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Impact of Using Renewable Energy on the Cost of Electricity and Environment in Northern Cameroon

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ABSTRACT

This paper determines and compares the cost of energy (COE) of various hybrid systems for several off-grid facilities in North and Far North regions of Cameroon by integrating renewable sources and/or storage with diesel generators. The estimated annual energy production by solar PV systems and wind turbines, based on meteorological data provided by NASA, is also discussed. A hybrid system using photovoltaic panels, wind turbines, diesel generators, batteries and converter was designed using HOMER software to supply electricity to these off-grid facilities. Parameters such as investment, cost of energy, total cost, renewable energy fraction, fuel consumption, and GHG emission have been compared over 25 years operation with the use of diesel generators only. It is shown that the use of renewable energies (wind and photovoltaic), despite the fact that it requires large investments initially, is the most economical, most profitable and least polluting system.

1. INTRODUCTION

Energy is considered as a prime agent in the generation of wealth, a significant factor in the economic development, and as a driving force for industrialization [1]. Cameroon is well known for its reserves of oil and gas, abundance of firewood and for its capability to produce hydroelectric energy. It should be recalled that Cameroon has the second-largest hydropower potential in Africa after the Democratic Republic of Congo. Yet, according to statistics from the Ministry of Water resources and Energy of Cameroon, only 5% of these resources are currently developed. Furthermore, fossil fuels are becoming increasingly expensive each year and are not readily available in some remote areas. This causes a low electricity access rate, estimated at 22% [2]. The great gap between supply and demand results in electricity rationing and intermittent power outages across the country.

It is clear that the solutions proposed to date are essentially based on the use of fossil fuels and hydropower. Yet, recent studies have revealed other alternatives [3] through wind power in the northern regions [4, 5] or solar energy [6] for the production of electricity. The present work covers the design of a solar-wind hybrid energy system and energy storage producing usable electricity as a support system and redress in case of failure of the existing network (Fig. 1). The aim is to set up a system with a high penetration of renewable energy sources to replace existing diesel generators, frequently used as the only alternative energy. This project is underway as part of Local Materials Promotion Authority/MIPROMALO activities aimed to contribute to sustainable development in accordance with the Kyoto Protocol [7, 8].

Figure 1. Example of a small-scale Wind-PV system

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Data collected in four facilities in the North and Far North regions of Cameroon (Fig. 2) was used in this study [9]. There is a research center in Garoua, a small-medium size enterprise (SME) specialized in the production of agricultural equipment in Maroua, a poultry farm in Yagoua and a health center in Kousseri. The Northern part of Cameroon is part of the Sahel region with high potential in solar [6] and wind energies. The annual and monthly mean wind speeds are the highest in the country. For each of these four facilities, hybrid system models were developed to get the most energy according to weather data and at the lowest possible cost.

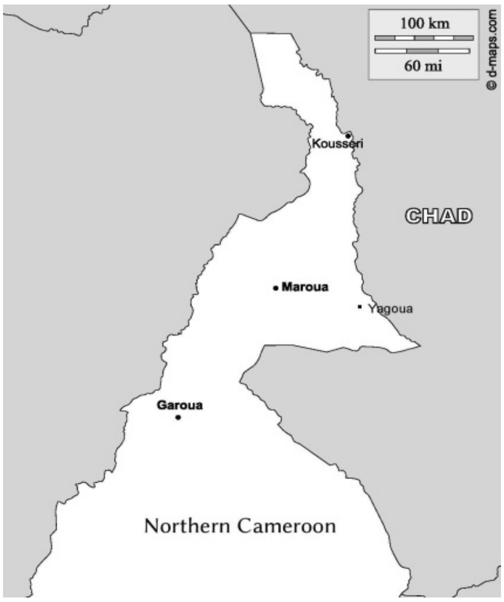


Figure 2. Map of Northern Cameroon showing the four locations of the study

Different approaches and/or software solutions have been used to simulate and optimize the performance of hybrid energy production systems such as ARENA, Opt-Quest tool [10-12], Matlab / Simulink [13], Response Surface Metamodels (RSM) [10] or Genetic Algorithms (GA) [14]. In this project we have used HOMER [15, 16] which is a design and analysis software for hybrid systems. It is worth mentioning that Kenfack et al. [17] studied a hybrid PV micro-hydro system at Batocha in Cameroon using HOMER software for design and optimization. Kanase-Patil et al. [18] studied the electrification of seven villages, off the grid in the district of Almora Uttarakhand state, India. Moreover, biomass, solar, hydroelectric sources and wind energy have been examined and analyzed using LINGO and HOMER software. Bakos [19] studied the feasibility of a hydro-wind hybrid system to electrify remote islands in Greece using the Monte Carlo simulation program. Connolly et al. [20] and Chauhan et al. [21] have made a comparative study of several computer tools for the integration of renewable resources in the different energy systems. HOMER software is one of the most used software for optimization, feasibility and analysis of hybrid power systems.

