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Conference paper

Feasibility Study of a Wind-Diesel Hybrid System in a Remote Site on Southern of Algeria

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ABSTRACT

In this study, we present an autonomous solution for a village located north of Timimoun in Algeria, with around thirty households. As the region has good wind potential with an average annual speed of around 5m/s, this resource is used to develop a hybrid wind/diesel/battery system. A technical-economic analysis is carried out using the HOMER optimization tool to determine the optimal solution. We considered a range of load sizes, from 0.9 kWh/d to 3.6 kWh/day, and a range of wind speeds, from 3.99 m/s to 5.42 m/s at 10 m from the ground. Several wind turbines with powers ranging from 1 kW to 10 kW have been tested.The best combination is given by the wind/diesel/battery system operating with the WES 5 Tulipo turbine with a rated power of 2.6 kW, with a diesel price equal to 0.22 $/kWh. This solution reduces the COE to 0.569 $/kWh and renewable fraction is maximum (86%). In addition, the emissions of CO_2, CO and SO_2 decrease to less than 70% of the emissions of Diesel power system. The sensitivity study shows that the wind/diesel/battery system is optimal for any wind speed greater than 3.5 m/s whatever the price of diesel.

1. INTRODUCTION

As the demand for energy around the world is increasingly strong, many countries have set themselves the objective of integrating renewable energies into their energy mix. This so-called 'clean' energy can be produced from large installations such as photovoltaic plants or wind farms, to then be injected into an existing electricity network (Saheb Koussa & Koussa, 2014; Kheder-Haddouche & Saheb Koussa, 2018), as it can also supplement an electric generator (Amara, Meziane & Zeblah, 2017; Shaahid, El-Amin, Rehman, Al-Shehri, Ahmad, Bakashwain & Al-Hadhrami, 2010). This is the case for hybrid renewable energy systems, which combine diesel generators and wind turbines or/and PV sensors. They generally take their place in a local network made up of energy storage, power converters and various

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control components, to generate electricity. Such a system is designed to increase capacity and reduce costs and environmental impact of electricity generation in remote communities and facilities that are not connected to a power grid. Hybrid systems reduce reliance on diesel fuel, which creates pollution and is expensive to transport (Drouilhet & Shirazi, 2002).

As a result, a large number of research studies on hybrid renewable energy systems for rural electrification have emerged in recent years. These studies show that adding other renewable energy resources such as photovoltaic energy, wind energy, hydroelectricity and biomass to a system based on conventional resources, could make a hybrid system more profitable and more environmentally friendly.

The review carried out by (López-Castrillón, Sepúlveda & Mattar, 2021), evaluated 168 studies over the period 2002-2019, developed in Asia, Northern Europe, Africa and South America. It shows that most approaches studied combined photovoltaic (PV) and wind power, and that diesel generators are the preferred backup system (61.3%), while batteries are the preferred method of storing energy (80.4%).

In a study carried out by (Come Zebra, Van der Windt, Nhumaio & Faaij, 2021), hybrid systems (HRES) in developing countries are analyzed and compared on the basis of the levelized cost of energy (LCOE). It appears that the price of a kWh of electricity varies from 0.92 to 1.30$ for diesel, from 0.40 to 0.61 $ for solar PV and from 0.54 to 0.77 $ for hybrid systems PV/diesel. Diesel is therefore the most expensive technology.

For remote and isolated regions, installations combining solar and wind with diesel have been the subject of studies in Bangladesh (Hossain Lipu, Uddin & Miah, 2013) and in Malaysia (Fadaeenejad, Radzi, AbKadir & Hizam, 2014).

Concerning wind/diesel/battery systems, the study carried out by (Shezan & Lai, 2017) for a village in Malaysia, concluded that the proposed hybrid system is financially and environmentally feasible and that the net present cost (NPC) as well as the outputs of CO2 are reduced by approximately 74% and 92% separately each year, unlike traditional power plants. The NPC of the streamlined framework is approximately 76,901$ with a cost of energy (COE) of approximately 0.198 $/kWh.

In Algeria, the authorities are committed to deploying renewable energies in the far south of the country, and to generalizing the hybridization of all production sites in the far south in the years to come (Idda & Bentouba, 2014).

The aim of this study is to find the best combination of Wind/Diesel renewable energy systems from available resources for a remote community located at an off-grid location in the Timimoun region of Algeria. Although the latter belongs to the autonomous electricity network, pole In Salah, Adrar, Timimoun (PIAT), there are still communities far from any electricity network. Power generation, techno-economic assessment and emissions assessment for different hybrid energy systems were carried out and compared for the selected community. It is expected that the optimal hybrid energy system can provide a cost-effective and environmentally friendly solution ensuring electricity supply to the community.

