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Study of Applying a Hybrid Standalone Wind-Photovoltaic Generation System

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Abstract: The purpose of this paper is the study of applying a hybrid system wind/photovoltaic to supply a community in southern Algeria. Diesel generators are always used to provide such remote regions with energy. Using renewable energy resources is a good alternative to overcome such pollutant generators. Hybrid Optimization Model for Electric Renewable (HOMER) software is used to determine the economic feasibility of the proposed configuration. Assessment of renewable resources consisting in wind and solar potentials, load profile determination and sensitivity of different parameters analysis were performed. The cost of energy (COE) of 0.226 $/kWh is very competitive with those found in literature.

Keywords: Hybrid system, HOMER, Sensitivity analysis, Cost of energy.

1 Introduction

Variable Distributed Generation (DG) is an attractive alternative to avoid technical and economic problems in electricity transmission to remote regions. The usually diesel generators used to overcome the local energy needs in such regions are facing several constraints such as instability in fuel prices, fuel supply, besides the relative high costs of operation and maintenance. Hence, renewable resources are becoming more suitable in providing energy to remote regions creating by the way jobs to local populations especially when biomass is used.

Solar and wind energy are the most available and viable sources to meet energy requirement. However, due to their unpredictable nature, energy storage means such batteries and hydrogen should be associated to adjust electricity production and load demand.

Hybrid systems consist in renewable resources associated with energy storage system, power conditioning units and controllers. Several papers presented models of such systems. In [1] three models of hybrid systems were presented. According to [1], it was found that if increasing load demand results always in an increasing either; in operating cost, maintenance (O&M), and in

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net present cost (NPC). It results also in reducing the cost of energy (COE). In [2], the role of hybrid DG as reliable source based on cost factors was presented. In [3], an optimal design focused on economical performance was studied, the COE was reduced significantly due to the increasing in load demand which is conform to what was stated in [1].

In this paper, the technical and economic feasibility, using HOMER, of an integrated model consisting of solar photovoltaic, wind turbines as renewable energy source, battery banks as a backup source are studied.

HOMER (Hybrid Optimization Model for Electricity Renewable) software developed by NREL (National Renewable Energy Laboratory) has been employed to carry out the present study. Inputs to HOMER include load data, renewable resource data, system components specification and costs, and various optimization parameters such as interest rate and lifetime project.

2 Wind Resources

Wind resources assessment is an important factor for harnessing wind power. It is interesting, in developing a wind farm, to know how much energy could be produced [4]. In Algeria, many studies related to wind power resources have been conducted. A wind speed classification based on the country topology is presented in [5]. The Algerian Wind Atlas containing the wind results statistics of 37 meteorological stations is presented in [6]. The recently Algerian wind map established shows that the maximum speed is reached in Adrar, (27.59°N, 0.11°W), with a value of about 6.5 m/s [7]. The wind rose and wind speed frequency in percent are given in Fig. 1.

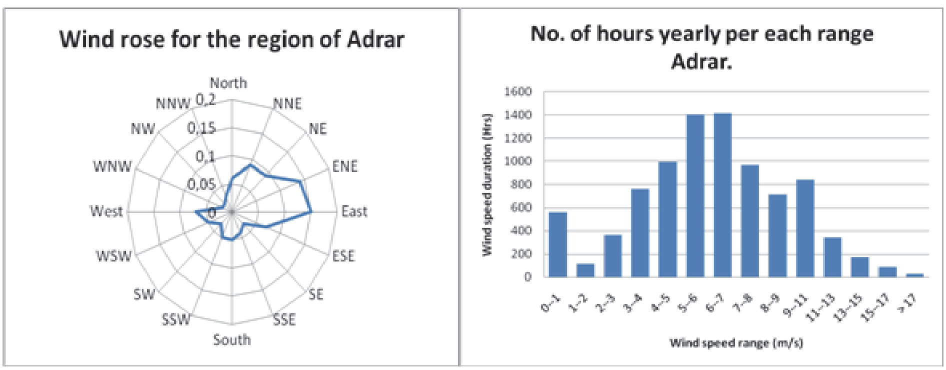


Fig. 1 – *Wind rose and wind speed frequency in the region of Adrar.*

In this figure, it is shown that the East and East-north-East are dominant (15% and 14% respectively) while the lowest frequencies are located in the North-West and North-North-West (2% both directions). The mean wind speed of 6.5 m/s is dominant, the region of Adrar belongs to wind class 3 (6.4 – 7 m/s).

