true that coal-fired power plants are extremely polluting, it would be advantageous for the country to use this resource to replace wood in households. It may seem paradoxical, but the CO2 emitted by coal will be absorbed by the trees spared by using coal.

3.2. Oil

The country also has some oil reserves, especially in the east, where exploration has proven the existence of about 350 million barrels. In 2011, a refinery was built in the Zinder area, which was supposed to produce 100,000 b/d, but only 20,000 barrels are being produced daily. This refinery is the result of a production sharing contract with CNODC (China National Oil and Gas Development and Exploration Corporation), a subsidiary of the CNPC group (China National Petroleum Corporation), which provides for the construction of a refinery as well as a pipeline to the port of Cotonou (Benin). Since Niger's current demand is 8,000 barrels per day, the surplus refined product from Zinder is sold in the markets of neighboring countries.

3.3. Gas

Gas reserves are estimated at around 30 billion m3 but are currently only marginally used for cooking in households and not for electricity generation. However, efforts are being made by the Niger government to promote the use of gas instead of coal and wood which, it should be noted, has led to high greenhouse gas emissions as well as large-scale deforestation in a country that is two-thirds desert and has very little forested land.

4. Renewable Energy

4.1. Solar Energy

The country's real energy potential is undoubtedly in renewable energies. Due to its geographical location, the country has a climate with clear skies for more than half of the year and a fairly long period of sunshine. There are also moderate and constant wind speeds in certain parts of the country, as well as a strong hydraulic flow along the river. These metrological and geographical conditions are favorable for solar, hydraulic and wind power plants.

The average solar radiation across the country ranges from 5 to 7 kWh/m2 per day and the average daily sunshine duration ranges from 7 to 8 hours. Maximum solar radiation is recorded from April to August, while the minimum is recorded in December and January; the remaining months fall between the maximum and minimum. The cities of Arlit and Agadez, located in the northern and central regions respectively, show greater variability throughout the year. The cities of Niamey and Zinder, located at lower latitudes, show less variability throughout the year and are therefore excellent places to harness solar energy. According to a study published by NASA between 1980 and 2005, Niger would be one of the sunniest regions on the planet, and under these conditions photovoltaic panels would only need an area of 1.4 km2 (representing only 1% of the territory) to meet the current electricity needs of the whole of Niger.

However, solar energy in Niger is not limited to electricity generation; in recent years, solar water heaters and ovens have become widespread in urban areas.

4.2. Wind energy

Wind speeds in the country range from 2-6 meters per second (m/s) at 10 m altitude and are generally 20% higher at higher altitudes. Wind speeds are moderate, less than 4 m/s in the southeast of the country but increase to over 5 m/s on average towards the north of the country. Niger has limited wind potential for electricity generation, but relatively high wind speeds in some parts of the country are favorable for electricity generation. To date, there are no wind power plants in the country, probably due to high investment costs and low human density in areas with good wind speeds. However, wind energy is widely used in the hydraulic sector to pump water in villages and there are currently about 30 small wind pump installations [6].

4.3. Hydraulic energy

After solar energy, hydropower is the country's most important renewable energy potential. Indeed, the hydropower potential at 3 sites along the river is estimated at around 400 MW: Kandadji dam with a capacity of 130 MW, Gambou dam with 122 MW and Dyodyonga dam with 26 MW, with an estimated annual generation of about 630 GWh, which should be delivered in 2017 but work is still ongoing. Mini-hydropower plants, which do not require dams and are therefore easier to construct, have been identified along four tributaries of the Niger River: Mekrou, Tapoa, Gorouol and Sirba, representing a total capacity of 8 MW [4].

5. The Country's Electrical Profile

National electricity generation is low and not cost-optimal as the electricity mix is largely dominated by oil and coal. The country's electricity consumption has increased over the last decade, making it increasingly dependent on foreign electricity imports. In fact, global electricity consumption in 2003 was 465 GWh, with national production representing only 40% of the electricity consumed, 6% produced by NIGELEC (Société Nigérienne d'Electricité) and 34% by SONICHAR (Société Nigérienne de Charbon). Nigeria's imports amounted to 60%. In 2020, electricity consumption reached 1,450 gigawatt hours (GWh), 75% of which was imported from Nigeria. This amount reached 1,107 GWh in 2020[7].

The country's electricity generation is too low to meet the growing needs of the population, of which only 10.2% had access to electricity in 2016. This is 46.1% in urban areas and 3.14% in rural areas, where more than 80% of the population lives.