2. METHODOLOGY

The design and development of an HRES system goes through several stages:

1. Choosing an off-grid site
2. Analysis of the availability of resources on the site, in our case the wind potential.
3. Evaluation of the load profile of the community studied.
4. A software tool, HOMER in our case, is necessary to carry out the simulation.

2.1 The Homer Tool

The present study was conducted using the HOMER software developed by the National Renewable Energy Laboratory (NREL, 2004). It is an economic optimization model that minimizes the production costs of an energy park to meet a final energy demand, under different constraints.

As inputs, the techno-economic parameters of the considered technologies (annual real interest rate, project lifetime, etc.), as well as the environmental characteristics of the considered location (wind, ...) are needed.

On another hand, various constraints as the renewable energy fraction and the monthly mean of hourly load demand are also needed.

As output data, the HOMER tool classifies the results according to the total Net present cost~~s~~ that per kWh over the project lifetime. The software tool is used also to describe the hourly systems-behavior over a full whole year and used particularly to integrate the intermittent nature of wind generation (Menanteau, Quéméré, Le Duigou & Le Basetard, 2010).

HOMER uses the following equation to calculate the total net present cost (Lambert, Gilman & Lilienthal, 2006).

$$C_{NPC} = \frac{\mathrm{Cann\_tot}}{\mathrm{CRF(i, Rproj)}} \quad (1)$$

where:

Cann_tot is the total annualized cost, [$/year]
i the annual real interest rate (the discount rate),
Rproj the project lifetime, [year],
and CRF(.) is the capital recovery factor, given by the equation:

$$\mathrm{CRF}(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (2)$$

where i is the annual real interest rate and N is the number of years.

2.2 Site Description

We choose, for the purposes of our study, a locality in the region of Timimoun located about twenty kilometers northwest of the capital of the wilaya.

Our solution relies on the region's wind resource, which has good wind potential, to produce electricity with wind turbines, which will compensate for the existing autonomous diesel generators.

The wind data used comes from the Timimoun meteorological station located at latitude 29.237° W and longitude 0.276° E.

2.3 Hybrid Renewable Energy System

The system was design as being standalone, with primary load, diesel generator, wind turbine, battery and converter. Figure (1) shows the system design.

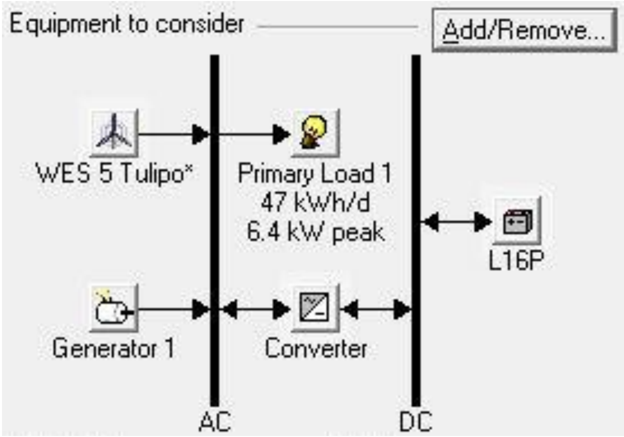

Fig 1. Configuration of the proposed hybrid system

2.3.1 Estimation of Load Demand

The load estimation, on which the simulation is strongly based, takes into account the needs of the community in the study area. To estimate the electrical load demand, a total of 36 housing units are considered. The types of charges are selected taking into account the standard of living of a village in the South. According to statistics from the Algerian Electricity and Gas Company Sonelgaz (SONELGAZ, 2021), electricity consumption for a household amounts on average to 1.3 kWh/d. Consumption for 36 households will therefore be 47 kWh.

Figure (2) shows the daily load profile which is estimated by Homer at 47 kWh/day with a peak of 6.4 kW.

The proposed system will therefore be a hybrid Wind/diesel system composed of one or more wind turbine(s), a 15 kW generator, batteries and a converter. It will have to meet the needs of an electricity demand of 47 kWh/d.