In [8], it was found that the maximum wind speed occurs at 9:00 h, while the minimum at 21:00 h. In general high speeds were observed between 9:00 h and 18:00 h, this indicate that the maximum electricity should be produced during these periods. Besides the absence of protected zones, the low density of population and many other favors such as absence of agricultural restriction zones, the available wind data, shows that region of Adrar is found to be the best one to install wind farms [7].

The monthly average wind speed is given in Fig. 2. May is the windiest month (6.9 m/s), while October and December have the lowest average wind speed (5.8 m/s). The annual average speed is 6.3 m/s. The wind power density is 283 W/m².

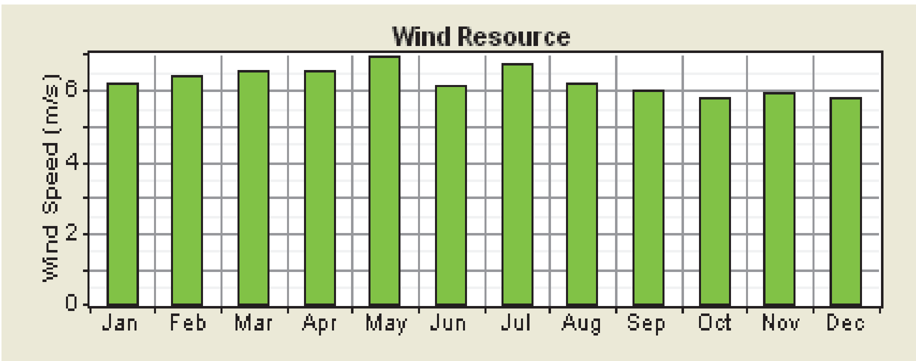


Fig. 2 – *Monthly average speed for Adrar* [9].

3 Solar Resources

Solar energy is another high potential in Algeria especially in its southern region. The daily obtained energy on a horizontal surface of 1 m² is about 2650 (kWh/m²/year). The average duration sunshine is about 3500 h/year. The Sahara represents 86% of the surface [10]. This opportunity conducted the Algerian Company of Electricity and Gas; to start a large-scale programme consisting in installing several renewable energy sources (RES) plants in the country. By 2020 the electricity produced by RES will represent 40% of the global production in the country, 10000 MW is expected to be exported to Europe.

Adrar, by its location in south Algeria, is blessed with a high insolation level (5.89 kWh/m²/d). April, May, June, July and August are the sunniest months in the year, while November, December and January have the lowest radiation level in the year Fig. 3. The sunniest months have also the longest daylight. The yearly mean daylight is about 12.125 h/d. The yearly mean temperature is about 24.3°C as shown in Fig. 4.

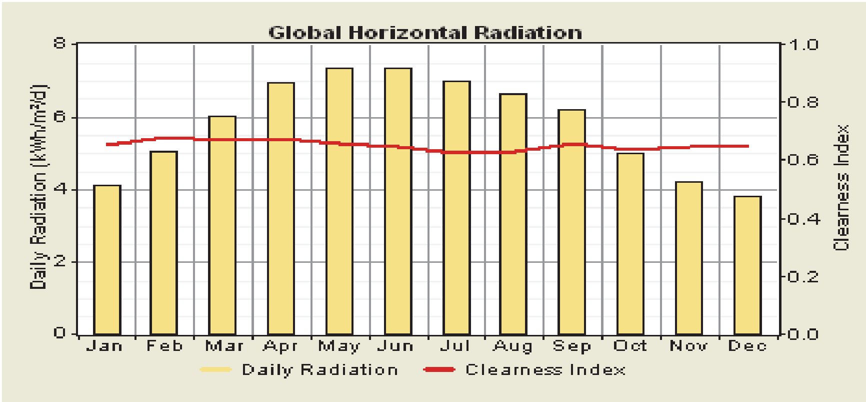


Fig. 3 – *Average solar radiation* (kWh/m²/d) *and clearness index*.