National electricity generation targets, as well as reducing dependence on electricity imports, are driving renewed interest in renewable energies in the country. The country's first solar power plant should open in 2018 with an installed capacity of 2.3 MW. Work is also underway on the construction of other power plants using renewable resources, particularly solar and hydroelectric power. The country's goal is to increase renewable energy from less than 2% of electricity generation to 30% by 2030[4].

Although the Malbaza solar power plant is the only medium-sized solar power plant using photovoltaic energy, there are mini solar power plants scattered across the country. These mini power plants are often used for the electrification of remote areas as well as for infrastructure needs such as schools and hospitals.

Unfortunately, Niger's energy policy has not sufficiently developed decentralized sources of electricity generation (solar photovoltaic and wind power). The country's vast size, very low population density (7 inhabitants/km2), great geographical inequality of the population and low urbanization rate (less than 20%) are factors that should support the use of renewable energy. It is clear that rural electricity needs to be developed through renewable sources to ensure universal access to energy. Rather, energy sources such as solar and wind power have shown only modest development. This leads to inequitable access to energy between rural and urban areas.

6. Solar Systems

There are various types of electricity generation systems that draw their source from the sun. Today, photovoltaic solar cells are the most common in large power plants as well as in small and medium-sized plants. Solar cells are semiconductor devices made of silicon that can convert sunlight into electrical energy. Solar cells are connected to each other in series or parallel to form modules that are combined to form the photovoltaic solar panel. Depending on the material and manufacturer, solar panels can provide a voltage between 0.1 and 5 V [8].

While it is true that solar panels need good solar radiation on their surface to achieve good efficiency, they are very sensitive to ambient temperature. In fact, paradoxical as it may seem, high temperatures reduce the efficiency of solar panels. The current and voltage output values found in the datasheet of the solar panels are those obtained in the laboratory under optimum temperature and irradiation conditions [9]. The power generated in the temperature region to which PV modules are exposed is approximately non-linear. Manufacturers usually give a value for this characteristic expressed as a percentage of the total power change per °C [10]. For example, if a module has a temperature coefficient of -0.50%/°C, this module will produce 0.5% less power for every 1°C increase in temperature [11]. Various factors other than temperature or solar radiation can affect the efficiency of solar photovoltaic panels, such as wind speed, losses in electronic components, dust, etc.

When setting up a solar power plant, technical studies on location and solar radiation should be carried out for at least one year in order to have all the metrological information and variations of solar radiation. In order to evaluate the total irradiance, it is necessary to know the diffuse solar radiation. Diffuse solar radiation data is necessary to determine the total amount of solar radiation on an inclined surface, which provides information on the performance of the system. However, unlike global irradiance, diffuse solar radiation data are only available for some countries. Therefore, in order to assess diffuse solar radiation, several studies have been carried out to develop mathematical equations based on meteorological data to estimate the diffuse component [12].

The HOMER program has an actual database of solar radiation from NASA or the International Renewable Energy Laboratory. However, the data is synthesized as global averages, it means that the data for a particular location at a specific time does not necessarily reflect the true value of solar energy for that location. Thus the system makes estimates based on the fact that if the weather is clear, there is a good chance that it will be clear for the rest of the day and vice versa. For this reason, when modeling solar systems on the HOMER program, it is important to take into account climatic and environmental factors, especially since in the real conditions of use of photovoltaic panels under the sun, they heat up by absorption of ultraviolet rays, so it is important that the simulation software can take into account these distortion factors.[11]. This feature is used to compensate for the reduction in efficiency as the actual operating conditions are less favorable than the standard experimental conditions.

7. Wind Energy Systems

Large horizontal axis wind turbines have efficiencies of about 50% and are widely used in wind farms. However, these types of wind turbines have a major disadvantage in that they cannot operate when the wind comes from the opposite direction of their blades because they are not equipped with a directional control system. This causes a danger because the blades turn very fast and risk to break down by high wind, but also their efficiency drops to 20% by turbulent wind. Unlike horizontal axis wind turbines, there is no direction finding in vertical axis wind turbines so no matter where the wind blows, the turbine always turns in the same direction. Vertical axis wind turbines are also less affected by turbulence and are quieter and safer than horizontal axis wind turbines for these reasons vertical axis wind turbines are more easily used in residential areas. Since the air flow is often turbulent in areas close to the ground, and can vary in direction and intensity continuously, vertical axis wind turbines are preferable and more advantageous than horizontal axis wind turbines of small power.

