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Study of a hybrid system with a renewable energy source from software in a rural locality in the Abengourou region in Côte d'Ivoire

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ABSTRACT: This study shows a simulation with the HOMER software of a hybrid system composed exclusively of renewable energy sources including a solar photovoltaic generator of 50 kW, a 50 kW wind generator and a 50 kW biogas generator linked to a 50 kW converter in Blekoum (rural area of the Abengourou region) fed to date by a 42 kVA diesel generator with a 5000 liters tank. After having modelled the load to satisfy and integrated the wind potential, the sunshine and the biomass residue potential, we carried out the calculation with HOMER. From the three scenarios of hybrid systems after optimization by HOMER, it is appear that, with regard to energy production, the hybrid system produces an average value of 277.364 kWh/year while the 42 kVA generator produces 105.108 kWh/year. The average price per kWh per year one is 481 172.453 FCFA for the hybrid system and 401 491.799 FCFA for the diesel generator. The emissions of gaseous pollutants are very high with the diesel generator where the values of CO_2 are raised to 142.933kg/year; CO at 353 kg/year and SO_2 at 287 kg/year while the hybrid system allows to preserve our climate by lowering these values respectively CO_2 to 33.533 kg/year; CO to 1.261 kg/year and SO_2 to 0 kg/year.

KEYWORDS: Hybrid system, Renewable Energy, HOMER, Blekoum.

1 INTRODUCTION

In a global context marked by the depletion of oil and gas resources, as well as the global warming attributed to gases from fossil fuels, household energy demand continues to grow. In Côte d'Ivoire, where the installed production capacity, mainly thermal and hydraulic, has reached 2275 MW, there are still nearly 6,000 communities not yet electrified according to the information published by the official portal of the government of Côte d'Ivoire, in 2021. Rural electrification is defined as any process by which electricity is supplied to households located in isolated rural areas and/or remote from the national grid, via an electricity grid or decentralized sources of renewable and/or non-renewable energy generation [1]. Rural areas, particularly those in sub-Saharan Africa, are mainly characterized by low population density, low-income population (mostly less than $1.5/day), very limited access to energy services, education, and health services [2].

The Côte d'Ivoire government, through its electricity company (CIE), which has about 40 diesel generating station locations in view of the difficulties of interconnecting with the national electricity grid, reported the CIE's maintenance and operation service in 2020. The locality of Blekoum (Latitude: 6°22'30" N; Longitude: 3°32'32" W), located in the department of Abengourou and the sub-prefecture of Zaranou, has a 42kVA generator with a 5000 liters tank. However, operating problems related to the routing and cost of diesel supply, the maintenance of the generator but also the constraints due to the contribution of diesel to global warming and the pollution of combustion gases whose Sulphur and carbon monoxide become untenable. Faced with this observation and with the aim of reducing the use of diesel; suggestions converge to the realization of hybrid solar-diesel generator systems considering the good sunshine of our localities. In Abengourou, for example, the very hot season lasts 2.2 months, from 15 January to 20 March, with a maximum daily average temperature above 34°C. The hottest month of the year in Abengourou is February, with a maximum average temperature of 35°C and a minimum temperature of 23°C. The cool season lasts 3.4 months, from 15 June to 27 September, with a maximum daily average temperature below 30°C. The coldest month of the year in Abengourou is August, with a minimum average temperature of 21°C and a maximum temperature of 29°C according to the internet review "Climate, weather per month, average temperature". According to the research work of TSUNANYO (2015) [2] the hybrid PV/Diesel system seems suitable for remote/isolated areas with high solar irradiation [3]. Moreover, the hybrid PV/Diesel system without battery allows to solve the maintenance problems, prohibitive costs of these installations without impacting their performance as evidenced by the concept «Flexy Energy» initiated by Azoumah et al. (2011) [4]. However, it should be noted that the usefulness of batteries lies in the response to transient loads and/or the possibility of obtaining maximum power from photovoltaic panels.

In addition, other research work has associated in the coupling a wind turbine and/or a biomass generator, testifies Gergaud (2002) [5], who therefore carried out the modelling of a hybrid wind photovoltaic system with accumulator (battery) and also Ludmil Stoyanov (2011) [6] who went further by reviewing the different structures of hybrid systems with renewable energy sources. The aim of setting up such a system is to diversify renewable energy sources. We are looking for a more significant decrease in the amount of fuel consumed since renewable sources can complement each other and provide a greater amount of energy. Among these systems, Ludmil Stoyanov (2011) [6] addressed the hybrid photovoltaic/wind/diesel system as well as various study and simulation software including Homer.

Related work on economic studies of hybrid PV/Diesel systems [7, 8] was conducted as well as an analysis of fuel not consumed in a hybrid wind-PV-Diesel system [9] or emissions avoided by the implementation of hybrid systems [10]. In addition, Pavlovic (2013) [11], Singh et al. (2015) [12] and several other researchers performed simulations with Homer Pro Software to optimize the hybrid systems generated.

As part of this last vision, we propose a study on the construction of a hybrid renewable energy system consisting of a photovoltaic solar generator, a wind generator and a generator using biogas (from biomass) replacing diesel with Homer software.

Using the potential for sunlight, wind speeds, biomass residues and after having modelled the energy load required at Blekoum, electrified to date by a diesel generator of 42 kVA, we assess energy generated from renewable sources and gas emissions. We then compare the cost per kWh of energy generated by the proposed hybrid system with that of the diesel-only generator; and we compare the gas emissions of the two systems.

2 Study Of The Hybrid System Using Renewable Energies

A hybrid renewable energy system is an electrical system consisting of more than one energy source, of which at least one is renewable [13]. The hybrid system (SHSER) may or may not include a storage device [4]. Our hybrid system which is the subject of this article does not have a storage system. We will describe in the following lines the components of the hybrid system starting with the diesel generator.

2.1 Diesel Generator

A diesel generator is a machine that converts a primary fuel such as fuel oil or diesel into electricity. A diesel generator can be divided into three main components: the main engine, which includes an engine with a speed regulator, the synchronous generator (alternator) and the automatic voltage regulator (control system) [14]. According to ISO 8528, there are three types of power for a generator: The main power or apparent power corresponds to the maximum available power, under variable load, for an unlimited number of hours per year, respecting the normal shutdowns for maintenance and under the defined environmental conditions. The average allowable power over a 24-hour period shall not exceed a fraction (generally 70%) of the main power. This permissible average power Pa, which is defined by the manufacturer of the diesel engine, is calculated by the following expression:

$$Pa = \frac{\sum_{24} P_i t_i}{\sum_{24} t_i} \quad (1)$$

With Pa, the power called during the time, t_i.