2. AREAS OF STUDY AND METEOROLOGICAL DATA

The geographical coordinates of the selected locations are given in Table 1. These are the towns of Garoua, Maroua, Kousseri and Yagoua. All four cities are located in the North of Cameroon. Meteorological data (wind speed, solar radiation, and clearness index) used in this study are those provided by NASA through Homer software [22]. The data represents the monthly average solar values of Global Horizontal Irradiance over a 22-year period (July 1983 – June 2005) and the monthly average wind speed data over a 10-year period (July 1983 – June 1993). Recent work of Kidmo et al. [23-26] in this region has shown that this data has not undergone any significant changes in the last twenty years.

TABLE 1. The geographical coordinates of the selected locations

locations	Latitude °N	Longitude °E	Elevation (m)
Garoua	9.3	13.4	332
Maroua	10.6	14.3	394
Yagoua	10.4	15.2	311
Kousseri	12.08	15.03	295

The average monthly wind speeds, measured at 50 m height, vary almost identically during the year in the four locations (Fig. 3). They all reach their maximum values in April. The highest monthly average speed is recorded in Kousseri with 6.04 m/s while the lowest was observed in Garoua with 3.37 m/s [27].

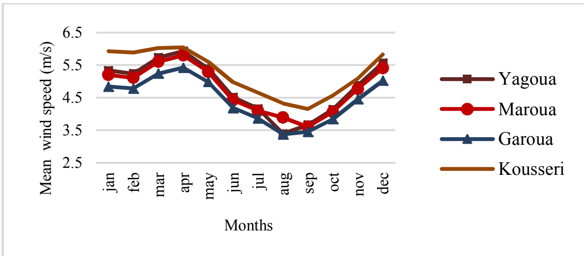
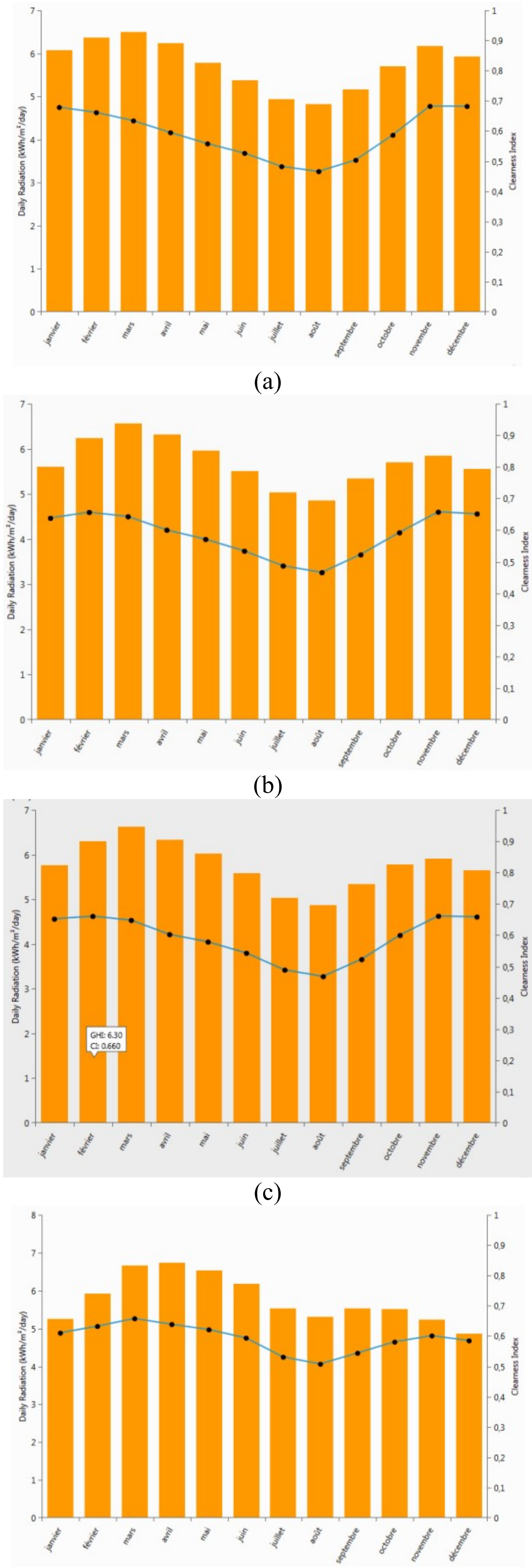