In wind turbines, the generation of electrical energy from the kinetic energy of air takes place in two steps. In the first step, the kinetic energy (or kinetic power Pw) of the air mass passing through the turbine is transferred as mechanical energy to the shaft to which the generator is connected. The design of the blades is of great importance here, and the maximum power that can be transferred from the kinetic energy of the air to the shaft per unit time is the Betz limit in percentage terms.

The theoretical maximum efficiency of an ideal wind turbine that can convert the kinetic energy of the air into mechanical energy was proposed by Lanchester in 1915 and then by Betz in 1920. In the second stage, the energy converted into mechanical energy by the blades is converted into electrical energy (or electrical power Pm) through gearboxes, generators and other equipment. The Betz Limit mentioned above is 0.5926.

$$c_p = \frac{P_m}{P_w} = \frac{P_m}{\frac{1}{2}\rho A v^3} \quad (1)$$

Here

$$P_m = \frac{1}{2}\rho A C_p v^3 \quad (2)$$

Here, ρ is the air density in kg/m3, A is the swept area of the blades in m2 and v is the wind speed in m/s. Increasing the length of the blades will also increase the power output of the wind turbines since the sweeping area of the blades is proportional to the square of the length of the blades. However, the length of the blades must be well dimensioned because if they are too long, they can bend and crush in the tower by strong wind and thus weaken the whole structure of the wind turbine. A second variable that increases the power that can be produced is the power coefficient of the turbine. It is a coefficient, which evolves according to the wind speed, which can take a maximum value of 0.5 at nominal power for large wind turbines. Many studies are conducted to increase this value [13].

Wind speed determination is a critical factor for large and medium sized wind power plants and the Weibull value of k is generally used to measure the distribution of wind speeds throughout the year. Generally, a value of K= 2 is used to accurately demonstrate wind regimes. Lower values correspond to wider wind speed distributions while higher values correspond to locations where wind speeds tend to vary.

Since wind regimes are rarely stable, the randomness of the wind must be included in the design or simulation of a wind turbine system. For this purpose, the dependency factor is used. If the wind speed in one hour depends directly on the wind speed in the previous hour then the dependency factor value should be high, while if the wind speed tends to change randomly from one hour to the next the dependency factor value should be low. The dependency factor is lower in areas with complex topography and higher in areas with empty and open topography.

The daily variation factor, which takes into account the variation of the wind speed in relation to a certain time of the day, is also one of the factors studied in wind power plants, since the wind regimes are not the same throughout the day, and it is often much windier in the afternoon than in the morning. This so-called daily variation factor would indicate a high dependency on the weather during the day if it has a high value.

The windiest time of the day according to the annual average (Puvant wind speed time) should also be entered in the wind speed variables.

All these factors (Weibull value (k), dependence factor (r1), daily variation factor (δ) and time of day of the wind speed) must be known when simulating wind power plants in HOMER software. This makes it a bit more complicated to simulate wind power plants compared to solar power plants, whose environmental values are already stored in the program's atlas library.

In our study, K=2, r1=0.85, δ=0.25 and the time of wind speed is assumed as 15H. The details of the wind speed in Niamey city are shown in the figure 4.

8. Economic Analysis

8.1. The levelized cost of energy COE

HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system and calculates it by its relationship;

$$COE = \frac{C_{ann\_tot} - C_{boiler} \cdot H_{served}}{E_{seved}} \quad (3)$$

C_{ann_tot} is the total annual cost ($/year), C_{boiler} is the marginal cost of the boiler, which is the marginal cost of the boiler's thermal energy. HOMER uses this value to calculate the adjusted cost of energy, H_{served} is the thermal load served, i.e. the total amount of thermal energy serving the thermal load during the year, and E_{seved} is the total electrical load served, i.e. the total amount of energy serving the primary and deferrable loads during the year plus the amount of energy sold to the grid. The HOMER program calculates the total electricity load served with the following equation:

$$E_{seved} = E_{prim\_AC} + E_{prim\_DC} + E_{grid\_sal} \quad (4)$$

For systems that do not serve thermal load, such as wind or PV, the thermal load served is H_{served} or Hthermal zero.