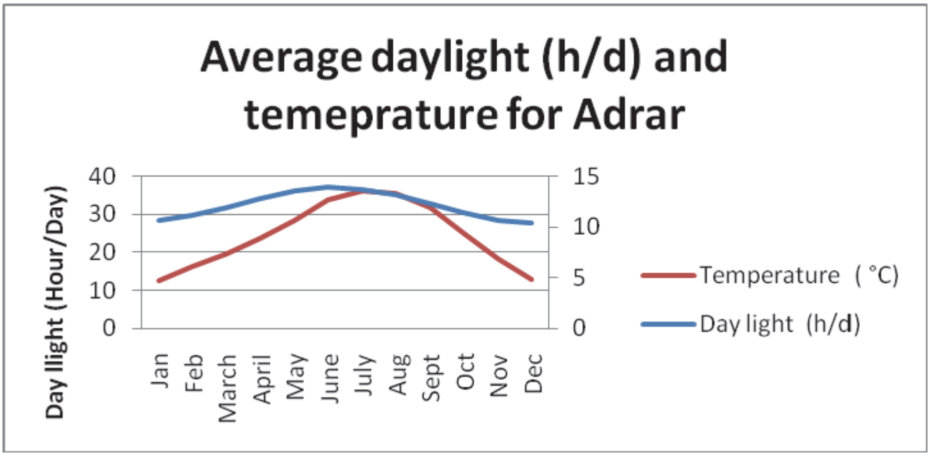


Fig. 4 – *Average daylight* [h/d] *and temperature* [°C] *for Adrar*.

4 Load Profile

In this case, the community of Boukzine is considered. It consists of 15 K'sours (plural of Ksar), a kind of ancients cities built centuries ago. This kind of k'sours are considered as national heritage hence, neither modification nor extensions in buildings are allowed. The total number of households is about 1147 [11]. Saguia, is the most populated among K'sours. It has 200 households. No data of its energy consumption is available, so, we have to predict it. Predicting the household daily energy consumption profile is crucial for planning and strategic design of renewable energy system for remote residential houses [10]. The average occupancy is six people per household [12]. The electric consumption of the residential sector represents 38% of the national production, which represents 1414 KTEP [12].

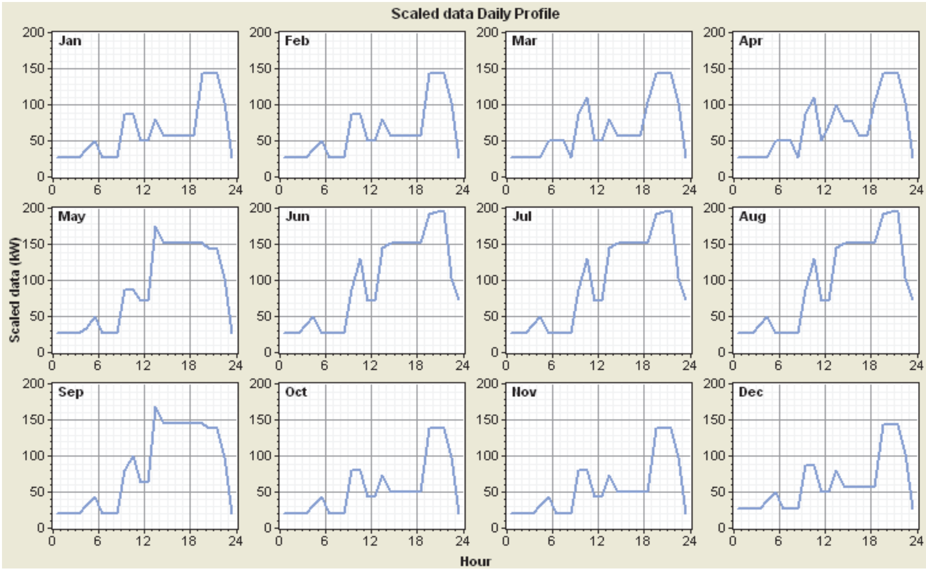


Fig. 5 – *Monthly load profile.*

People habits and seasons influence the behaviour has a great influence on energy consumption. For instance, in [15] it is mentioned that individual residences consumption is greater than collective ones. Another fact, hot season is characterised by high solicitation of air conditioners in particular in hot regions such as Adrar. The average household consumption is found out based on [13 – 15].

The peak load demands are observed during hot months of summer reaching 197 kW. The lowest values are observed in November, December, January and February where the average temperatures are below 20°C. Monthly load profile as predicted is presented in Fig. 5.