2.2 BIOGAS GENERATOR

Biomass electricity generation technologies consist of generating electricity from a biological or thermochemical process (combustion, gasification/pyrolysis, fermentation, etc.) of biomass through Rankine cycles or combined cycle (gas – steam). The fuel can be crude biomass, a by-product of pyrolysis (oil, coal or gas), vegetable oil or methane produced from organic waste. Methanization is the result of complex microbial activity under anaerobic conditions. Anaerobic digestion is a biological degradation process that transforms complex organic substrates into single-carbon molecules, such as methane (CH_4) and carbon dioxide (CO_2). The process takes place in four distinct phases, each performed by a class of specialized microorganisms, which develops in the absence of oxygen (optional or strict) [15]:

- Step 1 and 2: Hydrolysis and acidogenesis. Degradation of polymers into monomers and volatile fatty acids.
- Step 3: Acetogenesis. Transformation of volatile fatty acids, hydrogen and carbon dioxide into acetic acid.
- Step 4: Methanogenesis. Methane formation either by degradation of acetic acid (70% of production) or by reduction of CO_2 by hydrogen (30% of production).

A biogas generator is a generator that uses the biogas generated as fuel. The hourly consumption of a generator is strongly related to the load rate and the nominal power of the diesel generator. For diesel generators of less than 150 kW, the hourly consumption can be approximated by a linear function of the loading rate δ [2]:

$$\dot{f} = (f_0 + f_1\delta)\,\dot{W}_D \tag{2}$$

Where $\dot{f}$ is the hourly fuel consumption, generally expressed in (L/h); f_0 and f_1 are constants obtained from literature or experiments (L/kWh) and $\dot{W}_D$ is the generator power.

2.3 PHOTOVOLTAIC GENERATOR

A photovoltaic generator aims to transform solar radiation into electricity using a photovoltaic cell. It should be noted that a photovoltaic solar generator is composed of four (4) key organs: solar panels, the solar regulator, solar batteries and the converter or solar inverter [5]. The power produced by the photovoltaic generator P_{sj} is expressed as a function of the area of the A_{pv} system, its efficiency or efficiency η and the incident solar radiation I_{mj} [16, 17]:

$$Psj = I_{mj}\eta A_{pv} \tag{3}$$

The yield η or average yield η_m is determined by equation 4 below:

$$\eta_m = \eta_r\left[1 - \beta(T_c - T_r) + \gamma \log 10 I_m\right] \tag{4}$$

Where η_r is the efficiency of the module measured at the reference temperature of the cell, β is a temperature coefficient for the cell and is relatively constant for the range of operating temperatures encountered in the flat modules, T_c is the temperature of the cell, T_r is the reference temperature of the cell to which η_r is determined, γ is a coefficient of radiation intensity for the cell, and I_m is the incident radiation on the module per unit area.

2.4 WIND GENERATOR

A wind generator converts the kinetic energy of the wind into mechanical energy and then into electricity. The wind turbine rotor blades capture some of the energy contained in the wind and transfer it to the hub that is attached to the wind turbine shaft. It then transmits the mechanical energy to the electric generator. There are two types of wind turbines: vertical-axis wind turbines and horizontal-axis wind turbines (the most common) [5]. The available kinetic power at the turbine input is defined as [17]:

$$P_{dispo} = \frac{1}{2}\rho S V_e^3 \tag{5}$$

Where V_e is the wind speed, S is the air swept by the rotation of the wind turbine blades; ρ is the specific density of the wind which depends on atmospheric pressure and humidity.

Taking into account the coefficient of performance C_p of a wind generator, the electrical power generated at the output of the generator is as follows:

$$P_{elec} = \frac{1}{2}\rho C_p S V_e^3 \quad (6)$$

Where P_{elec} is the Generator Output Power.

2.5 Converter

According to Olivier GERAUD (2002) [5], a converter is a reversible system that allows to fully managing the transfers of energy, from the network to the continuous bus or the alternative bus. For the modeling of a converter, there are three operating speeds: one speed when the power goes from AC (Alternative current) to DC (continuous current) (rectifier mode), the second speed when the power goes from DC to AC (inverter mode) and the third is floating when there is no exchange of useful energy between the continuous bus and the network. The rectifier mode has a performance defined by:

$$\eta_{AC/DC} = \frac{P_{DC}}{P_{Netw}} \quad (7)$$

Inverter mode has a performance defined by:

$$\eta_{DC/AC} = \frac{P_{Netw}}{P_{DC}} \quad (8)$$

Where P_{Netw} is the active power and P_{DC} is the continuous power.

3 Methological Analysis

3.1 Study Site And Energy Load Profile

3.1.1 Study Site

Blekoum is located in Undeclared Djuablin, Abengourou Department, Zaranou Sub-Prefecture; Latitude: 6°22’30” N; Longitude: 3°32’32” W.

The sunshine data and wind speeds are derived from reports illustrating the typical Abengourou meteorology, based on statistical analysis of historical hourly weather reports and reconstructions modelled from 1 January 1980 to 31 December 2016. The biomass data were published in 2020 by the Ivorian Ministry of Oil, Energy and Development of Renewable Energies which assesses the potential of agro-industrial residues (cocoa, coffee, palm etc.) and municipal waste at 15 000 000 T/year. But also from the map of cocoa zones of Côte d'Ivoire, whose Abengourou’s area is credited with 7 % in the national tonnage produced. Regarding wind speeds we note that the mean hourly wind vector is extended (speed and direction) to 10 meters above ground level. The wind at a given location is highly dependent on local topography and other factors, and the speed and direction of the instantaneous wind varies more than hourly averages.

The average hourly wind speed in Abengourou experienced moderate seasonal variation during the year.

The windiest period of the year is 3.1 months, from June 14 to September 18, with average wind speeds above 9.1 kilometers per hour. The month with the most winds is the month of August with an average of 11.2 km/h.

The quietest period of the year lasts 8.9 months, from September 18 to June 14. The quietest month of the year is November with an average of 6.9 km/h as shown in Figure 1.