Thus, in our study, the adjusted cost of energy (COE) will be obtained by the following equation

$$COE = \frac{C_{ann\_tot}}{E_{prim\_AC} + E_{prim\_DC} + E_{grid\_sal}} \quad (5)$$

Where C_{ann_tot} is the annual cost ($/year), E_{prim_AC} is the amount of load supplied by AC (kWh/year), E_{prim_DC} is the amount of load supplied by DC (kWh/year) and E_{grid_sal} is the total sales to the grid (kWh/year). The total annual cost is the sum of the annual cost of each system element and other annual costs. This is an important quantity because HOMER uses this value to calculate the adjusted cost of energy and the total net present cost.

8.2. The net present cost

Net Present Cost (NPC) is the cost of installing the system and operating it over the project lifetime and is the main economic output of HOMER. All systems are ranked by net present cost and all other economic outputs are calculated to find the net present cost.

$$C_{NPC} = \frac{C_{ann\_tot}}{SGF(i, R_{proj})} \quad (6)$$

C_{ann_tot} is the total annual cost ($/year), SGF is the capital recovery factor, i is the real interest rate (%) and R_{proj} is the life of the project (years). The capital recovery factor is used to calculate the present value of the annual revenue expenditure stream and is calculated by the following equation:

$$SGF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (7)$$

Where i is the real interest rate (%) and N is the number of years. In our study, we assumed the lifetime of the system to be 25 years.

9. Simulation of Different Scenarios

For the simulation of performance and economic costs, a 20 MW electrical load is assumed, generated as follows:

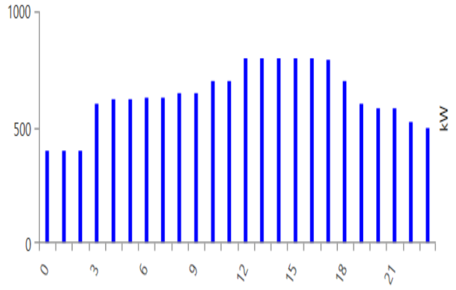

Figure 1. Consumption profile

The figure above is for January, with an average consumption of 18 MW and a peak of 7 MW/hour between April and July, when electricity consumption in Niger is highest.

9.1. Solar power only

Solar radiation in Niger is presented as follows according to the Homer software drawn in the library of the National Laboratory for Renewable Energies.

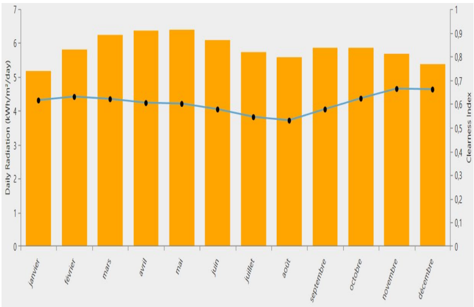

Figure 2. Solar irradiation of Niamey

We have evaluated the installation costs of a 2500$/KW system, referring to the construction projects of a 10 MW solar power plant in the DOSSO region with an estimated cost of 13.3 million Euros, the 30 MW MARADI plant at a cost of 39.9 million Euros, and the MALBAZA plant already in service with 7 MW at an installation cost of 27.7 million dollars [4].

In this scenario, using the irradiance data in Figure 2, the integration diagram of the solar power plant is presented in Figure 3. The total cost of the installation, assuming a lifetime of 25 years, is 99 783 921,24 €, of which 52 585 503,31 € for the solar panels including annual maintenance costs, 44 383 542,34 € for the batteries and 2 814 875,59 € for the inverter. The results show that a return on investment is possible after 9 years, with an adjusted energy cost estimated at €1.13. It is of course possible to reduce the initial costs of the system by removing the batteries from the system, especially since the batteries need to be replaced every 5 years. If batteries are removed from the system, an energy mix with diesel generators, coal generators or other renewable energy sources should be considered.