Figure 3. Monthly variations of average wind speed at 50 m height

Fig. 4 shows the monthly average daily solar radiation horizontal and clearness indices at the four locations. The greatest value of solar radiation is 6.73kWh/m^2/d in Kousseri during the month of April while the smallest value, 4.83kWh/m^2/d, is in Garoua during the month of August. In general, the annual average value in the four locations is above the 5.70 kWh/m^2/d.



(a) (b) (c) (d)

Figure 4. Daily radiation and clearness index in (a) Garoua; (b) Maroua; (c) Yagoua; and (d) Kousseri

On a scale from 0 to 1, we see that the monthly average of sky clearness index is around 0.5. This tells us that the sky is always clear. The highest value was observed in Garoua with 0.681, while the lowest value was observed in Garoua and Maroua with 0.465.

3. MATHEMATICAL MODEL FOR RENEWABLE ENERGY SOURCES

3.1. Mathematical model of the wind power system

The wind speed is a factor that varies continuously at a given site. It depends on the physical and geographical characteristics (topography, canopy, hydrography, etc.), the weather and the height from the ground. It is crucial to correctly estimate the variations and control the production of wind energy. There are different probability density functions that can be used to statistically describe the wind speed data. The most common is Weibull distribution with its particular case (for a shape factor k=2) the Rayleigh distribution. Weibull function is a special case of the generalized gamma distribution with two parameters. Rayleigh distribution is a subset of the Weibull distribution characterized by one parameter. Therefore, Weibull distribution is more flexible while Rayleigh is easier to use if not enough data is available [28, 29]. Weibull distribution is the most used as it provides the best fit on most sites for the monthly measurements of wind speed [28, 30, 31]:

$$f(V,k,c) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^{k}\right] \quad (1)$$

where, $f(V,k,c)$ = the probability of observing the wind speed V ; c = scale factor (m/s) and k = shape factor (dimensionless). An acceptable approximation of k is given by the following expression [32]:

$$k = \left(\frac{\sigma}{V_m}\right)^{-1,086} \quad (2)$$

where, σ is the standard deviation and V_m is the average wind speed (m/s). For values of k between 1.6 and 3.0, the factor c can be calculated within an error of approximately 1% by the following expression [33]:

$$c \cong \frac{2V_m}{\sqrt{\pi}} \quad (3)$$

The output power ($P_{o,we}$) and the capacity factor (C_f) are two important parameters of wind energy conversion system (WECS). ($P_{o,we}$) determines the total amount of produced energy, and the (C_f) is the fraction of the output power over the nominal electric power P_{eR} of the turbine [28, 32, 34]. These two parameters are calculated using the following formulas [28, 32]:

$$P_{o,we} = P_{eR}\left(\frac{e^{\left(\frac{V_c}{c}\right)^k} - e^{\left(\frac{V_r}{c}\right)^k}}{\left(\frac{V_r}{c}\right)^k - \left(\frac{V_c}{c}\right)^k} - e^{\left(\frac{V_f}{c}\right)^k}\right) \quad (4)$$

$$C_f = \frac{P_{o,we}}{P_{eR}} \quad (5)$$

where, V_c, V_r and V_f are the cut-in wind speed, rated wind speed, and cut-off wind speed, respectively.
The total annual energy production is given by:

$$\bar{E}_{a,we} = 365 \times 24 \times \left(\sum_{V=0}^{V_f} P_{out} \times f(V,k,c) \right) \quad (6)$$

In most situations, the measurement height of wind speeds is different from the height of the hubs installed wind turbines. These speeds may be adjusted using the following relation [4, 28, 32]:

$$\frac{V}{V_0} = \left(\frac{h}{h_0}\right)^{\alpha} \quad (7)$$

here, V is the wind speed at the height h of the turbine hub, V_0 is the wind speed at the reference height h_0 and α is the coefficient that characterizes the roughness of the site. It is taken to be 0.20 in most cases [32].