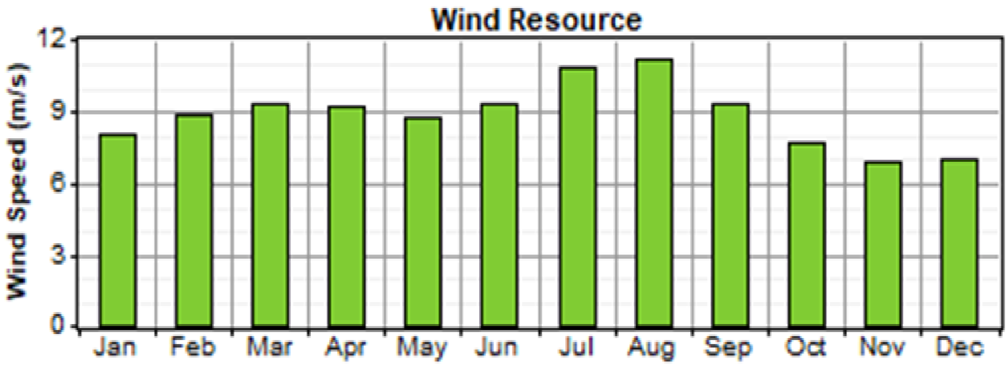

Fig. 1. Wind resources of Blekoum

During the year, temperatures generally range from 20°C to 35°C and are rarely below 16°C or above 38°C. The very hot season lasts 2.2 months, from 15 January to 20 March. The hottest month of the year in Abengourou is February, with a maximum average temperature of 35°C and a minimum temperature of 23°C. The cool season lasts 3.4 months, from June 15 to September 27, with a maximum daily average temperature below 30°C. The coldest month of the year in Abengourou is August, with a minimum average temperature of 21°C and a maximum temperature of 29°C. The length of the day at Abengourou does not vary much during the year, remaining at 30 minutes of 12 hours throughout the year. In 2021, the shortest day is December 21, with 11 hours and 44 minutes of day; the longest day is June 21, with 12 hours and 31 minutes of day. The earliest sunrise occurs at 05: 56am on May 25 and the latest sunrise occurs 35 minutes later at 06: 32am on February 1. The earliest sunset occurs at 5: 52pm on November 12 and the later sunset 41 minutes later at 6: 34pm on July 16. The average daily solar radiation is 5kWh/m²/day with a low value of 4.8 kWh/m²/d on 07 May and a high value of 5.3 kWh/m²/d on 31 October, all materialized by Figure 2.

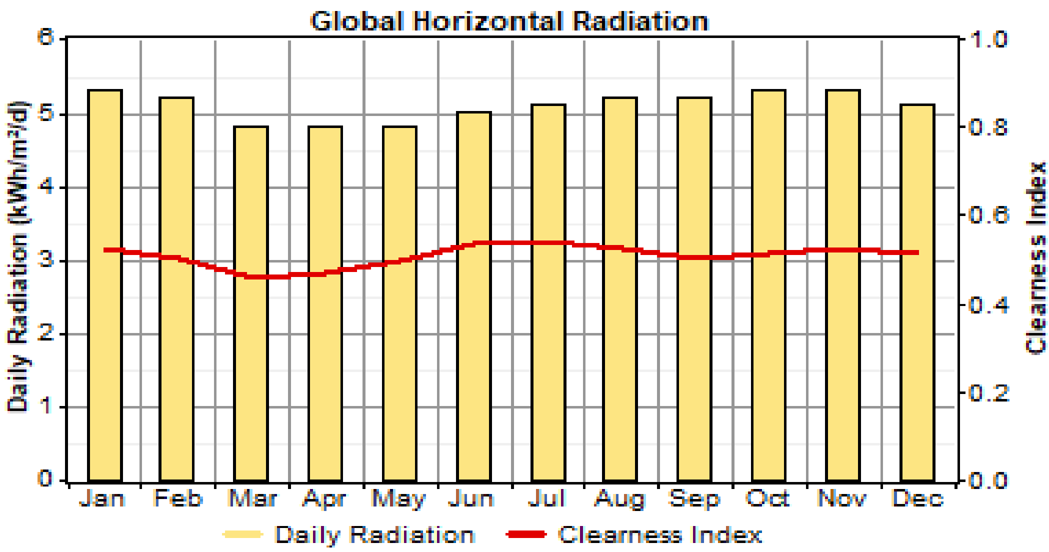

Fig. 2. Sunshine resources of Blekoum

The availability of biomass depends on the harvest periods of the main sources of biomass. As for cocoa, there are two harvests: the main harvest from October to March and the intermediate harvest from April to August. Residues range from less than 100 tons/day to more than 200 tons/day with negligible values in April and September marked by a low intake of coffee-cocoa residues as shown in Figure 3.

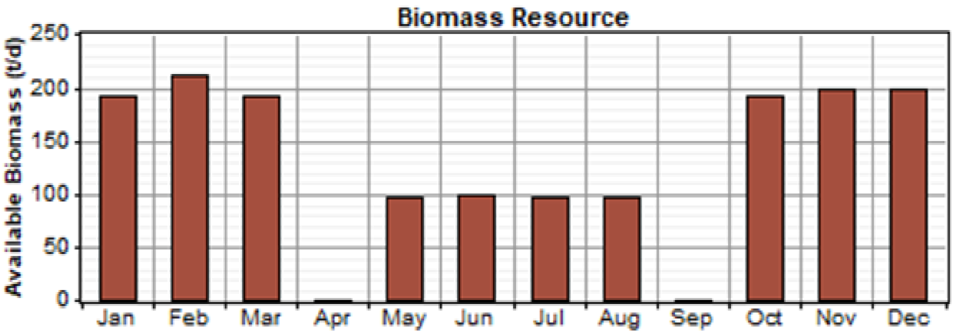

Fig. 3. Biomass resources of Blekoum

3.1.2 COMPONENTS OF HYBRID SYSTEM

To meet the maximum load of 40 kW, the proposed hybrid system consists of a 50kW photovoltaic solar field; a 50Kw Entegrity Ew15 wind generator, a 50kW biogas generator and a 50kW converter. On the basis of the costs of the optimal systems presented by TSUANYO (2015) [2] and Barbier (2013) [18], we establish for the first year a financial grid table of the equipment objects of the study and presented in table 1.

Table 1. Financial estimate of equipment

Estimated Amounts ($)	Solar generator 50kW	Wind generator 50kW	Biogas generator 50kW	Converter 50kW	Diesel generator 42kVA
Initial investment (supply and installation) ($)	61 539	85 565	10 000	24 449	7 130
Operating cost/year ($)	2 609	5217	1739	870	66 261
Total system cost/year ($)	64 147	90 783	11 739	25 318	73 391

This table firstly allows us to determine the overall investment cost for the first year of each of the systems by summing the budgets of each link, notably for the 42 kVA diesel generator and the hybrid system composed of the 50kW wind generator, the 50kW solar generator, the 50kW biogas generator and the 50kW converter. Secondly, from the energy produced by each of the systems, we will know the price per kWh of energy.

