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Decision-making and optimal design of off-grid hybrid renewable energy system for electrification of mobile buildings in Algeria: case study of drilling camps in Adrar

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ABSTRACT/RESUME

Abstract: *Hybrid renewable energy systems (HRES) have recently gained increased attention from researchers to meet the electricity demand of buildings in isolated areas where classical sources have become unattractive due to higher fuel costs as well as seeking to reduce GHG emissions and save fossil fuels. This paper presents an alternative methodology for the optimal design of hybrid PV / WT / energy storage and diesel generator backup, for the supply of electricity to oil and gas drilling camps in Adrar, southwest of Algeria. The simulation is performed using HOMER software. In addition, the multi-criteria decision-making method of the analytical hierarchy process (AHP) is used to select between renewable technologies and to determine optimal HRES options by considering technical, economic, environmental and social criteria. A sensitivity analysis is performed based on the cost variation of fuel and components up to 2030. The results show that the hybrid energy system with battery storage is the most viable solution for current and future scenarios. Furthermore, lead-acid batteries are found to be more cost-effective than Li-ion batteries for future assumptions. However, configurations based on hydrogen storage are still ineffective before 2030 due mainly to high investment costs, water needs to operate and difficulties in providing the required levels of security. Although hydrogen storage will be a feasible solution after 2030, but in limited applications. The proposed method is more effective in making better decisions in designing such complex energy systems. It will therefore help decision-makers and investors on optimal exploit renewable sources anywhere. It will therefore contribute to transiting to sustainable buildings locally and worldwide.*

I. Introduction

Heavy Nowadays, Electricity has become an essential thing to ensure the best life for communities anywhere. In 2017, the global electricity demand in the world increased by 3.1 % . In Algeria, the overall electricity consumption reflecting an increase of 8 % compared to 2016, due to the increase of population and fast development of industry sector. Around 99% of Algerian consumers are connected to the grid [1]. However, there is an important number of communities and houses, which located in isolated areas, especially in the Sahara of the country, suffer unavailability of the utility grid. Temporary buildings largely spread in these locations such as drilling camps which are quarterly moved from place to another it depends on their activity (exploration, drilling, work-over…etc.). Drilling camps are a small community, which provide all necessities of living for workers, including bedrooms, cafeteria, catering facilities, bathrooms, kitchen, and other services. Therefore, the diesel generator is the only source used to meet the electricity demand of these camps. ENTP, which work in drilling field, owns about 67 drillers, has reported that the average fuel consumption of a drilling camp is around 250m3/year or 17,000m3/year for all its own camps. Thus, the annual cost of diesel is US$ 2.5 million and the annual cost of transport is around US$ 60,000, so the total cost of diesel is US$ 2.56 million a year [2]. These costs with accounting the government subsidies to diesel fuel, which affect the economy of Algeria that is fully dependent on hydrocarbon incomes. Despite the challenge of fuel costs, which increase day per day, conventional sources, has faced some barriers to use, mainly environmental concerns, and the depletion of fossil fuels. For that reason, the transition toward more renewable resources integration to power generation will be mandatory.Fortunately, the country is blessed by a huge solar energy potential, the equivalent of more than 30 times the annual world energy consumption[3]. In this regards, Algerian government has adopted different policies and programs to promote the use of renewable energies and to diversify energy sources in the country and electricity supply of isolated areas. In 2015, Algeria adopted an update to its Renewable Energy and Energy Efficiency program, which firstly launched in 2011. The updated version of the Program aims to achieve about 27% renewable generation share in total electricity production [4]. Besides that, this program aims to reduce its GHG emissions by 7% before 2030 [5].

Solar energy is the primary renewable source recognized by the Algerian government to be developed. However, wind, biomass, geothermal is comparatively very small. Following this program, ENTP has set itself the challenge of achieving the ENTP Green Cabin project, a prototype of an autonomous Saharan cabin, totally powered by solar energy Figure 1. However, the intermittent and unstable nature of such renewable electricity generation affects the supply-demand balance and cannot replace definitely fossil fuels. Therefore, the hybrid renewable energy system, which constitutes of renewable sources, conventional source and/or energy storage system, is constituted a promising solution. Recently, electrification using HRES, in particular, Solar wind based hybrid renewable energy system has been largely exploited in isolated areas because it is more cost-effective and more reliable than only diesel based system [6]. Although, researchers face a big challenge with finding optimal sizing and configuration of HRES taking into account various constraints. Many research papers have been done on this topic using either optimization algorithms or commercial software such as HOMER, RETSCREEN, and HOGA, which are widely used [7].