3.2. Mathematical Model of the Solar System

Photovoltaic energy originates from the solar radiation that reaches the surface of the earth. The solar radiation depends on the orientation and inclination of the incident surface, the latitude of the location and degree of pollution, the period of year, the time of day, and the nature of the cloud layers. The total hourly solar radiation $\boldsymbol{I_t}$ over a sloping surface is estimated as [18, 21]:

$$I_t = I_b R_b + I_d R_d + (I_b + I_d) R_r \quad (8)$$

where, I_t is expressed in kWh/m^2, I_b and I_d are respectively the beam part of solar radiation and the diffused part of solar radiation, both expressed in kWh/m^2, R_b, R_d and R_r are respectively the tilt factor for beam radiation, the tilt factor for diffused radiation and the tilt factor for reflected radiation.
The power output of a PV system $P_{p,se}$ is calculated from the expression [18, 21]:

$$P_{p,se} = \eta I_t A \quad (9)$$

where, η is the conversion efficiency of the photovoltaic system and A is the area of the photovoltaic system.
The total annual energy produced by the system is given by the following expression:

$$\bar{E}_{a,se} = \sum_{i=1}^{8760} P_{p,se}(i) \quad (10)$$

4. LOADS DEFINITION

It is important to define the electrical loads of the photovoltaic–wind (PV-W) system as they affect the cost, size, and project feasibility. The capacity of the energy storage component (such as batteries) depends on the number of hours of operation of the PV-W system per day. In this work, the following four loads are considered:
- A research center in Garoua with major laboratory equipment, a water pumping station, computer equipment, air conditioning, lighting, etc.;
- A SME in Maroua specialized in the production of agricultural equipment with several high-power machines, a water pumping station, computer equipment, air conditioning, lighting, etc.;
- A poultry farm in Yagoua with an electric heating system, several medium-power machines, a water pumping station, lighting, etc.;
- A health center in Kousseri with medical equipment, air conditioning, a water pumping station, lighting, etc.

TABLE 2. Distribution of average hourly energy consumption of the four loads

Hours	Garoua (kWh)	Maroua (kWh)	Yagoua (kWh)	Kousseri (kWh)	Hours	Garoua (kWh)	Maroua (kWh)	Yagoua (kWh)	Kousseri (kWh)
0h-1h	0.7	1.1	0.9	0.4	12h-13h	2.2	4.3	2.1	2
1h-2h	0.7	1.1	0.9	0.4	13h-14h	3.1	4.6	2.1	1.9
2h-3h	0.7	1.1	0.9	0.4	14h-15h	3.2	6.7	3	3
3h-4h	0.7	1.1	0.9	0.4	15h-16h	2.9	6.2	2.9	2.9
4h-5h	0.7	1.1	0.9	0.4	16-17h	2.1	5.3	2.6	2.8
5h-6h	0.7	1.1	0.9	0.4	17h-18h	2	4.5	1.6	1.6
6h-7h	0.4	0.7	0.9	0.2	18-19h	1.8	1.7	1.3	1.3
7h-8h	1.6	1.6	2.4	2.3	19h-20h	1.7	1.7	0.9	0.9
8h-9h	2.25	2,25	2.6	2.6	20h-21h	1.5	1,4	0.9	0,6
9h-10h	3	3	3.2	3.1	21h-22h	0.7	1.1	0.9	0.4
10h-11h	4.4	6.5	3.3	3.2	22h-23h	0.7	1.1	0.9	0.4
11h-12h	4.3	6.3	3.5	3.2	23h-24h	0.7	1.1	0.9	0.4
					Total	**42.6**	**66.3**	**41.3**	**35.1**

Table 2 shows the average hourly distribution of energy consumption in the four loads. Maroua has the highest load with daily energy consumption of 66.65 kWh; this is the result of the frequent use of high power transformer machines at this location. The lowest charge is that of Kousseri at 35.2kWh per day. In general, the average hourly energy consumption distribution in a day's work shows that the energy consumption is higher in the intervals of 10 to 12 a.m. and 2 to 4 p.m. which corresponds to the periods of more intense activity.
The water pumping is considered as a deferrable load. Table 3 presents the annual average need of water per day and the storage capacity of each site. The pump used in this study draw 1300 W of electric power and pumps 4.5 m3 per hour. The minimum load ratio for each site is 25%.

