

Techno-Economic Analysis of Hybrid Renewable Power Generation Systems Across Various Climatic Zones in Algeria

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Article Info	ABSTRACT
Article history: Received , 20/04/2025 Revised , 20/05/2025 Accepted , 08/06/2025	This study provides a detailed analysis of the costs and benefits of a renewable energy system consisting of a photovoltaic system and a wind turbine connected to the power grid. The comparison is conducted across three distinct localities in Algeria: Sidi Bel Abbès, Béchar, and Adrar. The goal is to ascertain which of these systems is the most economically efficient after 25 years of operation. According to the findings, the Adrar system proves to be the most financially advantageous. With an initial expenditure of \$9,940, it generates a profit of \$242 over a span of 25 years. The system produces 8,659 kWh/year from solar panels and 13,052 kWh/year from the wind turbine. In contrast, the Sidi Bel Abbès system has the lowest profitability, incurring a loss of \$1,946 over a span of 25 years. This system generates 7,799 kWh/year from solar panels and 10,488 kWh/year from the wind turbine. The variation in production can be ascribed to the diverse meteorological conditions in different places, which have a considerable impact on the efficiency and economic feasibility of renewable energy systems. This analysis emphasises the significance of taking into account regional climatic characteristics when assessing the potential and financial viability of renewable energy projects.
Keywords: Sustainable energy; Solar panel; Wind turbine; Hybrid system; Techno-economic; Algeria.	

I. Introduction

Renewable energy is expanding at an unprecedented rate globally. According to the International Energy Agency's "Renewables 2023" report, global renewable energy capacity is set to grow by 2,400 gigawatts between 2022 and 2027, equivalent to China's current total energy capacity [1]. This growth is primarily driven by solar and wind power, which account for 60% and 25% of the increase, respectively. Factors like energy security concerns, supportive policies, and improved cost competitiveness are fueling this trend. For instance, the levelized cost of electricity (LCOE) for large-scale solar projects dropped by 85% between 2010 and 2020 [2,3].

Algeria, with an area of 2.38 million square kilometers and annual sunshine above 2000 kWh/m² in most parts, has one of the highest solar potentials globally [4,5]. The national renewable energy project, initiated in 2011 and revised in 2015, aims to install 22,000 MW of capacity by 2030, including 13,575 MW of photovoltaic solar and 5,010 MW of wind power [6]. This ambitious plan includes establishing the Algerian Institute of Renewable Energies and Energy Efficiency and developing industrial zones for renewable energy. However, Algeria faces challenges like inadequate infrastructure and regulatory hurdles that slow renewable energy deployment [7,8].

Several studies highlight the importance of site-specific analysis for renewable energy projects. In India, Kumar and Sudhakar (2015) compared 1 MW photovoltaic systems across 12 locations, showing significant variability in energy production and profitability due to local climate [9]. In Spain, Serrano-González et al. (2011) analyzed wind characteristics' influence on wind farm profitability, stressing the importance of site selection [10]. In the Middle East, Ramli et al. (2016) examined solar-wind hybrid systems in Saudi Arabia, illustrating how system configuration optimization varies with local conditions [11].

In this study, we present a comprehensive techno-economic analysis of a hybrid renewable energy system, combining photovoltaic and wind technologies across the diverse regions of Sidi Bel Abbès, Béchar, and Adrar in Algeria. By examining the unique climatic factors that influence system performance, we aim to identify the most profitable region over a 25-year period. Our findings offer valuable insights that can guide future investments and energy planning, helping to optimize renewable energy deployment in Algeria.

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II. Research Method

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II.1. Text Site Selection

Our study is conducted in three different regions of Algeria: Sidi Bel Abbès, Béchar, and Adrar, due to the significant climatic changes between these regions [12].