For example, Haratian et al. [8] proposed a method based on techno-economic analysis to find feasible options for zero-emission HRES in Iran. It is found that the most economical configuration is a PV battery with an energy cost (COE) of 0,546 $/kWh. A new meta-heuristic algorithm called Cuckoo Search is applied in [9] and [10] for solving the problem of techno-economic sizing of hybrid PV/wind/ diesel/battery for remote buildings. On the other hand, Das and Zaman[11] examined the performance of PV, Diesel, Lead Acid and/or Lithium-ion battery systems in a remote community in Bangladesh using HOMER software. He has studied the effects of the dispatch strategy, fuel and component costs on the cost of energy (COE) of the optimal HRES. Similarly, Barun[11] investigated the performance of hybrid PV/Diesel/ Lead Acid-LA and Lithium-ion battery system to supply a remote community in Bangladesh. His study aims to find the optimal configuration where minimizing system costs. F. Fodhil et al. [7]presented a methodology for analyzing an autonomous hybrid PV-diesel-battery energy system. In his study, particle swarm optimization (PSO) and ε-constraint method were used to minimize total system cost and CO2 emissions. Monotosh et al. [12] developed a metaheuristic optimization algorithm to determine the optimal design of an off-grid HRES with the goal of minimization of the total net present cost. The studied HRES, which consists of solar PV/biogas generator /pumped hydro and battery storage system, is proposed to supply a radio transmitter station in India. Zhang et al [13] also proposed a new hybrid optimization algorithm based on the combination of chaotic search, harmony search and simulated annealing algorithms for optimal sizing of stand-alone hybrid solar and wind energy system. The main objective is to minimize the total life-cycle cost. Besides that, in [14] and [15] the optimal design of the hybrid renewable energy with hydrogen storage system are discussed to minimize the total net present cost using an intelligent flower pollination algorithm. Bhatt and Sharma [16] studied the techno-economic feasibility of different hybrid energy systems in rural areas in India using HOMER software. Technical-economic factors include the cost of energy, net present cost, and renewable fraction and CO2 emissions. Differently, in the study of Luta [17], PV based hybrid energy system, including hybrid hydrogen fuel cell / super-capacitor storage system is examined. He is based on technical feasibility and cost-effectiveness to find the optimal size of HRES.

Despite stationary application, in [18], a new method is proposed for optimizing stand-alone hybrid systems consisting of PV /diesel/battery to supply mobile system electricity using multi-objective evolutionary algorithms. It is found that the hybrid system of flexible crystalline PV /diesel/battery is the solution that minimizes the weight of the system. This work is similar to the study of [19], which compared the life cycle energy and cost analysis of temporary housing after a disaster.

Highlight literature review, technical economic factors, mainly lower cost of energy, maximum reliability, renewable fraction …are the essential parameters in size of HRES in stand-alone applications. However, the successful design of HRES needs to take all aspects of sustainability which include technical, economic, environmental and social criteria [20], have to be considered to make better decisions. Further, a limited number of papers that study the design of HRES for mobile buildings. In several locations of the world, these types of buildings are widely spread. In the other hand, selecting appropriate components before sizing of HRES is an important process that must be included. In the present work, a diesel based HRES with different energy storage alternatives is analyzed to find optimal configurations for the electrification of temporary buildings in Algeria. The feasible HRES options are compared from technical, economic, environmental and social criteria. In this regard, this paper presents a design optimization method for optimal sizing of an HRES for electrification of temporary buildings in Algeria. The proposed HRES configurations are evaluated and compared considering technical, economic, environmental and social criteria. To achieve this goal, HOMER software and AHP multi-criteria decision-making technique were used. The method is applied on gas and oil-drilling camps of ENTP, the case study of Adrar fields, Algeria. The main contributions of this work are:

Selection of the optimal configuration among the feasible options is made based on various criteria linked to technical, economic, environmental and social criteria. To achieve these goals, HOMER software and Analytic hierarchy process (AHP) technique were used.

A comparative analysis is conducted between LA and Li-ion batteries and hydrogen as energy storage alternatives for PV/WT/Diesel-based hybrid system based on technical, economic, environmental, and social indicators.

A sensitivity analysis is demonstrated to examine the effects of various input cost parameters for the selection of best configuration for the proposed HRES.

The remainder of this paper is organized as follows: Section 2 explains the proposed method. The key results and discussions are provided in section 3. Finally, section 4 draws conclusions and future work.

Figure 1.*Drilling camps example in Sahara of Algeria*

II. Materials and methods

This work presents a methodology for the optimal design of an off-grid HRES for the supply of electricity to a drilling camp in Adrar, southwest of Algeria. The proposed hybrid system consists of PV panels, small wind turbines, diesel generators, batteries, hydrogen storage system and converters. HOMER software is used to size the hybrid system proposed. However, the AHP technique is used to select the best components and find the optimal HRES configuration for the case study.