TABLE 3. Annual average need of water and storage capacity

Sites	Garoua	Maroua	Yagoua	Kousseri
Annual average (kWh/d)	0.9	1.07	1.13	1.03
Storage capacity (kWh/d)	2.5	2.5	3.75	2.75

Fig. 5 shows the basic outline of the integrated PV-W with optional diesel generator. The control system is at the heart of the PV-W. It provides communication between the various system components.

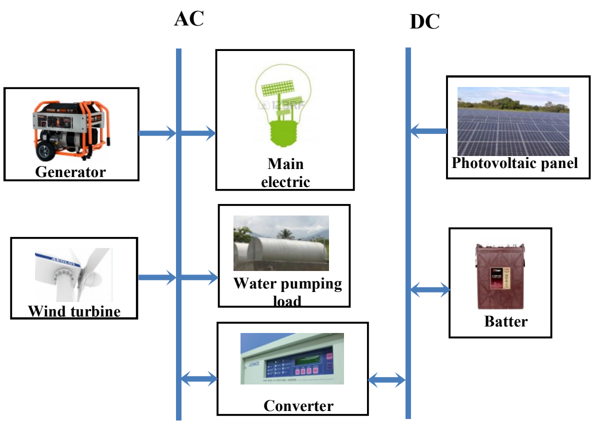


Figure 5. Schematic illustration of PV-Wind based energy system

5. TECHNICAL SPECIFICATIONS OF THE HYBRID SOLAR-WIND (PV-W) SYSTEM

The proposed configuration for HOMER simulation uses a DC and an AC bus as illustrated in Fig. 5. PV solar panels and batteries are connected to the DC bus while diesel generator, wind turbines and loads are connected to AC bus.
The size of the different components of the hybrid system with battery storage and backup diesel generator is chosen to (1) maximize the percentage of renewable power in total annual energy (2) provide a significant reduction of the use of the diesel generator and on/off cycling, (3) provide a significant reduction in fuel consumption and GHG emissions compared to diesel operation only, (4) maintain high reliability of electric power supply as required by the load systems [35-38].
The system has been designed so that the batteries provide at least 20 hours of autonomy to full load. The operating capacity power (generators, wind turbine and photovoltaic panels) is always greater than the load. Therefore, the capacity shortage is null. Technical specifications of devices (wind turbines and solar panels) are presented in Tables 4 and 5. The Aeolos-H 3kW wind turbine selected in the present study has the advantage to operate in low wind speed as it is the case in all sites. To increase system reliability during generator maintenance and to avoid the operation under the minimum load ratio of the generator (25%), we selected two generators of different sizes in each site so that the smallest size can operate at lower load. We model both Load Following (LF) and Cycling Charging (CC) strategies available in Homer software so that the optimal one is chosen for each case [16].

TABLE 4. The wind turbine Aeolos-H 3kW Specifications

Power	3 kW
Generator type	3 ph. permanent magnetic
Rotor diameter	5.0 m
Start wind speed	2.5 m/s
Rated wind speed	10 m/s
Working speed	2.5-45 m/s
Voltage	220V-240V
Number of blades	3

TABLE 5. The photovoltaic panel THINK-240 Specifications

Power class	240 Wp
Open circuit voltage (V_{oc})	36.8 V
Short circuit current (I_{sc})	8.32 A
Maximum voltage (V_{mp})	30.0 V
Maximum current (I_{mp})	7.83 A
Module efficiency (%)	14.8
Maximum system voltage	600 V
Maximum series fuse rating	15A

6. SIMULATIONS AND RESULTS

6.1. Presentation of the simulation software HOMER

HOMER is the design and analysis software used in this study to analyze the performance of the hybrid system. Based on an hourly balance between power production and load demand, it explores a large number of technical configurations and compares them based on kWh price, renewable fraction, etc.

TABLE 6. Summary of software inputs – Garoua

Item	Capacity (kW)	Capital($)	Replacement ($)	O & M cost ($/yr)	Size considered (kW)	Quantities considered	Life time
THINK-240 PV	1	5 000	5 000	40	0-5-6-7-7.5		25 years
Aeolos-H 3kW wind turbine	1 (unit)	13 500	13 500	100	0-3	0-1	25 years
Generator (Generac 5kW)	1	800	800	0.08 ($/hr)	0-5		25 000 h
Generator (Generac 1kW)	1	800	800	0.08 ($/hr)	0-1		25 000 h
Battery (Trojan L16P)	1(unit)	500	500	0.5		0-20-25-30	
Converter (Leonics)	1	800	800	40	0-5-6		15 years

