Research Article

Techno-economic investigation of solar-wind potential to power an industrial prototype using a hybrid renewable energy system

Kamal Anoune[1,2] · Mohsine Bouya[2] · Azzeddine Laknizi[3] · Abdellatif Ben Abdellah[3] · Abdelali Astito[1] · Mokhtar Ghazouani[2]

Abstract

Hybridization of solar and wind energy to supply an electrical load demand is considered as a realistic approach aiming to take the benefit of these power generation sources and facilitate their integration for a stand-alone and grid-connected application. However, an under-sizing of the hybrid system mays disturbs the operation of all-electric equipment; on the contrary, an over-sizing may turn higher the investment cost of the hybrid system. Therefore an appropriate size of the hybrid renewable plant could help to guarantee the minimal cost of integration with the maximum power reliability. A specific design under TRNSYS and Matlab has been used to assess weather condition of solar irradiation, wind speed, and temperature for the selected referee cities, after, a determined load demand profile of a laboratory prototype is used to describe daily energy consumption. Then a dynamic simulation of energy output performance for different hybrid configuration is analyzed during one year; as a result, only one optimized configuration is chosen for each referee cities with respect of minimal investment cost and maximal power reliability. Finally, a techno-economic investigation of the chosen optimized solution is presented as a result and discussed, as well as an environmental assessment.

Keywords Hybrid renewable energy sources (HRES) · Photovoltaic (PV) · Wind turbine (WT) · Hybrid system (HS) · Typical meteorological year (TMY2) · Economic and environmental assessment (EEA)

List of symbols

$P_{pv}(t)$	Output power of the PV panel (kW)
P_{rate}	Nominal output power of the PV panel (kW)
G	Solar radiation (W/m^2)
G_{etc}	Solar radiation at STC equal to 1000 (W/m^2)
T_{stc}	Cell temperature at STC equal to 25 °C (°C)
K	Temperature coefficient (N/A unit)
T_{cell}	Cell temperature (°C)
T_{amb}	Ambient temperature of the air (°C)
P_{WT}	Output power (mechanic) of WT (kWh)
C_p	Coefficient of power (N/A unit)
ρ	Air density (kg/m^3)
A	Swept area of WT (m^2)
λ	Tip speed ratio (N/A unit)
β	Blade pitch angle (°)
$V_{cut\text{-}in}$	Cut-in wind speed (m/s)
$V_{cut\text{-}out}$	Cut-out wind speed (m/s)
σ	Hourly self-discharge rate (%)
E_g	Generated energies (kWh)
E_l	Load demand (kWh)
SOC	State of charge (%)
η_{bat_char}	Charge efficiency (%)
$\eta_{Bat\_dischar}$	Discharge efficiency (%)
η_{inv}	Inverter efficiency (%)
q_d	Power of heat loss for dry sidewall
q_w	Power of heat loss for wet sidewall

✉ Kamal Anoune, kamal.anoune@gmail.com; Mohsine Bouya, mohsine.bouya@uir.ac.ma; Azzeddine Laknizi, eng.azzeddinelaknizi@gmail.com; Abdellatif Ben Abdellah, benabdellah.abdellatif@gmail.com; Abdelali Astito, abdelali_astito@yahoo.com; Mokhtar Ghazouani, ghazouani.mokhtar@gmail.com | [1]Laboratory of Informatics, Systems and Telecommunications (LIST), Faculty of Science and Technology (FST), Abdelmalek Essaâdi University (UAE), Tangier, Morocco. [2]Laboratory of Renewable Energies and Advanced Materials (LERMA), International University of Rabat (UIR), 11000 Sala Al Jadida, Morocco. [3]Laboratory of Engineering, Innovation, and Management of Industrial Systems (LEIMIS), Faculty of Science and Technology (FST), Abdelmalek Essaâdi University (UAE), Tangier, Morocco.

SN Applied Sciences (2019) 1:1313 | https://doi.org/10.1007/s42452-019-1358-7

Received: 13 July 2019 / Accepted: 25 September 2019 / Published online: 1 October 2019

q_b	Power of heat loss for tank bottom
q_r	Power of heat loss for tank roof
U_d	Overall heat coefficient for dry sidewall
U_w	Overall heat coefficient for wet sidewall
U_b	Overall heat coefficient for tank bottom
U_r	Overall heat coefficient for tank roof
A_d	Surface for dry sidewall
A_w	Surface for wet sidewall
A_b	Surface for tank bottom
A_r	Surface for tank roof
T_v	Vapour temperature
T_L	Liquide temperature
T_{amb}	Ambient temperature