Summary of the system

Solar panels (KW) :20000
Batteries (units): 67 414 (50 hours autonomy)
Inverter (Kw): 6 000 KW
Net present cost: 99 783 921,24 €
Adjusted energy cost: 1.13 €

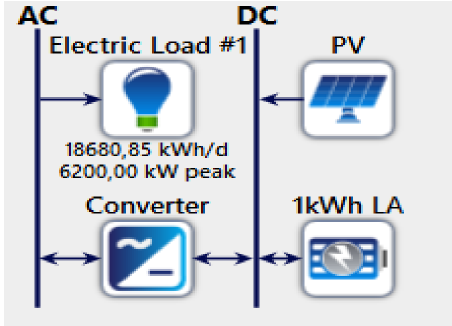

Figure 3. Homer solar systems model

9.2. Wind energy systems

In this case, we used GENERIC wind generators with an output power of 1.5 MW and a price of $3,000,000. We estimated the operation and maintenance costs at $30,000/year. At the end of the simulation, the optimal results proposed by the HOMER software for our electrical load shown in figure 1 are the following: 7 wind generators at a price of 26 636 696,69 €, 3 500 Kw inverters (cost = 1 561 601,90 €) and 42 563 batteries (cost = 28 103 958,70 €). In our simulation we did not consider the transportation and installation costs of the plant. The actual total cost of the simulation is 56.302.257,29 €, which includes the annual maintenance and operation costs.

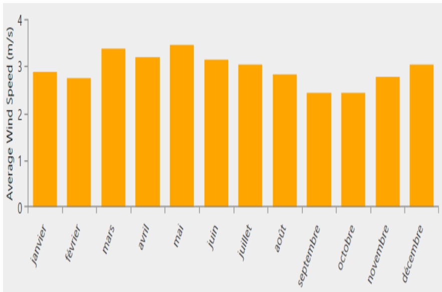

Figure 4. wind speed Niamey city

As with solar power systems, we see that batteries account for a large part of the installation costs of the plant. We decided to include batteries in our simulation to make the power generation more stable and balanced in moments when the wind regimes become intermittent.

Of course, as mentioned before, it is better to make an energy mix instead of using batteries,

which besides being expensive, need to be replaced on average every 5 years.

Summary of the system

Wind turbine generator: 7 GENERIC 1.5 MW
Inverters: 3 500 KW
batteries: 42 687 units
Net present cost: 56 302 257,29€
Adjusted energy cost: 4.92€

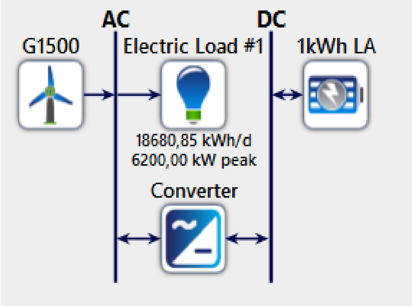

Figure 5. HOMER model of wind turbine system

9.3. Wind + PV mix

The efficiency of solar photovoltaic panels is greatly reduced when it is overcast and at night the efficiency is almost zero. In addition, the wind patterns on which wind generators depend are not constant throughout the day. To optimize the energy production of solar and wind power plants, a mix of both types of power plants can be made, taking advantage of the benefits of both types of power plants while reducing their disadvantages.

For the electricity profile, we have determined the optimum results recommended by the HOMER program for the energy mix between wind generators and photovoltaic solar cells as a production of 17 000 KW provided by photovoltaic cells and 4 wind generators of 1,5 MW.

The total cost of the installation is €82,700,869.56, of which €15,220,969.54 for the wind generators, €45,164,888.84 for the solar cells, €1,408,383.68 for the inverters and €20,906,627.51 for the storage batteries (including replacement and maintenance costs of the batteries).

Summary of the system

solar panels 17 000 KW
Wind generators 4 units 1.5MW
Inverter: 3 500 KW
Batteries: 31 755 units
Net present cost: 82 700 869,56€
Adjusted Energy Cost: 0.87€

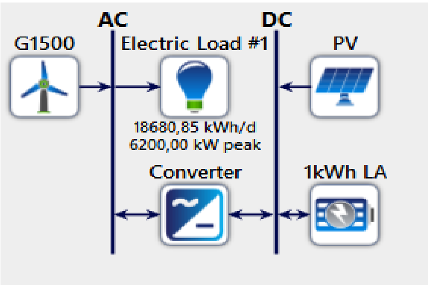

Figure 6. Mixed pv + wind turbine HOMER model

9.4. System connected to electricity grids

Connecting our photovoltaic or wind generation systems to the electricity grid offers several advantages. In cases where wind speed or solar radiation is insufficient to meet the electricity load we have identified in figure 1, or during technical maintenance on the electricity grid or in the event of a system failure, the required energy is supplied to the grid. Conversely, if the electricity produced by our power plants is more than the energy demand, the excess electricity is fed into the grid. The different configurations connected to the electricity grids are shown in Figures 7, 8 and 9.