TABLE 7. Summary of software inputs – Maroua

Item	Capacity (kW)	Capital($)	Replacement ($)	O & M cost ($/yr)	Size considered (kW)	Quantities considered	Life time
THINK-240 PV	1	5 000	5 000	40	0-9-10.5-12		25 years
Aeolos-H 3kW wind turbine	1 (unit)	13 500	13 500	100	0-3	0-1	25 years
Generator (Generac 7kW)	1	800	800	0.08 ($/hr)	0-7		25 000 h
Generator (Generac 2kW)	1	800	800	0.08 ($/hr)	0-2		25 000 h
Battery (Trojan L16P)	1(unit)	500	500	0.5		0-35-40-45	
Converter (Leonics)	1	800	800	40	0-5-6-7		15 years

TABLE 8. Summary of software inputs – Yagoua

Item	Capacity (kW)	Capital($)	Replacement ($)	O & M cost ($/yr)	Size considered (kW)	Quantities considered	Life time
THINK-240 PV	1	5 000	5 000	40	0-5-6		25 years
Aeolos-H 3kW wind turbine	1 (unity)	13 500	13 500	100	0-3	0-1	25 years
Generator (Generac 4kW)	1	800	800	0.08 ($/hr)	0-4		25 000 h
Generator (Generac 1kW)	1	800	800	0.08 ($/hr)	0-1		25 000 h
Battery (Trojan L16P)	1(unity)	500	500	0.5		0-20-25	
Converter (Leonics)	1	800	800	40	0-4-5		15 years

TABLE 9. Summary of software inputs – Kousseri

Item	Capacity (kW)	Capital($)	Replacement ($)	O & M cost ($/yr)	Size considered (kW)	Quantities considered	Life time
THINK-240 PV	1	5 000	5 000	40	0-4-4.5		25 years
Aeolos-H 3kW wind turbine	1 (unit)	13 500	13 500	100	0-3	0-1	25 years
Generator (Generac 3.5kW)	1	800	800	0.08 ($/hr)	0-3.5		25 000 h
Generator (Generac 1kW)	1	800	800	0.08 ($/hr)	0-1		25 000 h
Battery (Trojan L16P)	1(unit)	500	500	0.5		0-20-25	
Converter (Leonics)	1	800	800	40	0-3-4		15 years

6.2. Results analysis

HOMER simulates system configurations with all combinations of the components specified in Table 10. We propose to present in Table 10 only the results of the Garoua site but we will comment further the results of all sites. This table illustrates the best configurations for the site, classified according to the NPC (Net Present Cost) or COE (Cost of Energy).

Each line represents an alternative solution computed with HOMER. As justified in section 5, we eliminated the solutions where only one generator operates, either higher or lower power. Also, we eliminated all configurations without battery storage when renewable sources are present because the renewable penetration is high enough to cause stability problems (Homer software that recommend this!). In addition to the lowest COE system, two others are of particular interest, the DO (Diesel Only) system, using only generators as energy source without battery storage and BRF (Best Renewable Fraction) system with the highest annual fraction of renewable energy. In Table 10, the DO solution corresponds to gray color line (line 9) while BFR solution is in the first line colored in green, being the one with the lowest COE.

TABLE 10. Garoua optimization results, in a categorized form, ranking according to the NPC of each system type

Architecture						Cost						System	
 Think 240 PV	 Aeolos H3kW	5kW	1kW	 Trojan L16P	 Loenics	COE ($)	NPC ($)	Operating cost ($)	Initial cost ($)	Fuel cost ($)	O&M ($)	Ren Frac (%)	Total fuel (L)
○	○	○	○	○	○	0.467	93 934	2 718	58 800	1 095	789	86	843
○	○		○	○	○	0.489	98 411	3 374	54 800	1 648	782	76	1267
○	○	○	×	○	○	0.491	98 909	3 165	58 800	1 194	1 012	87	918
○	○	○	○	×	○	0.516	103 77	4 446	46 300	2 559	1 528	71	1969
○	×	○	○	○	○	0.518	104 213	4 673	43 800	2 549	1 151	67	1961
○	×	○	○	×	○	0.525	105 747	5 759	31 300	3 614	1 683	56	2780
○	×	○	×	○	○	0.590	118 828	5 672	45 500	2 815	930	59	2165
×	○	○	○	×	×	0.684	137 674	9 118	19 800	6265	2 205	20	4819
×	×	○	○	×	×	0.699	140 685	10 511	48 000	7 547	2 257	0.0	5805
×	○	○	○	○	○	0.736	148 067	8 646	36 300	5 823	1 597	19	4479
×	○	○	×	○	○	0.768	154 614	9 214	35 500	6 076	1 799	17	4674
○	○	○	×	×	○	0.822	165 387	9 274	45 500	5 250	3 024	45	4038
×	×	○		○	○	0.833	167 667	11 384	20 500	7 725	1 925	0.0	5942
×	×	○	○	○	○	0.837	168 448	11 383	21 300	7 528	2 304	0.24	5791
○	×	○	×	×	○	0.859	172 958	11 020	30 500	6 377	3 434	32	4905
×	○	○	×	×	×	0.901	181 264	12 552	19 000	8 137	3 290	2.4	6259
×	×	○	×	×	×	0.920	185 241	14 020	4 000	9 261	3 504	0.0	7124