- Sidi Bel Abbès: Located in the northwest of Algeria, this region enjoys a Mediterranean climate characterised by hot summers and mild winters. Its geographical coordinates are around 35.19° N latitude and 0.63° W longitude.
- Béchar, located in the southwest of the country, is characterised by a desert climate, with extremely hot summers and mild winters. Its geographical coordinates are around 31.62° N latitude and -2.22° W longitude.
- Adrar: Located in the far south of Algeria, Adrar experiences a hyperarid Saharan climate with extremely high summer temperatures and cooler winters. Its approximate geographic coordinates are -0.29° O longitude and 27.87° N latitude.

These climatic and geographical differences allow us to investigate the impact of various environmental factors on the results of our study, taking into account the specific conditions of each region.

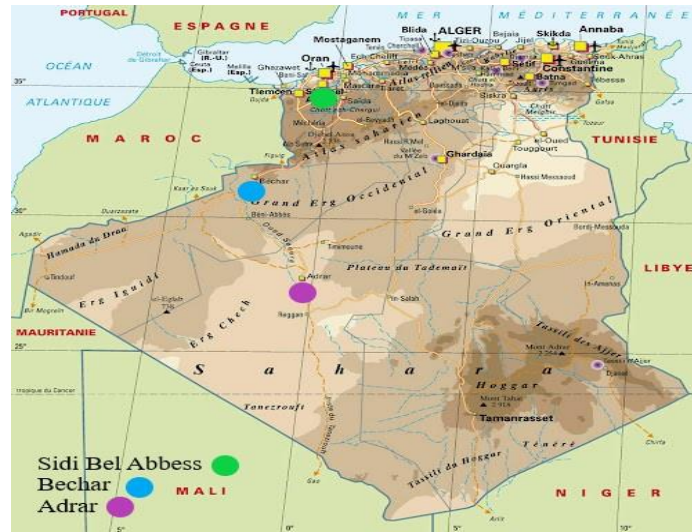


Figure 1. Selected site locations [13]

II.2. Mathematics Availability of resources at the selected stations:

Table 1 illustrates the extensive capacity of the annual average solar radiation and annual average wind speed at the chosen stations. According to NASA's projection data, Adrar has the most capacity for solar radiation and wind speed, while Sidi Bel abbess has the lowest capacity for these factors.

Table 1. Assessment of solar radiation and wind speed potential at various selected regions.

Months	Sidi Bel Abbès		Béchar		Adrar	
	Average Solar Irradiation (kWh/m ² /day)	Average Wind Speed (m/s)	Average Solar Irradiation (kWh/m ² /day)	Average Wind Speed (m/s)	Average Solar Irradiation (kWh/m ² /day)	Average Wind Speed (m/s)
Jan	2.760	6.170	3.510	4.980	3.740	6.190
Feb	3.720	6.050	4.450	5.270	4.870	6.380
Mar	4.680	5.780	5.500	5.720	6.140	6.620
Apr	5.780	5.720	6.720	6.170	7.140	6.720
May	6.630	5.000	7.120	6.240	7.580	6.560
Jun	7.220	4.560	7.180	5.910	7.590	6.310
Jul	7.260	4.340	7.020	5.460	7.820	6.800
Aug	6.310	4.330	6.270	5.190	7.260	6.800
Sep	5.080	4.480	5.480	5.270	6.320	6.100
Oct	3.900	5.030	4.540	5.050	4.770	5.970
Nov	2.850	6.050	3.610	4.980	3.900	5.930
Dec	2.450	6.210	3.160	4.780	3.360	6.070

III. ANALYSIS TOOLS

HOMER software: HOMER Pro is a sophisticated software programme specifically developed for analysing and optimising decentralised and hybrid energy systems. This application allows users to evaluate the technical and economic feasibility of energy system designs, considering various energy sources such as diesel generators, solar panels, wind turbines, and hydroelectric power. The programme utilises sophisticated optimisation algorithms to identify the most cost-effective and profitable solutions, considering the user's specific goals, such as cost reduction, improved energy reliability, or greenhouse gas emission reduction [14,15].