II.1. Location andclimaticdata

Adrar is an Algerian province, located in the Sahara, southwest of the country. Figure 2shows Adrar's geographical location. This region contains important oil and gas fields[21]. The required climatic data for Adrar are extracted from the

NASA database via HOMER (from 1983 to 2005). The hourly data for ambient temperature and wind speed and the average monthly clearness index and solar radiation are shownin Figure 3, Figure 4, and Figure 5respectively.

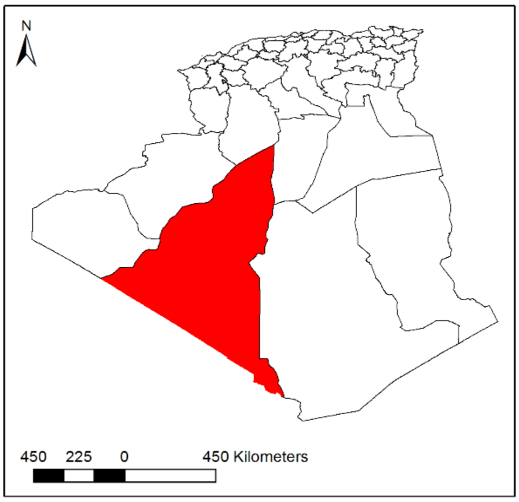

Figure 2.*The geographic location of Adrar*

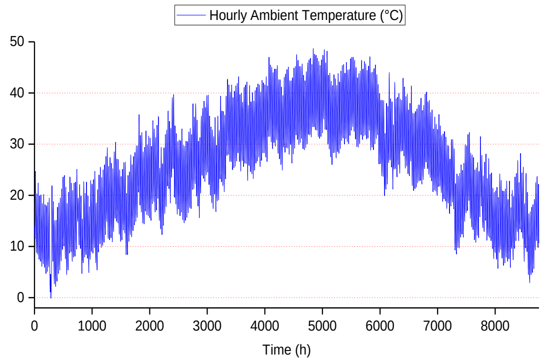

Figure 3.*Hourly Ambient Temperature at Adrar*

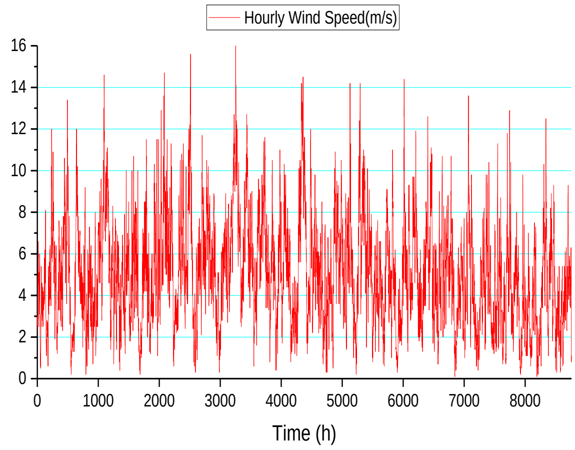

Figure 4.*Hourly Wind Speed at Adrar*

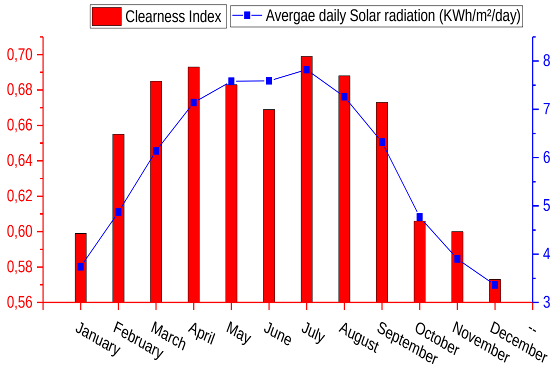

Figure 5.*Solar radiation and Clearness Index at Adrar*

II.2. Case studydescriptionandloadestimation

In this study, a typical drilling camp is selected. Many local companies have been involved in the construction of drilling camps, such as CLEMCA, SAFCAS... etc. CLEMCA is specialized in the construction of drilling camps by providing all life needs, such as accommodation cabin, administration and catering. Figure 6shows a typical drilling camp sketch.The overall roof area of the camp is 1446 m², which will be used to install solar panels. The energy demand of this camp is assumed based on the data collected from Clemca Company, the characteristics of the equipment and the information provided by some ENTP workers in the case study. The average daily demand of the camp is 1635 KWh / day, with a peak power of 225 kW. The seasonal load profile for the studied camp is provided by Figure 7.