5 Economic Analysis

Economic analysis is the second step in this paper. Actually, any project needs to be economically viable, otherwise it would be worthless to realise. Economic analysis consists in the determination of [16]:

- ✓ The total net present cost (NPC) of a project includes capital investment, replacement, maintenance and operation costs throughout the lifetime of the system.
- ✓ The interest rate (i): the rate at which we can get a loan.
- ✓ Levelized cost of energy (COE): is the average cost/kWh of useful electrical energy produced by the system.

The COE is given by:

$$COE = \frac{C_{an.tot}}{L_{primAC} + L_{grid\_sales}}, \quad (1)$$

where $C_{an.tot}$ is total annualized cost (\$/yr), L_{primAC} primary load served and if grid-connected system L_{grid_sales} is total grid sales (kWh/yr).

The NPC is related to $C_{an.tot}$ by:

$$C_{NPC} = \frac{C_{an.tot}}{CRF(i, R_{proj})} \quad (2)$$

where related $CRF(i, R_{proj})$ is the capital recovery factor, which is obtained by:

$$CRF(i, R_{proj}) = \frac{i(1+i)^{R_{proj}}}{(1+i)^{R_{proj}} - 1}, \quad (3)$$

where R_{proj} is the lifetime of the project in years. Usually, the lifetime of the elements that have the longer span is considered, i is the interest rate, calculated based on [17].

6 HOMER Inputs

In order to perform the simulation in HOMER, many parameters should be provided to HOMER software. For the wind turbine the statistical parameters of the wind speed given in **Table 1**, and they are:

- The Weibull shape factor: representing how windy is a location.
- The autocorrelation factor, which is the measure of how strong the wind speed in 1 hour, depends on the wind speed in the preceding hour. Higher values indicate that the wind speed in 1 h tends to depend strongly on the wind speed in the previous hour. Lower values mean that the wind speed tends to fluctuate in a more random fashion from hour to hour.
- The diurnal pattern strength and the hour of peak wind speed indicate the magnitude and the phase, respectively of the average daily pattern of the wind speed.

Initial installation costs (ICC) of wind turbine varies with their sizes and go in inverse to its size. For instance, ICC of turbine rating respectively 250, 100 and 30 kW are $2500, 3100 and 4400 ($/kW) [18, 19]. In order to see the effect of wind turbine size and cost affect the system other components, different sizes of wind turbines are considered here. Replacement cost is considered 90% of the ICC. The lifetime is taken to be 15 years.

Initial installation cost of PV panels is taken 2800 $/kW. Replacement cost is 2400 $/kW lifetime. The operating and maintenance (O&M) cost is assumed to be negligible and so is taken zero. Because tracking system is very expensive (around 8 $/kWp), no tracking system is considered.

Two other parameters are needed in the simulation:

- The derating factor which is a scaling factor meant to account for effects of anything that would cause the output of the PV array to deviate from that expected under ideal conditions (dust, wire losses, elevated temperature, etc.).
- Reflectance also known as the albedo and it ranges between 30 and 60% for light sand dune such as Adrar region.

Converters are an essential part in hybrid systems. They are responsible for both charging and regulating power to storage devices and adapting energy wave to the load requirements. In this study, ICC and replacement cost is 700 $/kW. O&M cost is 10 $/year.

7 Simulations and Case Studies

The optimisation procedure is done in two steps. In the first step, three case studies are investigated. Our system consists of PV panels, converter, batteries and wind turbines. For each case only the rated power of wind turbine is varied. In the first case, we will consider a turbine rated at 100 kW, in the second it should be 250 kW and in the last one of 30 kW. All the wind turbines are from the same manufacturer and models of them are available in HOMER library. Comparison parameters are the total net present cost (NPC), production in percent of PV and WT, excess of electricity, cost of energy (COE), capacity factor and finally payback period is calculated. In order to find out the effect of environmental parameters variation on the system a sensitivity simulation is done in the second step.