IV. RESULTATS AND DISCUSSIONS

The system under study consists of a SMA 5 DC-AC converter, priced at 1188 euros, together with 20 Trina Solar 245TSM solar generators, each with a capacity of 245 watts and costing 75 euros. Additionally, there is an AWS HC 5.1kW wind turbine priced at 2500 euros, and a public grid network.

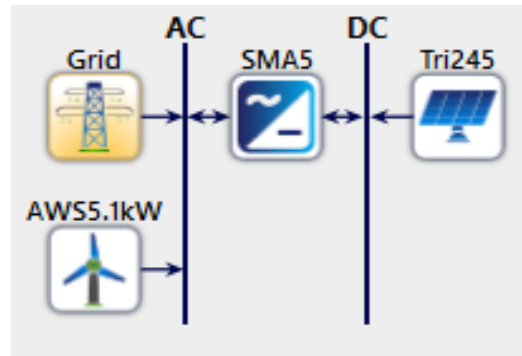


Figure 2. An overview of the system under study.

Figure 3 displays the annual solar energy production (Pv Power Output) for three unique regions in Algeria: Sidi Bel Abbès (A), Béchar (B), and Adrar (C). A comparison between these regions reveals significant differences in solar production, influenced by their distinct climatic conditions. Sidi Bel Abbès exhibits pronounced seasonal changes with higher output levels in summer and lower levels in winter, characteristic of its Mediterranean climate. Béchar, being in a desert area, exhibits a more consistent solar production throughout the year, although the peaks in summer are less pronounced than those in Sidi Bel Abbès. However, Adrar, located in the Sahara, enjoys intense and continuous sunlight almost all year round, resulting in maximum and stable solar production. This analysis highlights that the Saharan conditions in Adrar are the most favourable for solar energy generation, followed by Béchar and finally Sidi Bel Abbès, which exhibits the greatest seasonal changes. These insights are crucial for assessing the profitability and efficiency of photovoltaic systems under various climatic circumstances.

Figure 4 displays the annual wind energy production (Turbine Power Output) for three unique regions in Algeria: Sidi Bel Abbès (A), Béchar (B), and Adrar (C). A comparison between these regions reveals distinct differences in terms of wind power output, influenced by the specific climatic conditions of each region. Sidi Bel Abbès has seasonal variation with higher production periods in spring and autumn, reflecting a Mediterranean climate characterised by moderate yet consistent winds. However, Béchar, located in a desert area, exhibits a more variable and generally lower wind generation, with less predictable peaks due to sporadic winds influenced by quick temperature changes. Adrar, located in the Sahara, has the most favourable conditions with strong and consistent winds throughout the year, resulting in maximum and reliable wind power output. This analysis highlights that Adrar is the most conducive region for wind energy generation, followed by Sidi Bel Abbès and finally Béchar, which presents the least favourable conditions for wind energy. These findings are critical for assessing the profitability and efficiency of wind systems under different climatic circumstances.