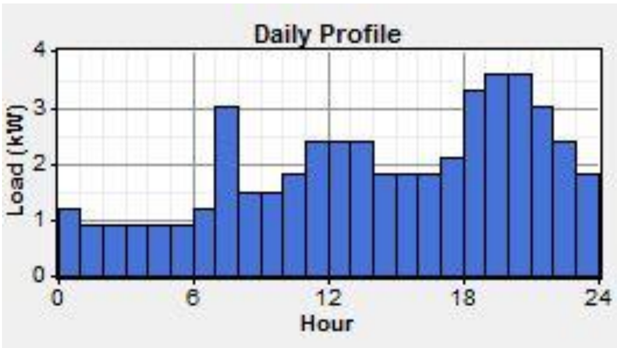

Fig 2. Daily load profile

2.3.2 Wind resource

Three-hourly measurements of wind speed and direction, over a period of 10 years (2008 to 2017), and collected at 10m a.g.l. at the Timimoun meteorological station, are used to calculate the monthly average wind speeds.

As shown in Fig. (3), the monthly average wind speed is highest during spring (April-June). The lowest speeds are recorded during January and November. The annual average wind speed obtained by the HOMER software is 4.75 m/s.

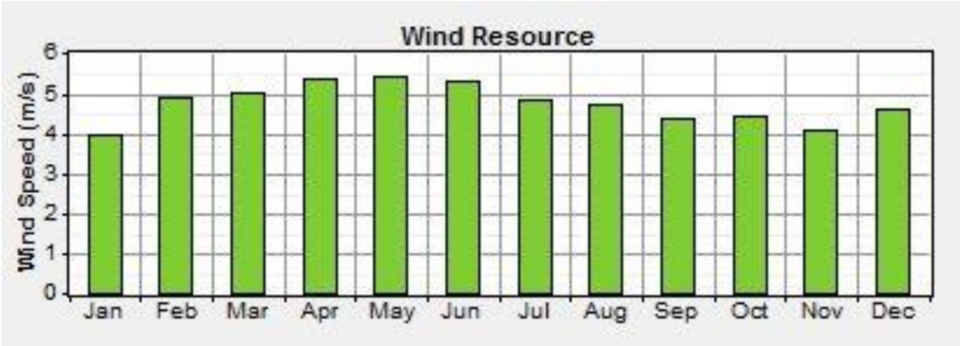

Fig 3. Monthly variation of wind speed

2.3.3 Hybrid System Components

Wind Turbine

Different turbine rated powers are modeled (1, 2.6, 3.3, 8 and 10 kW) to determine the optimal power and number. The table 1 shows the characteristics of selected wind turbines.

Table 1. Characteristics of the wind turbines used

Wind turbine	Manufacturer	Rated power
SW Whisper 200 - W200	Southwest Windpower	1 kW DC
SW Skystream – S3.7	Southwest Windpower	1.8 kW AC
WES 5 Tulipo - WES5	Wind Energy Solutions	2.6 kW AC
SW Whisper 500- W500	Southwest Windpower	3.3 kW DC
BWC Excel-R – XLR	Bergey Windpower	8.1 kW DC
BWC Excel 10 – BWC10	Bergey Windpower	10 kW DC

Diesel generator

A diesel generator with a nominal power of 15 kW was considered in this study. Diesel price is 0.22$/L. The generator is connected to an AC output with a lifetime of 15000 hours and a 30% minimum load ratio. To study the effect of the price of diesel on the cost of electricity, the price of diesel varied between 0.22 $/L and 0.7 $/L.

Battery

Batteries are used as a backup in the system and to maintain a constant voltage level during peak loads or a shortfall in generation capacity. The battery chosen in this study is a 06 V battery with a nominal capacity of 360 Ah. It has a lifetime throughput of 1075 kWh.

Power converter

A converter is required to convert from AC-DC or DC-AC. The lifetime of the converter was assumed to be 15 years, inverter efficiency as 90%, and rectifier efficiency as 85%. For a 1 kW system, the installation and replacement costs are 1000 $ and 1000 $, respectively, O&M are 100 $. A converter size of 6 kW is considered.

3. RESULTS AND DISCUSSION

3.1 Optimization Results

The optimization stage concerned the 05 scenarios representing the 05 types of wind turbine with rated powers ranging from 1kW to 10 kW. Table 2 presents the optimal configurations for each hybrid wind/diesel/battery system corresponding to a type of wind turbine, in addition to the diesel/battery configuration. In each system, the optimal number of wind turbines is given to satisfy the electrical load.