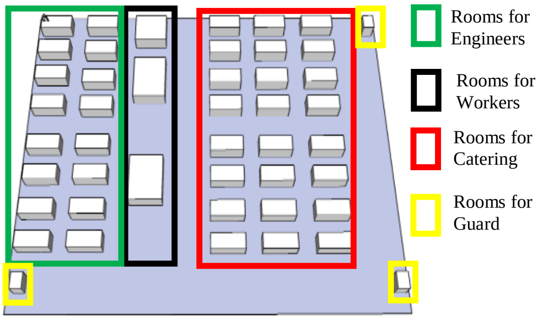

Figure 6.*Sketch of a typical drilling camp*

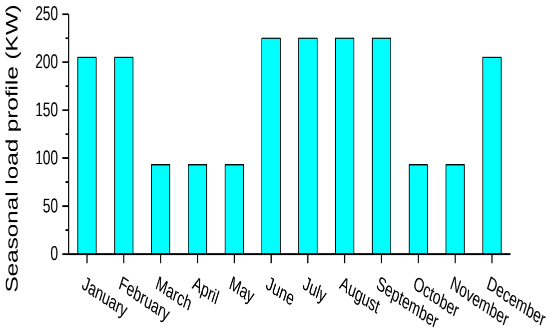

Figure 7.*The seasonal Load profile of the camp*

II.3. Simulation ofthe hybrid energysystem

HOMER software is widely used in literature to optimize hybrid power systems. HOMER was developed by the National Renewable Energy Laboratory (NREL). HOMER's calculation after three stages is a simulation, then an optimization, if any, sensitivity analysis. HOMER offers a wide library of various components, including conventional and renewable sources, storage systems and controllers. HOMER requires climatic data, component costs and load profile as main inputs for calculation. HOMER ranks solutions based on minimum energy costs (COE). In this study, the cycle-charging (CC) strategy is chosen to control the hybrid system in which, using Electrolyzer, the surplus energy is used to recharge the batteries or produce hydrogen gas. Figure 8shows the schematic of the proposed hybrid system.

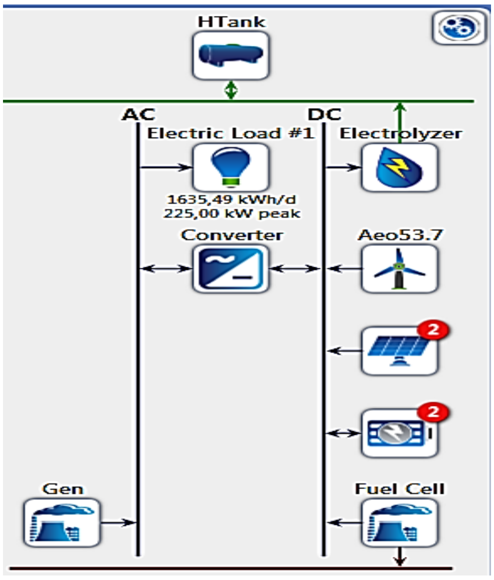

Figure 8.*Schematic of the studied system*

II.4. Solar PV

The solar PV panel is a device that converts solar energy into electrical energy. Eq. (1) can be used to evaluate the power supplied by PV panels as a function of solar radiation and ambient temperature as follows [22]:

$$P_{PV}(KW) = P_{NPV} * \frac{G}{G_{ref}} * \left[1 + Kt * \left(\left(T_{amb} + \left(\frac{NOCT-20}{800}\right) * G\right) - T_{ref}\right)\right] \quad \textbf{(1)}$$

Where, $P_{PV}$is the output power of the PV system, P_{NPV} is rated power under reference conditions, G is solar radiation (W/m²), G_{ref} and $T_{ref}$are solar irradiation and ambient temperature under reference conditions, which are 1000 W/m² and 25 °C respectively. Kt is the temperature coefficient of power (-3.7e-3 (1/°C)). Two PV panels were used in this study, multi-crystalline silicon and cadmium telluride (CdTe) thin film module. The cost of capital and replacement, operation and maintenance (O&M) for both PV panels is $1200/kW and $10/KW respectively[23]. Table 1 shows the characteristics of the panels selected. Due to techno-economic constraints, solar panels are installed on the camp's roof at an optimum inclination angle (27 °).

Table 1.*Technical economic data of PV panels.*

Component	**First Solar-108Wc**	**Condor-300Wc**
Model	CdTe	Multi-crystalline
Capital cost($/KW)	1200	1200
Capital cost at 2030 ($/KW)	800	800
O&M Cost ($/KW/year)	10	10
Lifetime (year)	25	25
Efficiency (%)	14,9	15,5
Efficiency at 2030 (%)	-	20 [24]
Module area (m²)	0,72	1,94
Weight (Kg/KW)	111	78
Derating factor (%)	88	88
Maximum Capacity (KW)	217	224