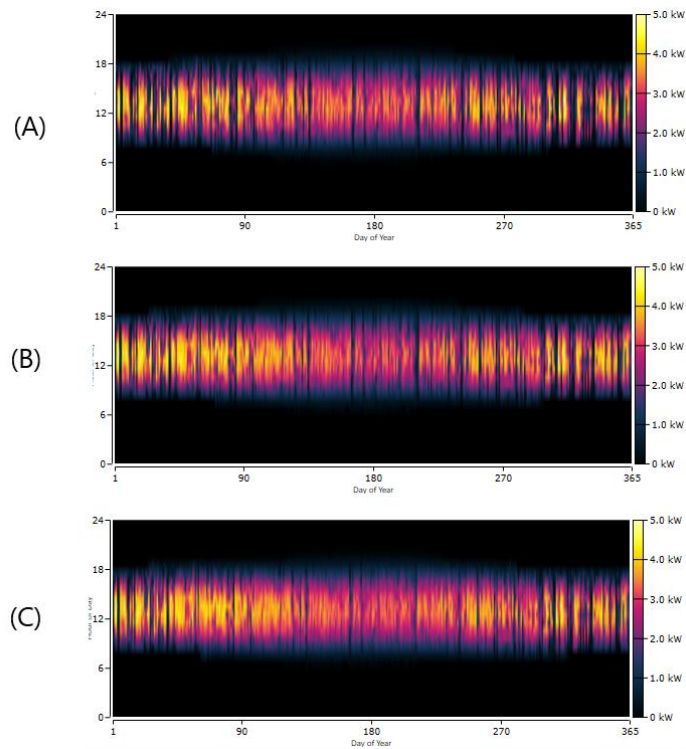


Figure 3. Power output of generic flat plate PV (A) Sidi Bel Abbès, (B) Bechar and (C) Adrar.

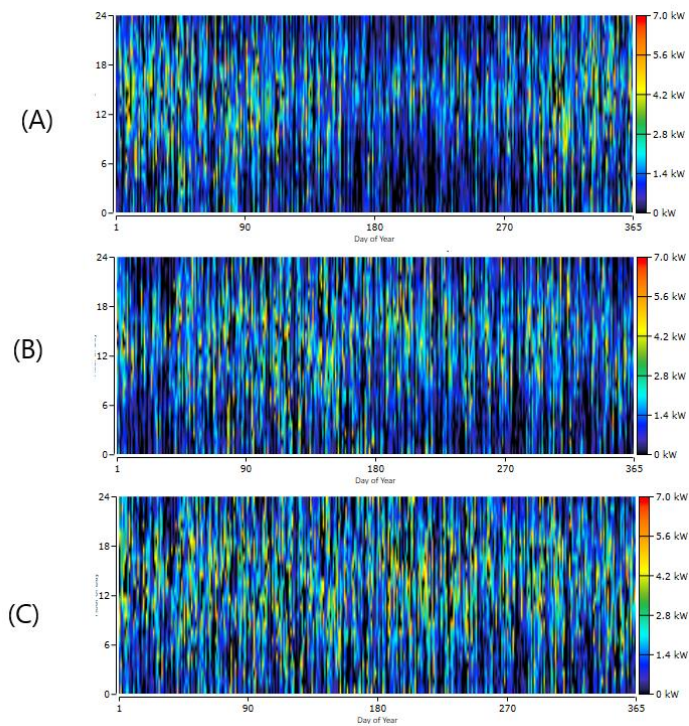
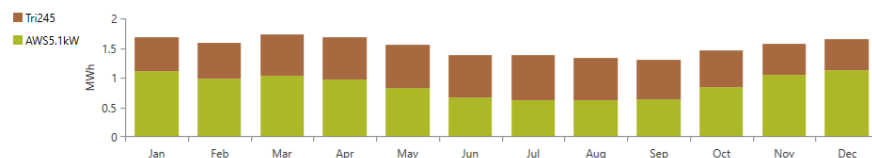


Figure 4. Power output of wind turbine (A) Sidi Bel Abbès, (B) Bechar and (C) Adrar.

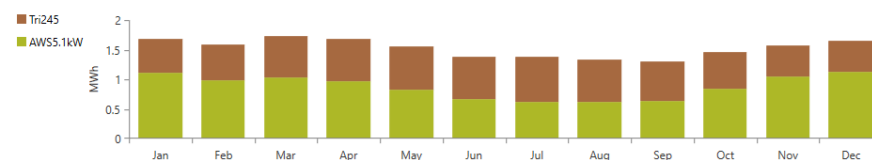
The Figure 5 and Table 2 provide a detailed illustration of the differences in renewable energy generation among three separate regions in Algeria: Sidi Bel Abbès, Béchar, and Adrar, with a focus on comparing these regions. In Sidi Bel Abbès, the total energy production is 18,287 kWh per year, with 7,799 kWh (42.6%) coming from solar panels and 10,488 kWh (57.4%) from wind turbines, making this region the one with the lowest wind contribution. Béchar, with a slightly higher total production of 19,277 kWh per year, receives 8,379 kWh (43.5%) of solar energy and 10,898 kWh (56.5%) of wind energy, reflecting a similar distribution to Sidi Bel Abbès but with a higher overall production. Adrar stands out prominently for its highest energy production among the three regions, totaling 21,711 kWh per year, of which 8,659 kWh (39.9%) comes from solar panels and 13,052 kWh (60.1%) from wind turbines.