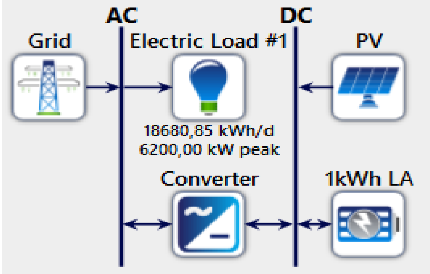

Figure 7. Solar model connected to the HOMER grid

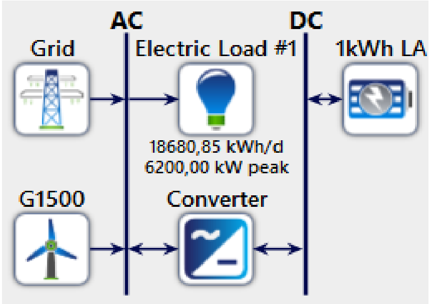

Figure 8. Model wind turbine connected to the HOMER grid

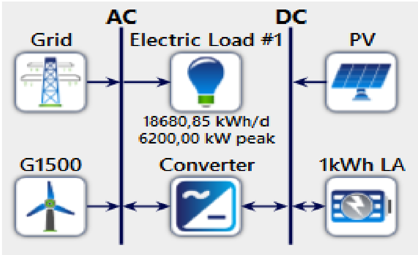

Figure 9. PV+ wind turbine model connected to the HOMER grid

10. Analysis of Results

From the results of our different simulations, we can conclude that the solar energy potential for the city of Niamey is much higher than wind energy. Indeed, even if the total investment costs of solar photovoltaic energy are higher than wind energy for the same installed capacity, the adjusted costs of solar energy are much lower than wind energy (4.92€ vs. 1.13€). This is because the town of NIAMEY has good sunshine and solar radiation for most of the year, allowing solar panels to operate at optimal power. On the other hand, the wind pattern of the town is very intermittent, and the wind speed is low.

The energy mix between the two sources results in a more balanced energy/investment cost ratio with an estimated adjusted energy price of 0.87€. This is because the mix allows for a much more balanced and optimal energy production that is not too much affected by sudden changes in wind and solar radiation patterns. For all the systems we simulated, storage batteries are not necessary, especially since they represent a large part of the investment costs. Generally, batteries are not used in large renewable electricity systems due to their cost and the ecological problems of regular replacement and recycling every 5 years on average. However, there are major advances in battery design that can give hope for their use in renewable energy installations. But for this to happen, batteries need to have a higher storage capacity, a longer charging cycle and a low investment cost.

11. Conclusion

As we have seen, Niger's potential for electrical energy is immense, whether using primary fossil or renewable resources. However, Niger is still very dependent on electricity from Nigeria, probably due to the preferential tariff of imported electricity at 0.04 USD/kWh[6]. In addition, there are physical problems that can occur on the interconnection networks between the two countries. In the event of a problem on the transport network linking the two countries, a large part of the Nigerien population would be without electricity because the national electricity production of Niger is insufficient to take over the electricity production. In view of the results of our simulation, solar energy would be a sure value on which the country can invest in order to expand its electricity production and also diversify its energy mix.

However, it would be important to learn from history and retain the benefits. Of course, it is important for a country to provide sufficient energy to its population, but it would be an ecological disaster for the planet if this country started to produce all its energy needs from primary fossil resources, even though it has a good potential for renewable energy. As we have seen in this study, the solar potential of Niger is enormous, and the investment of an installation can be amortized in less than ten years. In addition, there is considerable hydroelectric potential and significant wind power potential in some parts of the country. Therefore, Niger has everything it needs to initiate an energy transition from the ground up and thus avoid finding itself in the situation of certain major economic powers that have relied entirely on primary fossil resources and are forced to fall back on renewable energies in order to limit their greenhouse gas emissions from electricity production.

HOMER software is quite powerful and can simulate hydroelectric plants or diesel generators very well and propose very optimized economic and energy results. Referring to the current solar power plant project and the price of wind generators, we proposed a simulation for a 20 MW electricity load, the optimal result leans towards solar and the mix between solar and wind, wind power plants being the least profitable for the city of Niamey due to the very modest wind regime.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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How to Cite This Article

Tınnı, I.H., Çavuş, T.F., Analysis of Niger's Renewable Energy Potential, Brilliant Engineering, 2(2023), 4822.
https://doi.org/10.36937/ben.2023.4822.