Abbreviations

TRNSYS	Transient simulation package
CO_2	Carbon dioxide
TMY	Typical meteorological year
RES	Renewable energy source
HRES	Hybrid renewable energy system
HS	Hybrid system
WE	Wind energy
PV	Photovoltaic
WT	Wind turbine
LP	Laboratory prototype
DC	Direct current
SOC	State of charge
UIR	International University of Rabat
kWh	Kilo Watt-hours
kWp	Kilo Watt-pick
STC	Standard condition
NOCT	Normal operating cell temperature (°C)

1 Introduction

Different sizing approach can be used to make a choice among a variety of system [1, 2]. Combining more than a single renewable power source with an appropriate battery capacity help to minimize the intermittency of the output power, and then to reduce the grid dependency [3]. Moreover, the thoughtful size of the HS helps to minimize the cost of energy by choosing the minimal configuration able to ensure supplying with continuity [4]. In this regard, a literature review of the most recent techniques used for sizing an HS, a different technique is compared and adopted according to the size and the utility of the installation [5]. The deterministic method requires data such as electric load profile and weather to estimate the long-term energy output of a specific hybrid configuration; data must be provided as hourly times-series and related to the location of the hybrid PV wind plant. In contrary, the electric load profile and weather are considered as stochastic in the probabilistic method [6, 7]. A comparison study has been made in order to compare the feasibility use of sizing deterministic approach, it is found that the yearly average month method helps to provide an optimized configuration of an HS connected to the gird, otherwise, the worst month methods servers to estimate the optimized configuration in a location without a grid connection [8].

In the literature, several studies have focused on the use of the TRNSYS software [9] for the evaluation of susceptible renewable energy implantation. In the Polytechnic University of Valencia, a validation procedure that evaluates an experimental result using measured data of a PV installation along two successive years [10], these result was confronted with the result of TRNSYS simulation of long-term energy output and present an acceptable accuracy. Mondol et al. [11] proposed a new TRNSYS component to estimate the energy exchange between a PV system and grid; this component is integrated into a designed TRNSYS model which simulate the long-term output of PV system. Moreover, an experimental study has been made to measure the uncertainties prediction results of TRNSYS simulation, compared with the long-term measurement data during 3 years of the PV installation planted in Northern Ireland. As a result, the uncertainties between the simulation and experimentation result are less than 5%. Panayiotou et al. [12] designed a TRNSYS model to examined an HS installation located at Nicosia, Cyprus, and Nice, France. This designed TRNSYS simulates the long-term output performance of this installation. As a result, Nicosia presents a higher solar potential compared to Nice, which is explained by less PV Array 11.7 kWp installation than 15.3 kWp for Nice with the same storage capacity of 108 kWh in both cases. Moreover Nice shows better performance in the HS due to its potential of wind energy, as optimum hybrid configuration, it is found 9.9 kWp of PV array, two wind turbines of 2.4 kW and 108 kWh of storage capacity. Otherwise, the same configuration is conserved for Nicosia. Bakić et al. [13] proposed a TRNSYS design to simulate a hybrid PV wind configuration, and they presented a dynamic simulation of solar and wind potential in Belgrade city, moreover, they presented a long-term electrical production for a specific hybrid PV wind configuration and the estimation of CO_2 reduction. As a result, HS represents a promising means of clean energy generation [14].

Providing an optimized configuration of the renewable hybrid power plant is the principal target of this manuscript. These renewable power plants must, first of all, ensuring a reliable power supply of the load demand and being more cost-competitive in terms of investment. In the current work, an appropriate design under TRNSYS and Matlab has been used to assess weather condition for the referee cities and to perform a simulation of the energy exchange of the HS configuration, after, a determined load demand profile of a laboratory prototype is used to describe daily energy consumption. Then a dynamic simulation of energy out-put performance for different hybrid configuration is analyzed during 1 year. Finally, a techno-economic investigation of the chosen optimized solution is presented as a result and discussed, as well as an environmental assessment.

In this paper, the methodology adopted for sizing HS start by defining the electrical load demand (ELD) of the LP as a first step. One ton of bitumen required to be maintained at 160 °C by compensating its heat losses and ensuring it electrical equipment consumption during one day, and then 1 year period. The second step consists of deep weather data analysis of the location under study, i.e.: solar radiation, temperature, humidity, and wind speed. It supposed that these parameters may or not influence and decide the energy output from a RES. Therefore, a deep investigation of solar and wind potential is required to validate this supposition. Then if one referred cities is investigated, it admits numerous HS configurations sizes that are composed of PV panel, WT and batteries sizes. Only one optimized HS configuration with the lowest investment cost is adopted. Dynamic simulation of the energy output vs ELD profile is required to validate the power reliability of this configuration. But for the other referee cites witch are characterized by a different weather condition, the optimized HS configuration may or not satisfied the ELD, otherwise, a techno-economic investigation is required for each referee cities.