Table 2. Total solar PV and Turbine production for all the stations

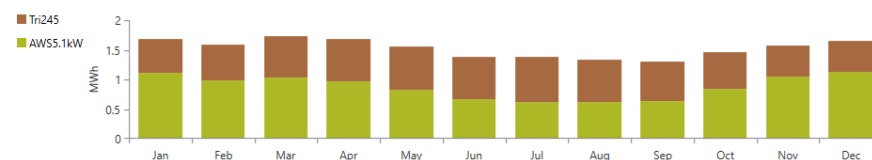
Region	Solar panel (KW/h)	Percentage (%)	Turbine (KW/h)	Percentage (%)	Total (KW/h)
Sidi Bel Abbess	7799	42.6	10488	57.4	18287
Bechar	8379	43.5	10898	56.5	19277
Adrar	8659	39.9	13052	60.1	21711



(A)



(B)



(C)

Figure 5. Total solar PV and Turbine production for all the stations (A) Sidi Bel Abbès, (B) Béchar and (C) Adrar.

Table 3 compares the initial investments, annual energy sales revenue to the grid, and net present cost (NPC) over a 25-year period for renewable energy systems in three regions of Algeria: Sidi Bel Abbès, Béchar, and Adrar. The initial investment is the same for all three regions, set at \$9,940. The annual energy sales revenues vary, with Adrar recording the highest revenue (\$787.62), followed by Béchar (\$666.54), and finally Sidi Bel Abbès (\$618.38).

The NPC reveals the profits or losses after 25 years, showing that Sidi Bel Abbès and Béchar have negative NPCs, indicating net losses of -\$1,946 and -\$1,323, respectively, with corresponding COEs (Cost of Energy) of \$0.00839 and \$0.00542. In contrast, Adrar has a positive NPC of \$242.03 and a negative COE (-\$0.000878), making it the only region to generate a net profit over this period.

This comparison highlights that Adrar is the most profitable region for the installation of renewable energy systems, due to its high annual energy sales revenue and positive NPC. Although Béchar is less profitable than Adrar, it is still more favorable than Sidi Bel Abbès, which shows the most significant losses. These economic differences underscore the importance of considering regional climate and economic factors when assessing the viability and profitability of renewable energy projects.

Tableau 3 Total optimized NPC of HRES in 25 years of operation at different regions

Region	Capital (\$)	Selling to grid (\$/y)	COE (\$)	NPC (\$)
Sidi Bel Abbess	-9940	-618.38	0.00839	-1946
Bechar	-9940	-666.54	0.00542	-1323
Adrar	-9940	-787.62	-0.000878	242.03

V. CONCLUSION

This study conducted a techno-economic comparison of hybrid renewable energy systems (photovoltaic and wind) in three regions of Algeria: Sidi Bel Abbès, Béchar, and Adrar. The objective was to identify the region that offers the most cost-effective system after 25 years of operation.

Adrar proved to be the most profitable, yielding a net profit of \$242 after an initial investment of \$9,940. The system annually produces 21,711 kWh (8,659 kWh solar, 13,052 kWh wind), taking use of favourable Saharan climatic conditions.

Sidi Bel Abbès had the lowest profitability, with a net loss of \$1,946 and an annual production of 18,287 kWh (7,799 kWh solar, 10,488 kWh wind). Its Mediterranean climate leads to lower and more erratic productivity.

In the desert zone, Béchar achieved intermediate performance with an annual production of 19,277 kWh (8,379 kWh solar, 10,898 kWh wind) and a net loss of \$1,323.

This analysis emphasises the vital significance of regional climatic variables in the planning and evaluation of renewable energy projects, highlighting the necessity of a site-specific approach to improve the profitability and sustainability of systems.

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