3.1.3 ENERGY LOAD PROFILE OF THE SITE

To date, the locality of Blekoum located in the sub-prefecture of Zaranou in the department of Abengourou is powered by a generator of 42 kVA, a maximum power of 40kW. According to the 2014 census, this locality has 3,472 inhabitants, including 1,804 men and 1,668 women. KOUADIO (2021) [19], who spoke about the challenges of rural electrification in Côte d'Ivoire, reviews the consumption patterns and energy needs of the populations living in these areas. His field surveys further confirm the isolated site load model used by Kaabeche (2006) [20] to complete the study on the optimization of a fully autonomous hybrid system. We have modest consumption during the day from 06h to 12 as well as in the afternoon from 12h to 17h and a peak observed between 18h and 22h followed by a decrease from 23h. From all this information above, the following profile of the energy load of the locality emerges (see Figure 4).

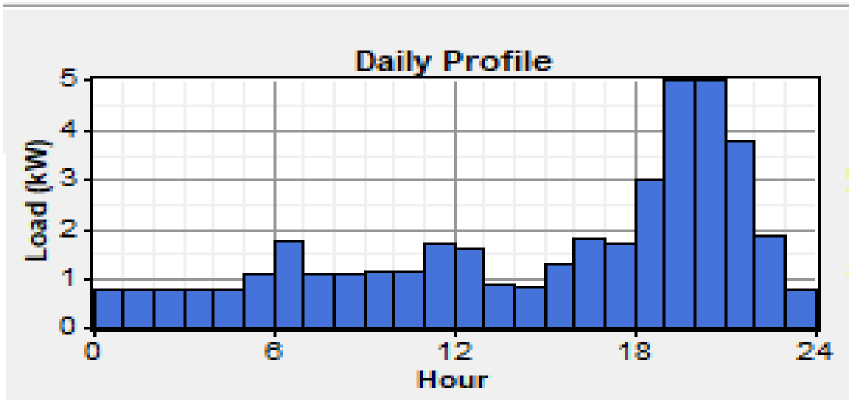

Fig. 4. Daily energy load profile Blekoum

3.2 Simulation Software: HOMER

HOMER (Hybrid Optimization Model for Electric Renewable) is suitable software for the rapid realization of technical and economic pre-feasibility studies of hybrid systems in isolated site (autonomous system) or connected to the network.

HOMER was developed in 1993 by the US National Renewable Energy Laboratory (NREL) for internal use by the Department of Energy (DOE) and a few years later a public version was developed by the NREL for wider use [2, 21]. HOMER uses as input the various technological options, component costs, resource availability, manufacturer's data, etc. to simulate different system configurations and generate output results as a list of possible configurations sorted in ascending order of Life Cycle Cost. We have chosen to use the HOMER 2.68 beta version which has models of conventional generators and has renewable energy sources. It also contains optimization algorithms with which it is possible to choose the best hybrid system.

4 Results And Discussion

4.1 SIMULATION RESULTS OBTAINED WITH THE EXSTING 42 Kva GENERATOR

For the existing 42 kVA generator, modelling with HOMER gives the following figure 5.

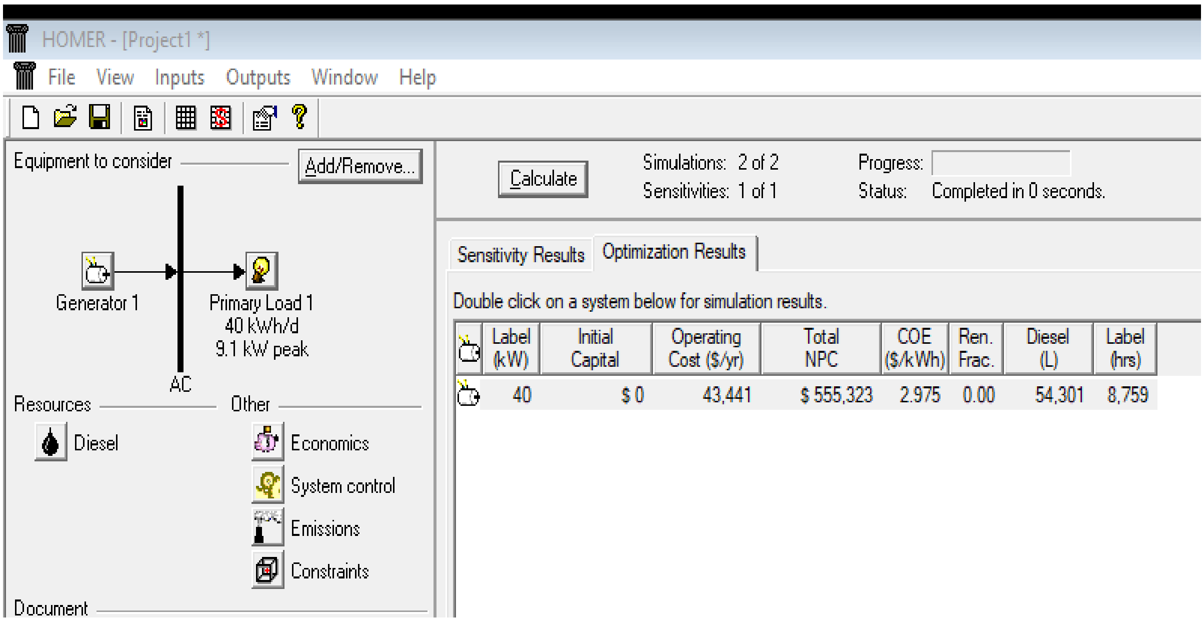

Fig. 5. Existing 42 kVA DIESEL GENERATOR HOMER simulation in Blekoum

The Fig. 6 presents the modelling of the energy generated by the 42 kVA generator.