Table 2. Component combinations for the six scenarios considered in this study

System	Wind turbine-Rated power	Units number of wind tubine	Generator (kW)	Battery Trojan-L16P	Converter (kW)
Hybrid system 1	W200 - 1kW	9	15	48	6
Hybrid system 2	WES5 - 2.6kW	3	15	56	6
Hybrid system 3	W500 - 3.3kW	3	15	56	6
Hybrid system 4	BW XLR - 8kW	1	15	56	6
Hybrid system 5	Generic - 10kW	1	15	56	6

The cost analysis for the six scenarios is presented in Table 3. It shows the total net present cost (total NPC) based on different components as well as the COE. The Diesel/battery system has the highest net present cost and COE of the six scenarios (197521$, 0.908 $/kWh). Among the hybrid systems, the configuration with the 10 kW rated power wind turbine presents the highest NPC and COE (172508.00 $, 0.793 $/kWh), while the configuration with 03 units of 2.6 kW turbines presents the lowest NPC and COE (123729.00 $, 0.569 $/kWh). This last configuration is characterized by the highest renewable fraction (86%), followed by the configuration with 3 kW turbines (81%) (See Table 4). Electricity production is highest for the Diesel/battery system (23.226 kWh/year), and for the hybrid system with 03 units of 2.6 kW rated power wind turbines (21.048 kWh/year) which presents an excess electricity production of 16.6%.

Table 3. Initial capital, operating cost, total NPC and COE (cost of electricity) of six scenarios

System	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)
W200-1kW (09 units)	$ 65400	6109	$ 143497	0.660
WES5-2.6kW (03units)	$ 64800	461	$ 123729	0.569
W500-3.3kW (03units)	$ 70050	5197	$ 136489	0.628
BW XLR-8kW 01unit)	$ 65300	7151	$ 156717	0.721
Generic-10kW (01unit)	$ 75300	7604	$ 172508	0.793
Diesel-battery	$ 45300	11908	$ 197521	0.908

Table 4. Electricity production, excess electricity, and renewable fraction of six scenarios

System	Electricity production (kWh/ year)	Excess electricity generation (%)	Renewable. fraction
W200-1kW (9 units)	17.681	13.4	0.74
WES5-2.6kW (3 units)	21.048	16.6	0.86
W500-3.3kW (3 units)	19.532	14.4	0.81
BW XLR-8kW (1 unit)	12.774	3.58	0.58
Generic-10kW (1 unit)	14.445	9.10	0.62
Diesel-battery	23.226	100	0.00

The energy production throughout the year for the 2.6 kW rated wind turbine Wind/Diesel/Battery system is shown in Fig. (4).

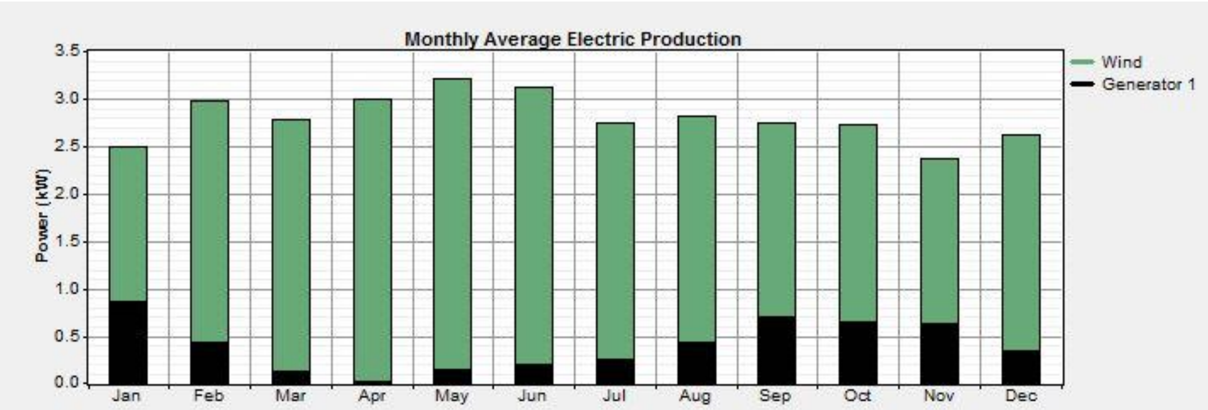

Fig 4. Monthly average electric production of the optimal Wind/Diesel/Battery system

Emissions resulting from gas consumption have a very negative impact on the environment. As shown in Table 5 in which the emissions of CO2, NOx and SO2 are presented, and by making a comparison between different configurations retained, we see that the maximum emission rates result from the Diesel/Battery system. The lowest rates are generated by the configuration with the 2.6 kW rated power wind turbines.