II.5. Wind turbine

Wind turbine (WT) can be considered as an available and free energy source that can be used to produce electricity by converting the kinetic energy into electrical energy. This source is more reliable in locations where wind speed is high, likewise the southwestern regions of Algeria. The power output of wind turbines can be approximated using Eq. (2), Eq. (3) , and Eq. (4) as follows [25]:

$$P_{WT}(KW) = 0 \quad if \quad V < Vcut_{in} \quad or \quad V > Vcut_{out} \quad \textbf{(2)}$$

$$P_{WT}(KW) = V^3\left(\frac{Pr}{Vr^3 - Vcut_{in}{}^3}\right) - \left(\frac{Vcut_{in}{}^3}{Vrated^3 - Vcut_{in}{}^3}\right) \quad if \quad V > Vcut_{in} \quad and \quad V < V_{rated} \quad \textbf{(3)}$$

$$P_{WT}(KW) = P_r \quad if \quad V > V_{rated} \quad and \quad V < Vcut_{out} \quad \textbf{(4)}$$

Where t_{in} ,V_{rated} , $Vcut_{out}$ are respectively the cut in, rated, cut out speed of the WT.P_r(KW) represents the rated power of the WT.however, V represents the hourly wind speed at the hub height.

HOMER software calculates the wind turbine power output based on wind speed data at the hub high and the wind turbine power curve delivered by the manufacturer. In this work, The Aeolos 50 KW wind turbine model is selected. Capital and replacement costs and O&M costs for the WT are $1500/KW and $12/kW / year respectively [26]. The selected WT has a lifespan of 20 years and a hub height of 30 m. The WT's weight is 6800 Kg, i.e. 136 Kg / KW.

II.6. Diesel generator

Diesel generator (DG) is used in the hybrid energy system to meet the load demand in case of deficit power from renewable energy and/or from stored energy. The hourly fuel consumption of the diesel generator is a function of its output power and rated power as given in Eq. (5) [9]:

$$q(t) = a * P_{DG} + b * P_r \quad \textbf{(5)}$$

Where P_{DG} (t) is generated power by DG (kW) at the hour (t), q (t) is fuel consumption (L/h), P_r is the rated power of DG, a and b are constant parameters (L/kW) representing fuel consumption coefficients, with standard values of 0.08415 and 0.246 respectively.

Generic DG's capital / replacement costs and O&M costs are 500 $/KW and 0.03 $/h respectively [27]. DG's lifetime is 60 000 h [28]. The current and expected price of diesel fuel in Algeria up to 2030 is 0.19 $/L and 0.65 $/L respectively. The diesel fuel prices forecasting at 2030 represent the prices of non-subsidized diesel fuel. Because the real diesel fuel prices in Algeria as mentioned by the government and a lot of expertise are about 0.65 $/L. These assumptions according to many economic researchers and following the Algerian government plans which intends to give up fuel subsidies in the coming years. This scenario is emphasized by the increase on fuel prices from 2016 by 50% [5].

II.7. Converter

Converter is the device that converts electrical energy from AC to DC or vice versa. The converter's rated power depends on the peak load. The Converter's efficiency is set at 95 % and its lifetime is 12 years.

The converter's capital cost and replacement cost are the same and are taken at $115/KW [29]. This converter has an efficiency of 95 % and a lifetime of 15 years.

II.8. Batterystorage

Battery storage (BS) is the common storage feature and is highly acceptable. Two types of battery are analyzed and compared, Lead-acid (LA) and L-ion (LI). The costs and specifications of both batteries are summarized in Table 2. The excess electricity that is produced by renewable and/or diesel generator is used to charge the battery bank whereas the shortage of energy can be supplied from a battery bank or diesel generator. the state of charge of battery on charging mode can be assessed by Eq. (6) [9].

$$E_b(t+1) = E_b(t) * (1-\sigma) + \left(E_g(t) - \frac{E_l(t)}{\eta_{inv}}\right) * \eta_{BC} \quad \textbf{(6)}$$

However, in the discharging mode, the state of charge of the battery can be assessed by Eq. (7) [9].

$$E_b(t+1) = E_b(t) * (1-\sigma) + \left(\frac{E_l(t)}{\eta_{inv}} - E_g(t)\right) / \eta_{BD} \quad \textbf{(7)}$$

At each hour (t), the state of charge of the battery $E_b(t)$ is constrained by a minimum and a maximum capacity of storage, $E_{bmin}$and E_{bmax}, as specified in Eq. (8).

$$E_{bmin} \le E_b(t) \le E_{bmax} \quad or \quad E_{bmin} = (1 - DOD) * E_{bmax} \quad \textbf{(8)}$$

Where: η_{inv} , η_{BC} , $\eta_{BD}$are the efficiency of the inverter (95%), battery charge efficiency (100%) and battery discharge efficiency (85%) respectively. σ is the self-discharge of the battery that is neglected here. DOD is the dept of discharge. E_g and $E_l(t)$are the generated power and the load at the hour t respectively.