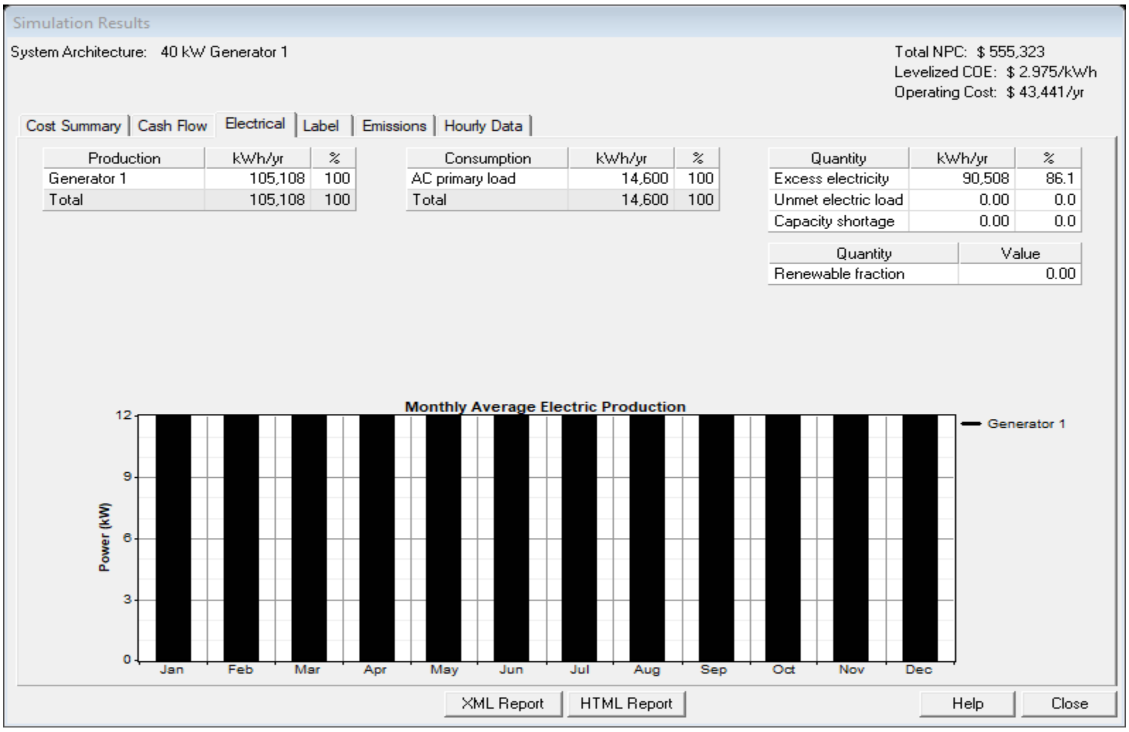

Fig. 6. Energy produced by the diesel generator in Blekoum

The modelling of gas emissions from the 42 kVA generator is characterized by the following figure 7.

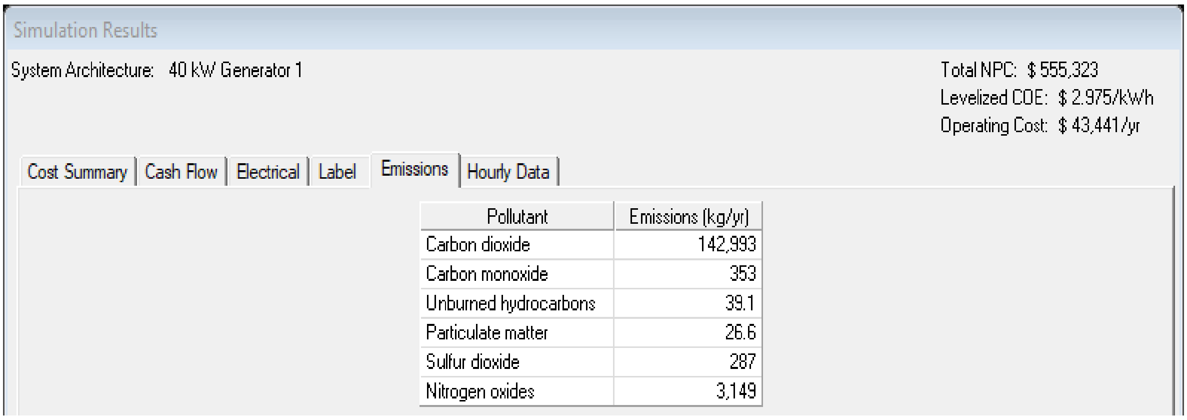

Fig. 7. 42 kVA diesel generator gas emissions at Blekoum

4.2 RESULTS OBTAINED FROM THE SIMULATION OF HYBRID SYSTEM

There are three scenario of hybrid systems observed after optimization of conditions in real time by HOMER including following sunny day, semi-sunny day, cloudy day, good wind speed, low wind speed, high biomass availability or low biomass availability as evidenced by the following rendering in figure 8.

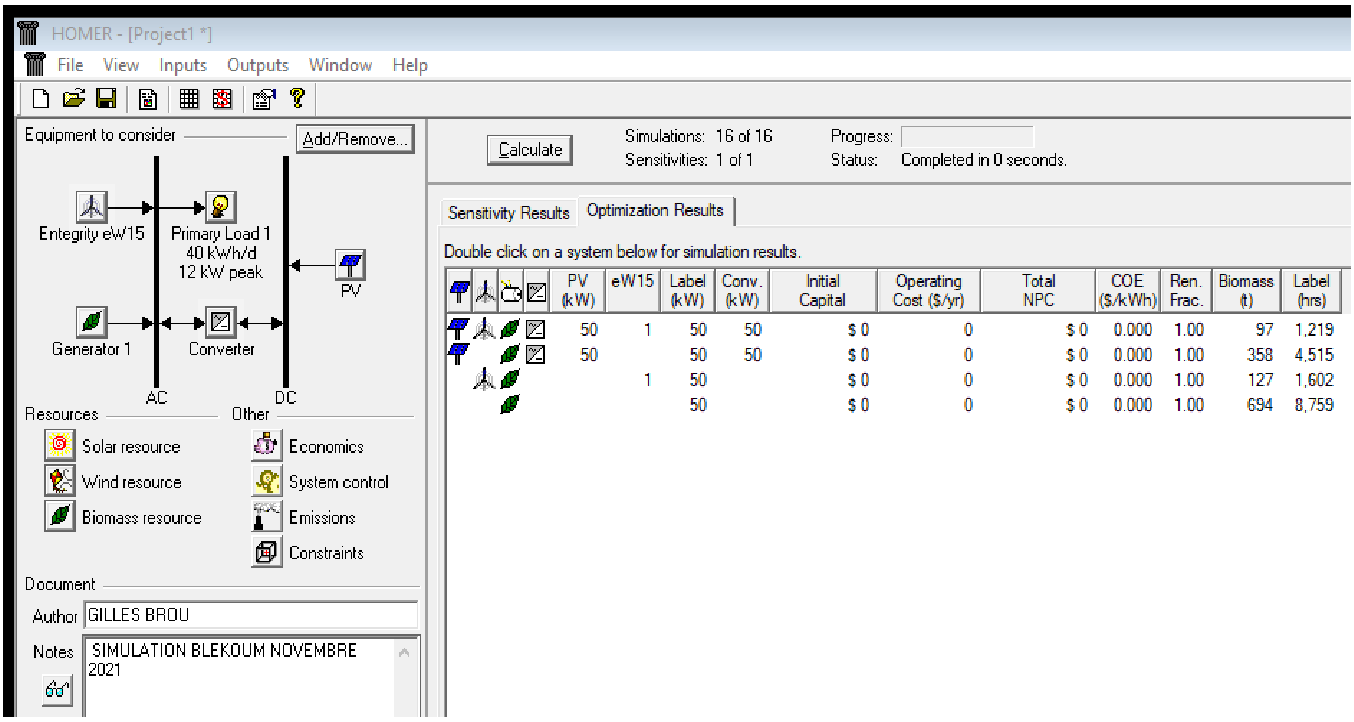

Fig. 8. The three scenarios of hybrid production with renewable energy sources in Blekoum

The first scenario is that the three systems (solar, wind and generator biogas) function and contribute for each to the production of energy according to the figure 9.