Table 1 summarizes the results of simulation done in the first step. At first sight, it is seen that the number of both wind turbines and batteries are the same in the two first cases. The wind generation system consists in one turbine. The storage of energy consists in 576 batteries. In the third case, five wind turbines are necessary. The land occupation for WT is greater than the in the two first cases. The first case has both the lowest total NPC ($2,900,393) and consequently the lowest COE (0.226 $/kWh). The PV generation represents 68% of the global production. Excess of electricity is the lowest in the last case, this is due to the large number of storage capacity, 1152 batteries are used, this is just equal to the number of batteries used in the two first cases. The wind turbine capacity factor (46.4%) is the highest one. Capacity shortage, which is the amount of energy demand that cannot be provided from the generation, is taken zero. Finally, it is obviously clear, that the land occupied by PV panels in the first case is the greatest. The payback period is practically the same for the all the systems and it is around 19.78 years.

Table 1
Simulation results.

	PV [kW]	WT	TNPC [$]	COE [$/kWh]	Excess of electricity [%]	W T Capacity Factor
Case I FL100	400 (68%)	1 (32%)	2,900,393	0.226	41.5 consisting of 576 bat.	45 %
Case II FL250	350 (48%)	1 (52%)	3,088,393	0.238	54.7 consisting of 576 bat.	36.8%
Case III FL30	250 (46%)	5 (54%)	4,194,324	0.329	37.4 consisting of 1152 bat.	46.4 %

In the sensitivity analysis, many parameters can be considered. Solar radiation and wind speed variation have a significant impact on the cost analysis and they are two factors on which the selection of region where the implantation of hybrid systems depends greatly. Unfortunately, for a specific location we cannot vary these two parameters. The interest rate and capacity shortage are also very important parameters. The hybrid system will become more feasible and economically efficient if the interest rate is lower. Engineers and managers have the ability, based on their studies and calculations, to select the more suitable values for a specified case. Capacity shortage is also another parameter which is considered in the sensitivity analysis.

7.1 Effect of wind speed and solar radiation

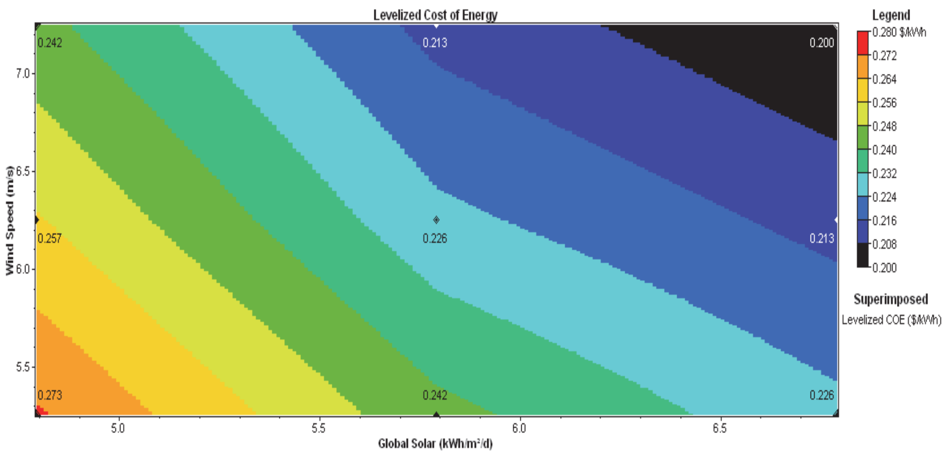
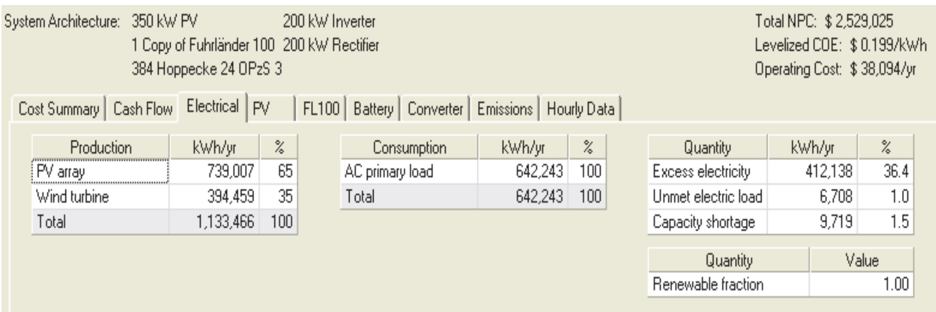


Fig. 6 – *Sensitivity analysis for wind speed and solar radiation.*

The best results were obtained for both the higher values of wind speed and solar radiation. The COE passes from 0.273 $/kWh to 0.200 $/kWh, a reduction by around 26.74% when solar radiation and wind speed varied both from 4.79 kWh/m²/d to 6.79 kWh/m²/d, and from 5.25 m/s to 7.25 m/s respectively. The same amount of reduction is observed for the total NPC that passes from $3,500,580 to $2,568,900. This means that the most suitable location for installing a hybrid generation system would be the region where both the solar radiation and wind speed are the highest. Fig. 6 bellow demonstrates the sensitivity analysis for both wind speed and solar radiation.