Table 5. Emissions of gases of the different configurations proposed by the HOMER software

System	CO2 (kg/year)	CO (kg/year)	SO2 (kg/year)
Hybrid system 1	6.853	16.9	13.8
Hybrid system 2	3.610	8.91	7.25
Hybrid system 3	4.662	11.5	9.36
Hybrid system 4	9.691	23.9	19.5
Hybrid system 5	9.376	23.1	18.8
System 6/Diesel-battery	23.326	57.6	46.8

3.2 Sensitivity Results

In this study, sensitivity analysis was done to study the effects of variation in the load size and wind speed.

A range of load sizes, from 50 kWh/day to 100 kWh/day, and a range of wind speeds, from 3 m/s to 8 m/s are considered. The optimal system type graph presented in Fig. (5) shows that Wind/Diesel/Battery systems are optimal throughout the sensitivity space. The graph of the levelized cost of energy shows that at the smaller sizes, the power is more expensive. At a load size of 50 kWh per day, the price per kWh is 0.850$. At a load size of 100 kWh per day, the price per kWh ranges from $0.568 to $0.283, depending on the wind speed.

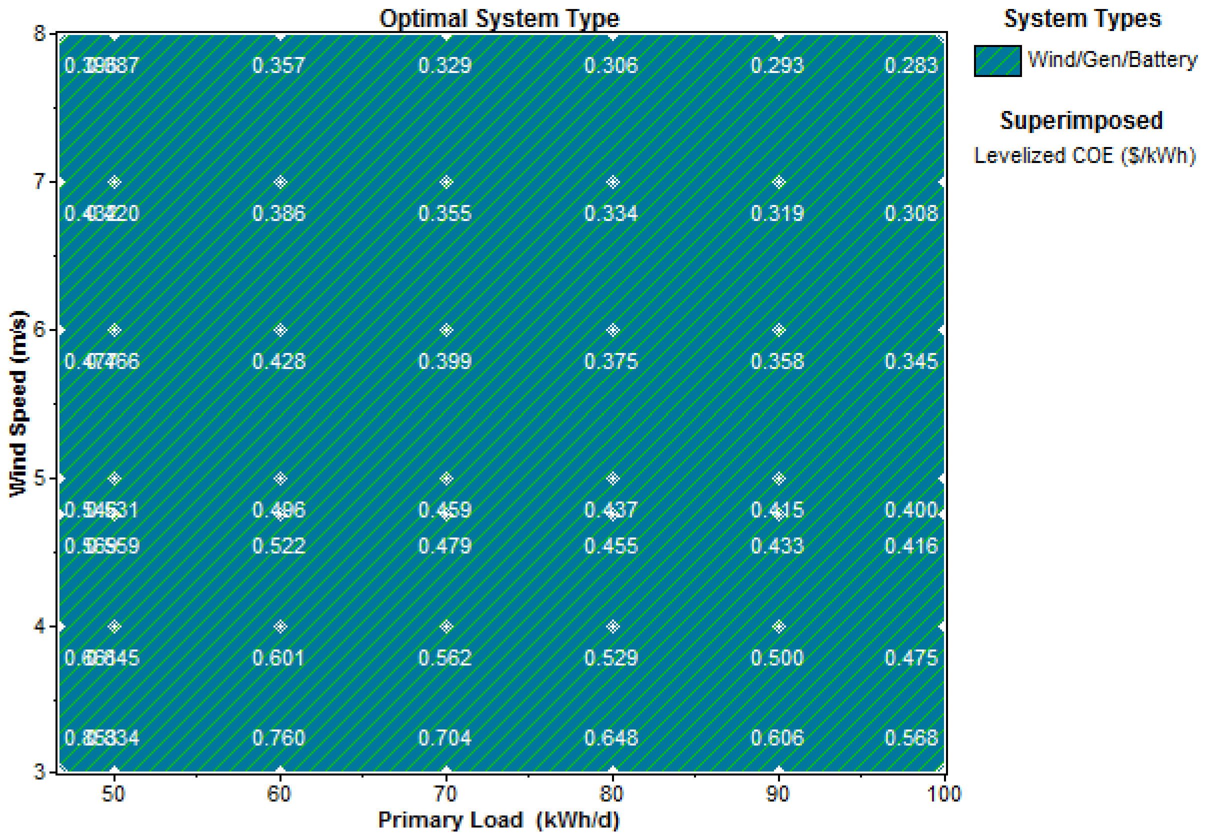

Fig 5. Optimal system type

4. CONCLUSION

This study simulates a wind/diesel/battery hybrid system for an off-grid community in the remote region in the South of Algeria. The wind energy resource data are collected from the meteorological station of Timimoun over a period of ten years (2008 to 2017). The annual mean wind speed was 4.75 m/s. The electricity load is assumed as 47 kWh per day. The hybrid renewable energy system sizing is done using the software HOMER to meet the requirements of emission reduction and cost saving. The optimized HRES including a WES5 Tulipo wind turbine reduces the COE to 0.569 $/kWh and renewable fraction is maximum (86%). In addition, the emissions of CO_2, CO and SO_2 decrease to less than 70% of the emissions of Diesel power system. The sensitivity analysis indicates that wind/diesel/battery HRES are feasible under the meteorological conditions in Timimoun region. When the load and wind speed increase, the COE of the hybrid renewable energy system reduces.

REFERENCES

Amara M, Meziane R, Zeblah A. (2017) Techno-economic configuration for hybrid renewable energy systems in isolated area in Algeria. Journal of Electrical Engineering, 17(4), 8–8.

Come Zebra E I, Van der Windt H J, Nhumaio G, Faaij A P C. (2021) A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries. Renewable and Sustainable Energy Reviews, 144. doi.org/10.1016/j.rser.2021.111036.

Drouilhet S, Shirazi M. (2002) Wales, Alaska High-Penetration Wind-Diesel Hybrid Power System Theory of Operation [archive]. National Renewable Energy Laboratory.