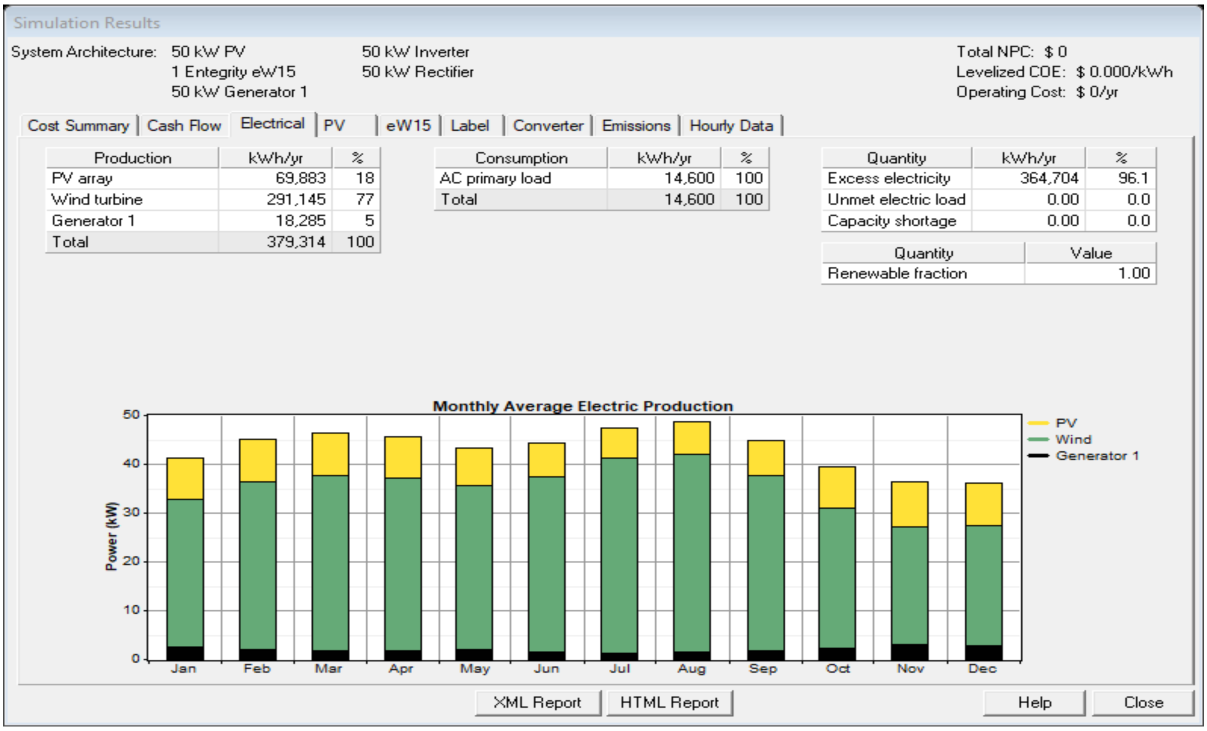

Fig. 9. Energy diagram produced by the hybrid scenario 1 system in Blekoum

Gas emissions from the operation of the three systems are shown in the figure 10.

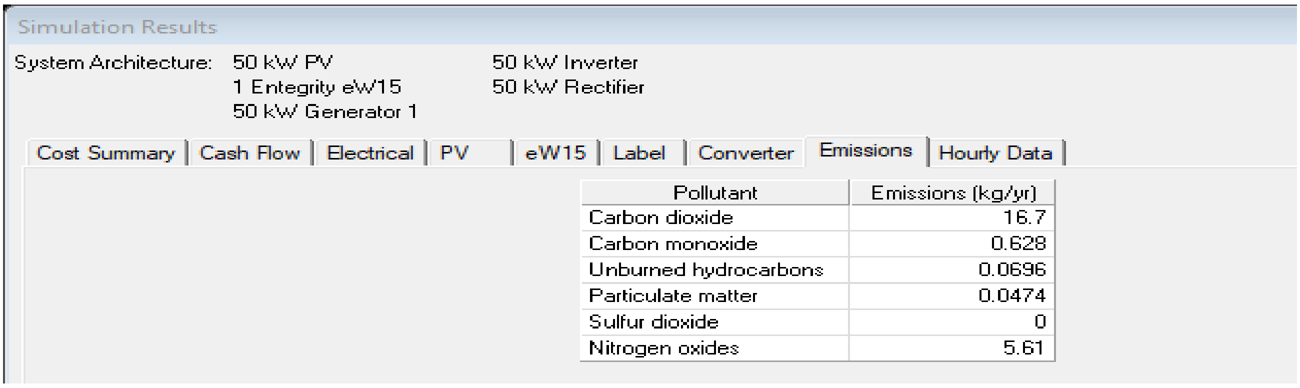

Fig. 10. Scenario 1 hybrid gas emissions in Blekoum

In this scenario 1 the expected output carried by the operation of the three solar generator systems, wind generator and biogas generator is estimated at 379.314 kWh/year much higher than the energy generated by the existing diesel generator alone which is 105,108 kWh/year confirming the results of Mohammed (2009) [22]. The economic analysis based on the data from of the two systems with scenario 1 is shown in Table 2.

Table 2. Economic and Energy Data Comparison of Scenario 1 & Diesel Group Systems

Economic data	Hybrid system scenario 1 including converter	Diesel generator set 42kVA
Initial Investment ($)	181 553	7 130
Cost of Operations ($)	10 435	66 261
Total System Cost ($)	191 987	73 391
Total energy (kWh)	379.314	105.108
kWh price ($)	506	698

The price per kWh of energy generated by the diesel-only generator is more expensive than that of the hybrid system in this scenario 1 as reported by the economic study conducted by TSUANYO (2015) [2]. In addition, with respect to gas emissions, the values are summarized in below and indicate that the diesel generator is more polluting than our hybrid system as outlined by Mohammed (2009) [22].

Table 3. Comparison Data Gas Emissions Scenario 1 & Diesel Group

Gas emissions & miscellaneous (Kg/year)	Hybrid scenario 1	Diesel generator 42kVA
CO_2	16.7	142.933
CO	0.628	353
Unburnt hydrocarbons	0.0696	39.1
Miscellaneous particulates	0.0474	26.6
SO_2	0	287
NO	5.61	3.149

Scenario 2 in figure 11 below is where we have the solar generator and the biogas generator in operation. The wind turbine does not contribute due to low wind speed sequences.