Table 2.*Technical-economic data of Batteries.*

Type of battery	(LA)	(LI)	References
Capital cost ($/KWh)	110-200	350	[30][31]
Capital cost at 2030 ($/KWh)	50	145	[31]
O&M cost ($/KWh/year)	10	10	
Lifetime (year)	10	15	
Current Specific energy (Wh/Kg)	40	274	[31][32][33]
Specific energy at 2030 (Wh/Kg)	60-100	350	[31][32][33]
DOD (%)	60	80	
Round trip efficiency	80-85	90-95	[32]
Round trip efficiency at 2030	90	98	[31]

II.9. Hydrogen storage

The hydrogen storage (HS) system consists of Fuel Cell (FC), Electrolyzer (EL), and Storage Tank (ST).

Fuel cell: FC is a device that converts stored hydrogen gas into electricity. The polymer electrolyte membrane (PEM) fuel cell is selected because is the most promising types of fuel cells due to its simplicity and low operating temperature [34].

Electrolyzer: An EL generates hydrogen through the electrolysis of water.

Storage tank: The hydrogen generated from the Electrolyzer is stored in a tank. Hydrogen gas storage is very environmentally friendly and has no GHG emissions. However, hydrogen gas needs a high level of safety, because the lower flammability limit of hydrogen is 4.1 % in normal air condition and its release incidences can lead to massive losses [35]. In Table 3, the technical economic data for hydrogen storage components are summarized.

Table 3.*Technical-economic data of hydrogen storage.*

Component	ELectrrolyzer	Fuel Cell	Storage Tank	References
Capital cost($/KW)	1000-1500	2000	500/kg	[26][36][37][38]
Capital cost at 2030 ($/KW)	800	800	300/Kg	[39][40][41]
O&M Cost ($/KW/year)	10	0.01/h	0	
Lifetime (hour)	40000 (20 year)	30000	25	[42]
Lifetime at 2030 (hour)	80000	50000	-	[39][40]
Efficiency (%)	Up to 85	50	-	[37][43]
Efficiency at 2030 (%)	90	>50	-	[40]
Weight (Kg/KW)	15	5	20 Kg/Kg stored H2 at 700 bars	[44][45][46]

In this work, HOMER simulation is carried out with a 20-year project lifetime and a 6 % interest rate and a minimum renewable fraction of 30 %. Other CO2 emissions are only linked to DG, as they have the largest and most dominant Lifecycle emissions of 0.88 Kg CO2-eq / Kwh [30]. Solar energy has the priority than wind energy, so we have set 60 % of the total share of solar energy in renewable energy. However, the available roof area, panel area, and inclination are the constraints that determine the maximum allowable capacity of PV panels.

II.10. Levelizedcostofenergy

Levelized cost of energy (COE) is commonly used to compare different energy producer technologies. HOMER calculates the cost of energy using Eq. (9) [11].

$$COE(\$/KWh) = \frac{C_{A\_cap}+C_{A\_OM}+C_{A\_rep}}{E_{served}} \quad \textbf{(9)}$$

HOMER determines the optimal solutions according to lower energy Costs. Despite to COE, total net present cost (NPC), fuel consumption, CO2 emission, and others parameters are also extracted for all the feasible options. Because, in this study, a MCDM analysis was carried out to select the best configurations for the HRES.

II.11. Multi-criteriadecision-making

In order to make the best decisions, it is necessary to consider various criteria, mainly technical, economic, environmental and social criteria [47]. However, analyzing different conflict criteria needs to use an MCDM method. Therefore, the Analytic Hierarchy Process (AHP) technique is used. AHP method based on weights calculation, compare of alternatives according to its available data. The evaluated criteria in this work, which have reported in [48][49] are given in Table 4.

Table 4.*Evaluation criteria definition.*

Criteria	Sub-criteria	Definition
Economic	Initial Capital cost (ICC)	The investmentcostofthesystem (Decreasethiscostmakethesystemattractivebyinvestors)
	Cost of energy (COE)	The lifetimecostofthesystemdividedbyEnergyproducedduringitslifetime
	Fuel consumption (F-Cons)	Yearlyfuelconsumption(minimizefuelconsumptionisourgoal)
Technical	The Weight (Wt)	The weightofthesystem in Kg (theweight must beminimizedaspossiblefor mobile buildings)
	Renewable Fraction (Ren-Fr)	Increase RE fractionisourgoal
Environ mental	CO2 emission (CO2-E)	CO2 producedbythesystem (wehavetominimize CO2 emissions)
	Safety Aspect (Safety)	SafetyRequirementtoavoiddamageandsystemmenace (must beminimized)
	Water use (Water)	needwaterforworking (usingwateris a bigproblem in the Sahara, must beminimized)
Social	Government policy (Gvr-P)	Support Localpolicypriorities (Algeria supportlocalproducer, andwehavetofollow RE programtrends)
	Local market availability (L-M-A)	Availabilityofproduct in theAlgerianmarketiscrucialbecauseourcountrylimitstheexportationofsomeproductstodevelopthe national economy.
	Social benefits (Soc-B)	Benefitsforthelocalproducer (encouragelocalproducerbybuyingitsproductsandincreasingthenumberof workers/contributiontocreatingjobsthatis a bigproblem in Algeria nowadays.