The DO solution is the one that is currently being operating at the four sites in absence of main grid electricity (nonexistent network, network failure, load shedding, power rationing, etc.). The DO solution is the one with the lowest initial capital of $4,800 in Garoua, $7,200 in Maroua, $4,000 in Yagoua, and $3,600 in Kousseri. However, when considering the operation over 25-year period, it is the most expensive system ($140, 685 in Garoua, $226,772 in Maroua, $158,745 in Yagoua, and $120,650 in Kousseri), mostly for fuel purchase.

Best Renewable Fraction (BRF) solution is the one that requires the highest initial investment, approximately $58,800 in Garoua, $80,500 in Maroua, $50,200 in Yagoua, and $45,300 in Kousseri. However, even with the largest initial investment, this is by far the most economical system with the lowest NPC, up to one and half times less than DO solution. The results show a very high renewable energy penetration rate; more than 80% in all sites (see Table 10, column "Renewable Fraction").

Additional data about BRF operation is illustrated in Fig. 6. This figure shows the monthly average electricity production from each energy source, wind (green colored), solar (orange colored) and diesel, respectively. It appears that PV is the most important source for the four sites with average annual production rate of 67.18% in Garoua, 70.05% in Maroua, 56.36% in Yagoua, and 47.76% in Kousseri.

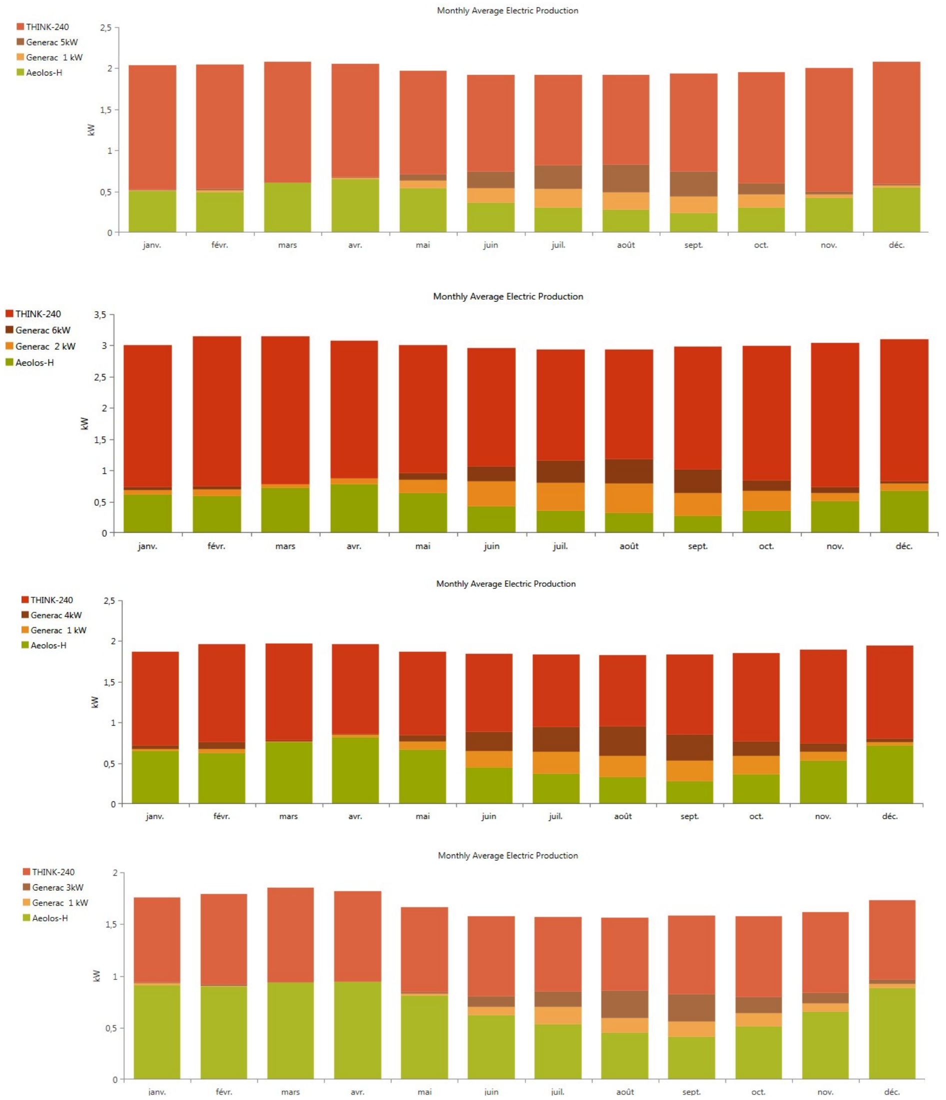
The largest average annual production rate of wind energy is recorded in Kousseri (42.5%), which benefits of the best wind potential of all sites (see Fig. 3).