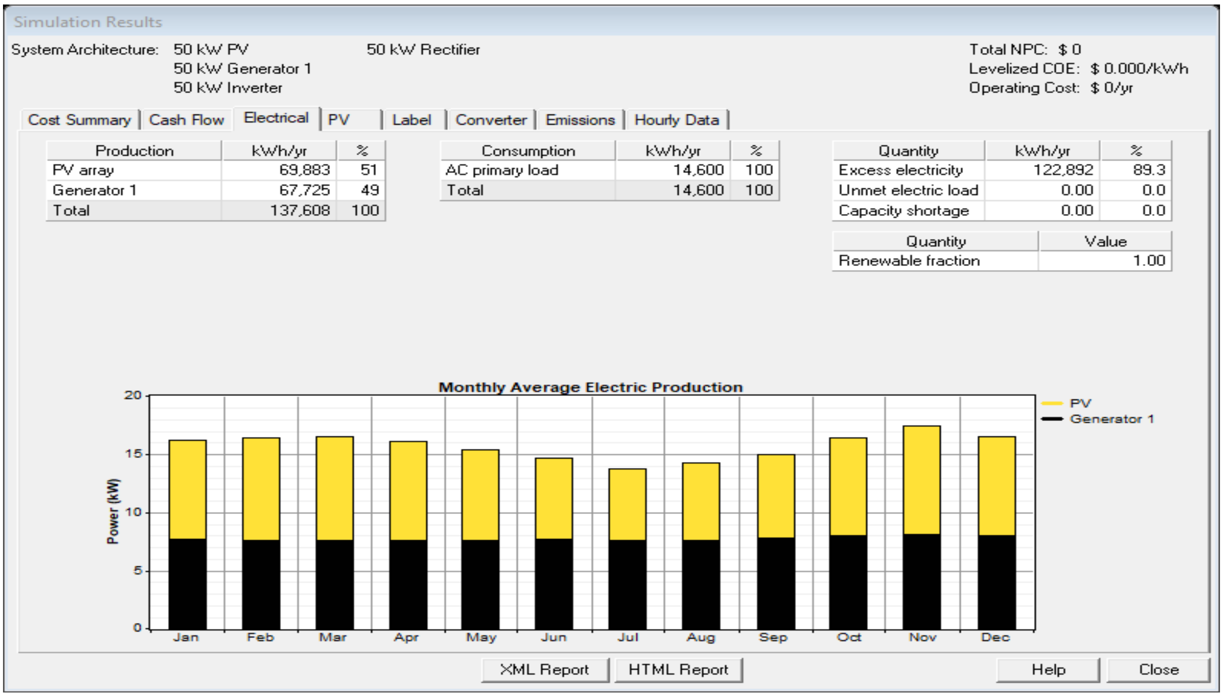

Fig. 11. Energy produced by the hybrid scenario 2 system in Blekoum

The gas emissions from the two systems in operation are shown in the figure 12.

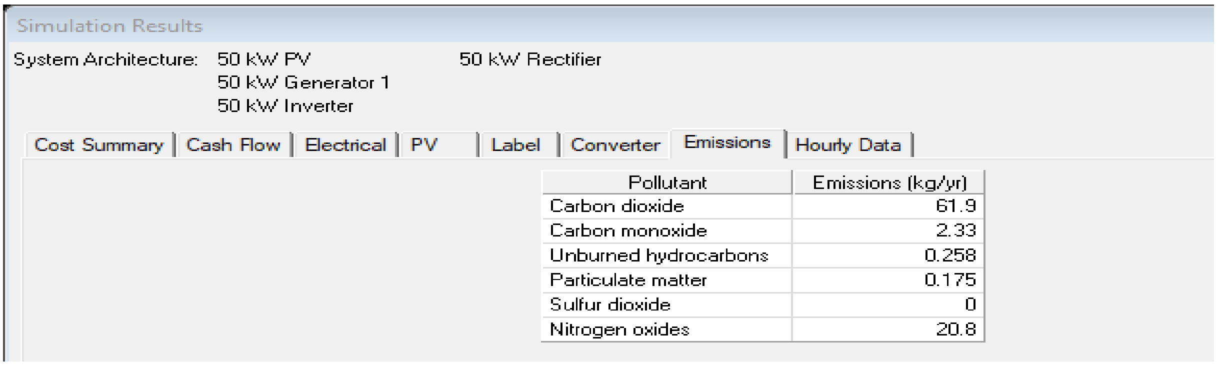

Fig. 12. Scenario 2 hybrid gas emissions in Blekoum

In scenario 2 the production of our hybrid system powered by the operation of wind and biogas generator systems is estimated to be 137.608 kWh/year higher than the energy generated by the existing diesel generator alone which is 105,108 kWh/year remaining in line with the results of Mohammed (2009) [22]. The economic analysis of the two systems with scenario 2 is shown in table 4.

Table 4. Comparison of economic and energy data of Scenario 2 & diesel systems

Economic data	Hybrid system scenario 2 including converter	Diesel generator set 42kVA
Initial Investment ($)	181 553	7 130
Cost of Operations ($)	10 435	66 261
Total System Cost ($)	191 987	73 391
Total energy (kWh)	137.608	105.108
kWh price ($)	1395	698

In the absence of the wind generator whose investment has already been made, the kWh of energy generated by the diesel generator alone is cheaper than that of the hybrid system. This scenario is contrary to the economic values of David TSUANYO (2015) [2] but remains understandable because the hybrid system considered was PV/Diesel without the integration of the cost of a wind turbine. However, with regard to gas emissions, the values listed in confirm that the diesel unit pollutes more than the remaining hybrid system faithful to the results presented by Mohammed (2009) [22].

Table 5. Comparison of gas emissions hybrid system scenario 2 & diesel group

Gas emissions & miscellaneous (Kg/year)	Hybrid scenario 2	Diesel generator 42kVA
CO2	61.9	142.933
CO	2.33	353
Unburnt hydrocarbons	0.258	39.1
Miscellaneous particulates	0.175	26.6
SO2	0	287
NO	20.8	3.149

Scenario 3 is where we have the wind turbine and biogas generator in operation. The solar does not contribute because of the sequences of weak sunshine (cloudy days) or lack of sunshine (nights) in figure 13.