III. Results and discussion

III.1. Resultsfor solar PV panel'sselection

Before comparing the feasible HRES' options, the best renewable energy componentsare selected. Since there are several PV panels on the market. Select adequate components such as PV panel, influenced by different factors and depending on many criteria. Table 5 and Table 6 shows the required data and MCDA results.

Table 5.*Input data of selected PV technologies.*

Criteria	FS-CdTe	Condor multi-cry.
COE ($/Kwh)	0,056	0,058
Weight (Kg/KW)	111	78
Annual production (Kwh)	411 432	420 000
Local market availability	Low	High
Social benefits	Low	High
Government policy	Not Supported	Highly Supported

Table 6.*Results of MCDM for PV technology selection.*

Criteria	Criteria Weights	FS-CdTe	Condor-multi-cry.
COE ($/Kwh)	0.2	0.100	0.100
Weight (Kg/KW)	0.2	0.050	0.150
Annual production (Kwh)	0.15	0.050	0.101
Local market availability	0.15	0.026	0.125
Social benefits	0.15	0.021	0.129
Government policy	0.15	0.020	0.131
Sum of Weights	1	0.27	0.73
Rank	/	2	1

From the results of MCDA, multi-crystalline PV panelsare the most appropriate PV panels for the present case study. Thereby, only multi-crystalline PV panels are used for the simulation.

III.2. HOMER results

After select the components of the HRES, the simulation was carried out in HOMER software. Two different scenarios are investigated. Forthe both scenarios, the feasible configurations are compared. For all the obtained configurations, the size of DG and PV system are found 250 KW and

224 KW respectively. In addition, for the hydrogen based configurations, Hydrogen storage (HS) system includes FC (500 KW), EL (200 KW), and ST (100 Kg). The composition of the all-possible HRES' configurations and their representation indices are given in Table 7.

Table 7.*Indices of possible configurations of HRES.*

Index	**Configuration components**	**Index**	**Configuration components**
HYB-0	DG	/	/
HYB-1	DG/PV	HYB-7	DG/PV/LI/HS
HYB-2	DG/PV/WT	HYB-8	DG/PV/WT/LA
HYB-3	DG/PV/LA	HYB-9	DG/PV/WT/LI
HYB-4	DG/PV/LI	HYB-10	DG/PV/WT/HS
HYB-5	DG/PV/HS	HYB-11	DG/PV/WT/LA/HS
HYB-6	DG/PV/LA/HS	HYB-12	DG/PV/WT/LI/HS

Before doing the comparison between the feasible HRES' configurations, some configurations are eliminated which either have no PV panels, or with renewable fraction smaller than 30%, or with COE greater than 0.23 $/KWh (that represents the COE for the configuration with DG alone with taking current data). Hence, a multi-criteria decision analysis is carried out to select the best options.Here, many technical, economic and environmental evaluation criteria are taken into account. The weights of these criteria are given in Table 8.

Table 8.*Criteria' weights.*

Crit-eria	**Criteria-Weight (1)**	**Sub-criteria**	**Sub-Criteria-Weight (2)**	**Final-Weight (1*2)**
Economic	0.4	Initial Capital cost	0.25	0.1
		Cost of energy	0.5	0.2
		Fuel consumption	0.25	0.1
Technical	0.35	The Weight	0.8	0.28
		Renewable Fraction	0.2	0.07
Environmental	0.25	CO2 emission	0.4	0.1
		Safety Aspect	0.3	0.075
		Water use	0.3	0.075

III.3. The firstscenario (at present)

In this scenario, the current technical-economic data of components and diesel fuel price are used.

The results of the feasible hybrid energy system are summarized in Table A.1. However, the ranking of hybrid energy system configurations based on MCDA analysis for this scenario is presented in Table 9.

Table 9.*The result of HRES ranking (First scenario).*

Criteria	**HYB-2**	**HYB-3**	**HYB-4**	**HYB-8**	**HYB-9**
ICC	0.016	0.031	0.031	0.006	0.016
COE	0.012	0.030	0.056	0.038	0.064
F-Cons	0.005	0.009	0.016	0.027	0.043
Weight	0.028	0.045	0.120	0.017	0.073
Ren-Fr	0.003	0.010	0.010	0.024	0.024
CO2-E	0.004	0.014	0.014	0.034	0.034
Safety	0.015	0.015	0.015	0.015	0.015
Water	0.015	0.015	0.015	0.015	0.015
Sum-Weight	0.098	0.169	0.277	0.176	0.284
Rank	5	4	2	3	1

III.4. The secondscenario (at 2030)

In this scenario, the assumption of technical-economic data of components and diesel fuel price is used. The results of the feasible hybrid system are summarized in Table A.2. The result of MCDM for ranking hybrid system configuration for this scenario is presented in Table 10.