Fadaeenejad M, Radzi M A M, AbKadir M Z A, Hizam H. (2014) Assessment of hybrid renewable power sources for rural electrification in Malaysia. Renewable and Sustainable Energy Reviews 30, 299–305. doi.org/10.1016/j.rser.2013.10.003.

Hossain Lipu M S, Uddin M, Miah M. (2013) A feasibility study of solar-wind-diesel hybrid system in rural and remote areas of Bangladesh. International Journal of Renewable Energy Research 3(4), 892–900. doi.org/10.20508/ijrer.v3i4.898.g6220.

Idda A, Bentouba S. (2014) Hybridation d'une Centrale Diesel en Energie Photovoltaïque: Effet de l'ajout d'un système de stockage. La Conférence Nationale: Energie Hydrocarbures et Environnement, 3–4 Décembre 2014.

Kheder-Haddouche S, Saheb-Koussa D. (2018) Wind resource assessment and economic analysis of a grid-connected wind farm in an Algerian Highlands site. 2018 International Conference on Wind Energy and Applications in Algeria (ICWEAA), pp. 1–6. IEEE, Algiers, Algeria. doi:10.1109/ICWEAA.2018.8605105.

Lambert T, Gilman P, Lilienthal P. (2006) Micropower System Modeling With Homer. Integration of alternative sources of energy. Wiley-IEEE Press, 1(1), 379–385.

López-Castrillón W, Sepúlveda H H, Mattar C. (2021) Off-Grid Hybrid Electrical Generation Systems in Remote Communities: Trends and Characteristics in Sustainability Solutions. Sustainability 13(11), 5856. doi.org/10.3390/su13115856.

Menanteau P, Quéméré M, Le Duigou A, Le Basetard S. Une analyse économique de la production d'hydrogène à partir d'électricité éolienne pour des usages transport. Revue de l'Energie 61(597), 322–333 (2010).

Saheb Koussa D, Koussa M. (2014) HOMER analysis for integrating wind energy into the grid in southern of Algeria. 2014 International Renewable and Sustainable Energy Conference (IRSEC), Ouarzazate, Morocco, 2014, pp. 360-365, doi: 10.1109/IRSEC.2014.7059826.

Shaahid S M, El-Amin I, Rehman S, Al-Shehri A, Ahmad F, Bakashwain J, Al-Hadhrami L M. (2010) Techno-Economic Potential of Retrofitting Diesel Power Systems with Hybrid Wind-Photovoltaic-Diesel Systems for Off-Grid Electrification of Remote Villages of Saudi Arabia. International Journal of Green Energy 7(6), 632-646. doi: 10.1080/15435075.2010.529408.

Shezan SK A, Lai C Y. (2017) Optimization of hybrid wind-diesel-battery energy system for remote areas of Malaysia. 2017 Australasian Universities Power Engineering Conference (AUPEC), pp. 1–6. IEEE, Melbourne, Australia. doi: 10.1109/AUPEC.2017.8282390.

SONELGAZ, (2021) Rapport mensuel statistiques décembre 2021, SONELGAZ, Algeria.