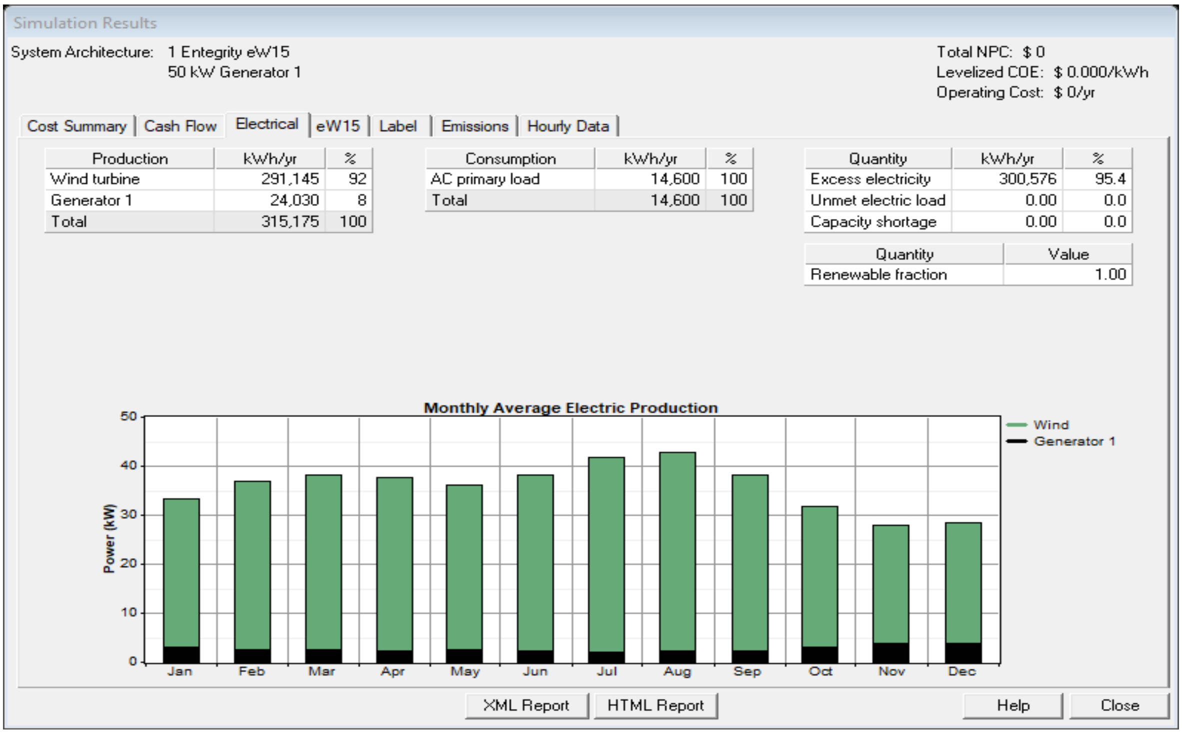

Fig. 13. Energy produced by the hybrid scenario 3 system in Blekoum

Gas emissions from the Scenario 3 hybrid system with both systems in operation are shown in the figure 14.

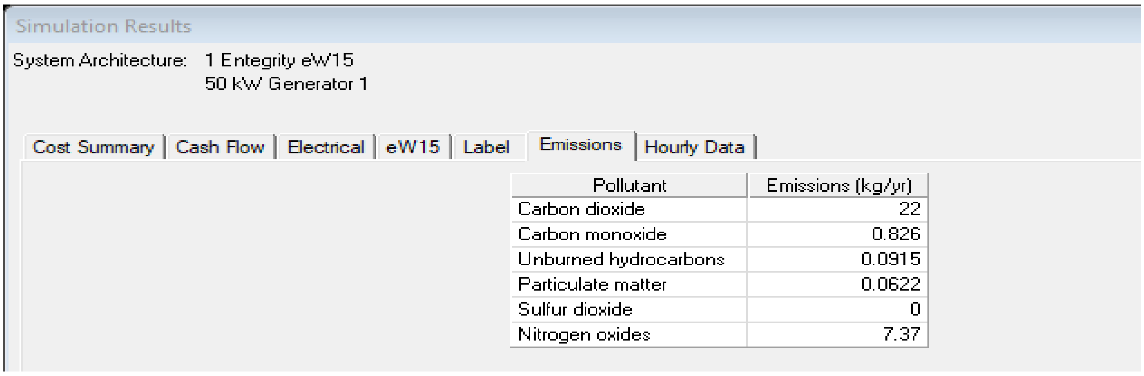

Fig. 14. Gas emissions from the hybrid scenario 3 system in Blekoum

In scenario 3 the production supported by the operation of the wind and biogas generator systems, in the absence of the solar generator input (at night, overcast), is estimated to be 315.175 kWh/year significantly higher than the energy generated by the existing diesel generator which is 105.108 kWh/year remaining consistent with the results of Mohammed [22].

The economic analysis of the two systems in operation in scenario 3 is shown in table 6.

Table 6. Comparison of economic and energy data of the hybrid system scenario 3 & diesel group

Economic data	Hybrid system scenario 3 including converter	Diesel generator set 42kVA
Initial Investment ($)	181 553	7 130
Cost of Operations ($)	10 435	66 261
Total System Cost ($)	191 987	73 391
Total energy (kWh)	315.175	105.108
Prix kWh	609	698

We conclude again that the kWh of energy generated by the diesel generator is more expensive than that of the hybrid system again conforming to the economic analysis of TSUANYO (2015) [2].

Further on gas emissions; the values in confirm that the diesel generator according to Mohammed (2009) [22] pollutes the environment more than the hybrid system of scenario 3.

Table 7. Comparison of gas emissions data hybrid system scenario 3 & diesel group

Gas emissions & miscellaneous (Kg/year)	Hybrid scenario 2	Diesel generator 42kVA
CO_2	22	142.933
CO	0.826	353
Unburnt hydrocarbons	0.0915	39.1
Miscellaneous particulates	0.0622	26.6
SO_2	0	287
NO	7.37	3.149

5 CONCLUSION

The HOMER software has made it possible to study a hybrid system compared to the existing diesel generator for the power supply of the locality of Blekoum. The results of the hybrid system consisting of solar, wind and biogas generators, including the converter all of 50kW, give generated energies of 379.314kWh/year; 137.608kWh/year and 315.175kWh/year respectively, an average of 277.364 kWh/year according to the scenarios, greater than 105.108 kWh/year due to the 42 kVA diesel generator. The prices of the hybrid kWh go from 291,032.54FCFA to 802,226.33 FCFA before falling back to 350,258.49 FCFA, an average cost of 481,172.453 FCFA, whereas the price per kWh of the diesel generator is 401,491.799 FCFA.

In addition, gas emissions remain by far higher with the diesel generator where the CO_2 peak at 142.933 kg/year, CO at 353 kg/year and SO_2 at 287 kg/year while with our hybrid generator these values in the mean are displayed for CO_2 at 33,533 kg/year; CO at 1.261 and SO_2 at 0 kg/year. The diesel generator is therefore a real accelerator of global warming and environmental pollution in contrast to the hybrid system that helps preserve our climate.

This study can also be carried out for the forty and one other localities equipped with diesel generators throughout the territory in order to validate or explain the limits of our hybrid system model.

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