Table 10.*The result of HRES ranking (Second scenario).*

Criteria	HYB-3	HYB-4	HYB-8	HYB-9	HYB-11	HYB-12
ICC	0.025	0.041	0.010	0.014	0.005	0.003
COE	0.048	0.026	0.048	0.048	0.016	0.014
F-Cons	0.006	0.004	0.015	0.011	0.033	0.033
Weight	0.118	0.045	0.014	0.073	0.008	0.025
Ren-Fr	0.004	0.004	0.012	0.007	0.022	0.022
CO2-E	0.004	0.004	0.015	0.009	0.034	0.034
Safety	0.017	0.017	0.017	0.017	0.004	0.004
Water	0.016	0.016	0.016	0.016	0.005	0.005
Sum-Weight	0.238	0.157	0.147	0.195	0.127	0.140
Ranking	1	3	4	2	6	5

In the first scenario, HYB-9 (DG/PV/WT/LI) and HYB-4 (DG/PV/LI) are the best configurations. We have shown that hydrogen storage is not included in the competitive configurations of this scenario, because of its high COE, capital cost, and the overall weight of the system. Other, these configurations have COE smaller than the COE obtained by only using DG. Therefore, the hybrid system is highly feasible.

In the second scenario, HYB-3 (DG/PV/LA) and HYB-9 (DG/PV/WT/LI) are the best configurations. However, other configuration has more advantages and have COE smaller than the COE obtained using DG alone. In addition, Hydrogen storage is included in HYB-11 and HYB-12, which gather battery and HS. Thus, there is no feasible configuration with only HS. Therefore, Battery storage has been stilled the optimal storage system for building application, especially for mobile buildings until 2030. Besides, in the next year, DG will be the infeasible solution for mobile buildings, especially with the rise of diesel fuel prices higher than one dollar.

IV. Conclusion

The aim of this work is to develop an optimal methodology to design of off-grid hybrid renewable energy system to electrify temporary buildings in isolated areas of Algeria, HOMER software and AHP method of multi-criteria decision-makingare used to achieve this goal. The method is applied to case studyof gas and oil drilling camps in Adrar, Algeria. The main objectives of this study were to minimize fuel consumption, reduce energy costs, mitigate GHG emissions and minimize system weight. In addition, a comparison was made between different storage systems and renewable energy technologies in order to select the best solutions. Sensitivity analysis is carried out taking into account two scenarios that represent current and future assumptions of technical-economic data.The results show that DG / PV / WT / Li-ion battery is the best configuration for the case study when considering the present scenario. However, for the future scenario, the optimal HRES' configuration consists of DG / PV / Load acid battery. In addition, hydrogen storage system is not currently a viable solution for energy storage in such remote locations. Nevertheless, if no significant improvements are made with batteries, hydrogen storage will be more competitive in next years. The proposed method will help decision-makers to make better decisions in the future to determine optimal configurations of the hybrid renewable energy systems for the electrification of remote areas. The method is not only feasible for the location studied, but it can be applied to any location in Algeria and around the world. It will therefore contribute significantly to transit to sustainable communities by saving fossil fuels and reducing GHG emissions locally and worldwide.

V. Appendices

Table A. 1.*First scenario (Current data).*

HYB	ICC ($)	COE ($)	F-Cons (L/year)	Weight (Kg)	Ren-Fr	CO2-E (Kg/year)	Safety requirement	Water Requirement
HYB-0	125000	0.23	253580	0	0	663773	/	/
HYB-4	506341	0.15	93312	18492	46	244254	No	No
HYB-3	514255	0.17	96467	29897	47	252513	No	No
HYB-2	558499	0.23	162656	31072	18	425770	No	No
HYB-9	567521	0.14	75256	25136	57	196990	No	No
HYB-8	589119	0.16	79898	36422	56	209143	No	No

Table A. 2.*First scenario (Future assumptions).*

HYB	ICC ($)	COE ($)	F-Cons (L/year)	Weight (Kg)	Ren-Fr	CO2-E (Kg/year)	Safety required	Need Water
HYB-0	125000	0.42	253580	0	0	663773	/	/
HYB-3	421128	0.18	79405	20040	52	207852	No	No
HYB-4	380243	0.20	83416	43772	50	218350	No	No
HYB-8	604354	0.17	43884	61147	74	114871	No	No
HYB-9	532231	0.17	57371	32500	65	150176	No	No
HYB-11	1259375	0.23	22276	67822	87	58311	Required	Yes
HYB-12	1270857	0.22	21912	53496	87	57356	Required	Yes

VI. References

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