7.2 Effect of capacity shortage

Capacity shortage is almost the same as unmet load. Usually the value of 2% is acceptable. In this part, different values were simulated 0, 1, 1.5 and 2. Fig. 7 shows the optimisation results found for capacity shortage of 1.5%. The lowest value of COE (0.199 $/kWh) is obtained.


System Architecture: 350 kW PV; 1 Copy of Fuhrländer 100; 384 Hoppecke 24 OPzS 3; 200 kW Inverter; 200 kW Rectifier

Total NPC: $ 2,529,025
Levelized COE: $ 0.199/kWh
Operating Cost: $ 38,094/yr

Cost Summary | Cash Flow | Electrical | PV | FL100 | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	739,007	65
Wind turbine	394,459	35
Total	1,133,466	100

Consumption	kWh/yr	%
AC primary load	642,243	100
Total	642,243	100

Quantity	kWh/yr	%
Excess electricity	412,138	36.4
Unmet electric load	6,708	1.0
Capacity shortage	9,719	1.5

Quantity	Value
Renewable fraction	1.00

Fig. 7 – *Optimization results for capacity shortage* 1,5%.

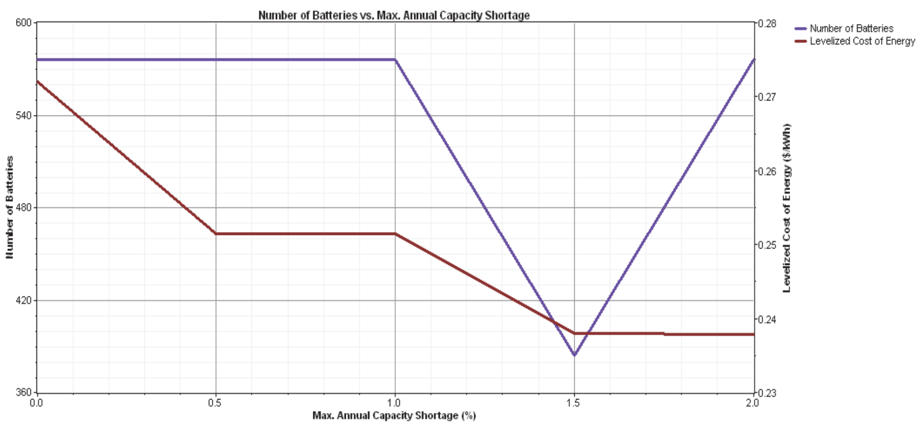


Fig. 8 – *Sensitivity analysis for Max. Annual Capacity Shortage and Number of Batteries.*

This is due to:

a. The reduction in the number of storage devices, which is in this case 384 batteries.
b. The rated power of the PV system required in this case is 350 kW, and finally.
c. The rated power of the converters is only 200 kW.

The PV generated power represents 65% of the total production of hybrid system. Excess of energy is only 36.4% according to the results in **Table 1**. It seems to be the lowest one. This excess of energy could be used to overcome any extra demand in energy. The total NPC is $2,529,025. Fig. 7 and Fig. 8 give the optimized results obtained by HOMER.

8 Conclusion

This paper analyses the prospect of hybrid standalone wind/PV based system generation. The assessment of renewable energy resources has been presented. The region is the windiest and no environmental or rural restrictions are found to implement such system. The system considered has successfully demonstrated that the location studied could be supplied with zero capacity of shortage. Nevertheless, for optimised results, assuming a capacity shortage equal to 1.5 % seems to be the best choice, in this case since it is an acceptable value. The Levelized cost of energy $0.199 kWh, for a total net present cost of $2,529,025 is acceptable compared to those found in literature, even it is still too high compared to the price offered by the Algerian Company of Electricity and Gas. Sensitivity analysis demonstrated that the most both windy and sunny region would have the lowest *LCOE*.

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