For the BRF System, the combined contribution of renewable sources and battery storage results in minimal use of diesel generators and translates into significant fuel savings, i.e., annual consumption of 843L in Garoua, 1456L in Maroua, 931L in Yagoua and 548 L in Kousseri over the 25-year operation

In addition to the economic aspects, the use of renewable energy also results in GHG emission reduction. Table 11 provides a comparison between DO and BRF solutions of the pollutant emissions: carbon dioxide, carbon monoxide, unburned hydrocarbons, particular matter, sulfur dioxide, and nitrogen oxides [42]. The reduction of the environmental impact by using BRF compared to DO solution is significant.

7. CONCLUSIONS

The wind speed and solar data from NASA weather database for four sites (Garoua, Maroua, Yagoua and Kousseri) of the North and Far North of Cameroon have been used to study the potential of using renewable sources in addition to diesel generators. The wind energy potential is small but usable if turbines are installed at least at 20 m height. On the other hand, solar energy is abundant in the four sites and use of photovoltaic panels is suitable.



(a)

(b)

(c)

(d)

Figure 6. Monthly average electric production in the case of the BRF for (a) Garoua; (b) Maroua; (c) Yagoua; and (d) Kousseri

TABLE 11. Comparative emission of polluting particles between the two solutions in the four areas of the study

Pollutants	**Emissions (kg/yr)**							
	Garoua		**Maroua**		**Yagoua**		**Kousseri**	
	DO solution	BRF solution	DO solution	BRF solution	DO solution	BRF solution	DO solution	BRF solution
Carbon dioxide	15 288	2 032	23 299	3 512	14 522	2 485	12 464	1 447
Carbon monoxide	37.7	5.02	57.51	8.67	35.8	6.13	30.8	3.57
Unburned hydrocarbon	4.18	0.556	6.37	0.96	3.97	0.679	3.41	0.396
Particular matter	2.84	0.378	4.34	0.65	2.7	0.462	2.32	0.269
Sulfur dioxide	30.7	4.08	46.79	7.05	29.2	4.99	25	2.91
Nitrogen oxides	337	44.8	513.18	77.35	320	54.7	275	31.9

The feasibility of using renewable energy to replace diesel has been explored for specific existing off-grid facilities in each of the four sites (Table 2). The comparison of different configurations of renewable energy and battery storage was done using HOMER software. It is shown that the use of renewable energies presents the lowest cost per kWh of all solutions, i.e., \$0.467 in Garoua, \$0.438 in Maroua, \$0.423 in Yagoua, and \$0.412 in Kousseri. These costs of energy which also include the water supply cost, a rare and expensive commodity in these areas, are highly competitive compared with the one from the national grid considering the many inconveniencies already mentioned [43]. It also presents the minimum environmental impact in terms of GHG emissions with 2642.28 kg/yr in Garoua, 3606.6 kg/yr in Maroua, 2546.97 kg/yr in Yagoua, and 1486.05 in Kousseri of polluting particles emitted i.e., on average seven times less than the use of diesel alone.

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