2 Overview of the industrial laboratory prototype

The laboratory prototype (LP) is a miniaturized industrial process used for maintaining heated a ton of bitumen in a metal tank thermally insulated. The heat losses are compensated by the aid of a crew-on immersion heater. The main object of the LP is to experiment the behaviors of the process component and to integrate the renewable energy, i.e., solar photovoltaic and wind energy in order to supply the load demand (see Fig. 1).

The LP is composed principally of:

- Storage tank characterized by thermic isolation, which allowed feeding, evacuation, and agitation of bitumen.
- Process control: Allowed to control various stratification temperature and level of the liquid, controls numerous

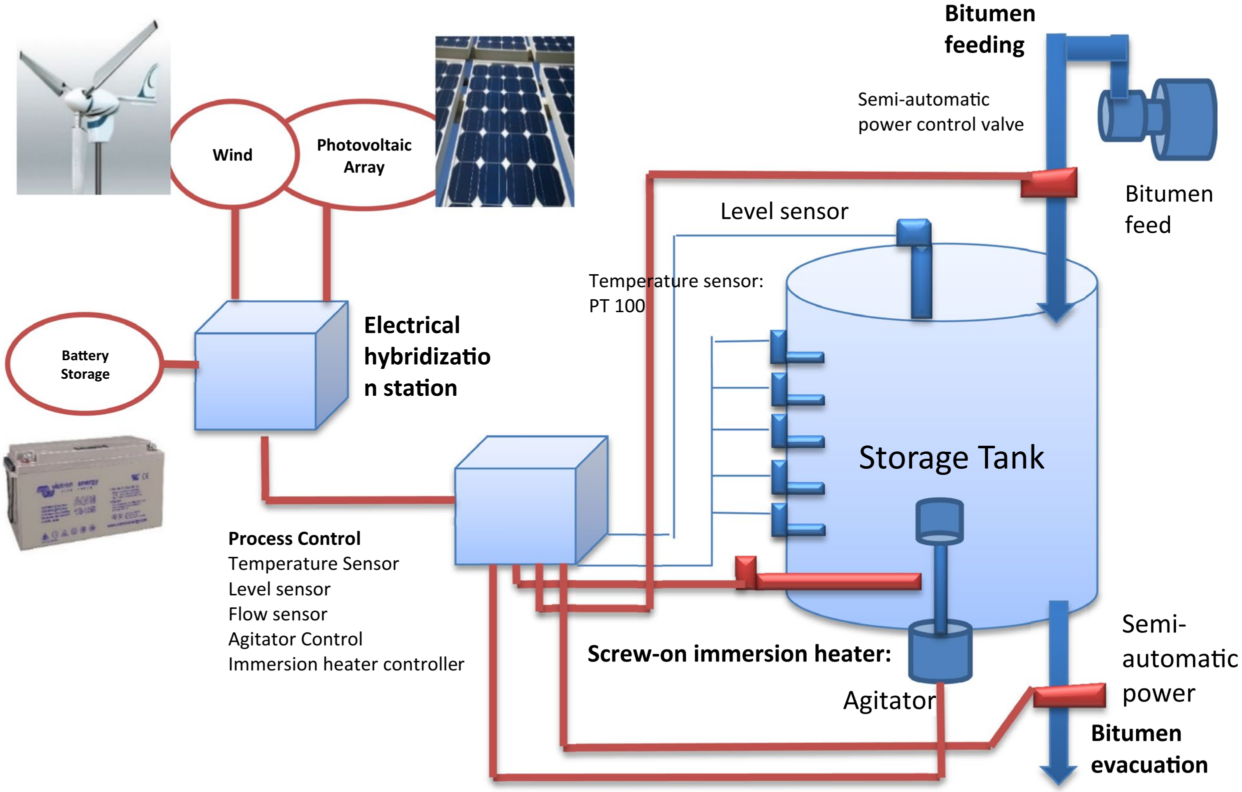

Fig. 1 Simplified scheme of the LP of the industrial process

valve and circuit breaker, ensuring the conventional temperature storage for the bitumen.

3 Modeling the system components

3.1 Photovoltaic panel model

The photovoltaic panel is considered as the widespread renewable power sources, it is composed of numerous solar cell matrixed to form a panel, and it converts solar radiation to electricity through p–n semiconductor junction technology. The output power can be influenced by two parameters: radiation and temperature and can be explained:

$$P_{pv}(t) = P_{rate}\left(\frac{G}{G_{stc}}\right)\left[1 + k\left(T_{cell} - T_{stc}\right)\right] \tag{1}$$

$$T_{cell} = T_{amb} + \left(\frac{NOCT - 20}{800}\right) \tag{2}$$

$P_{pv}(t)$ represent the output power of the PV panel, P_{rate} describe the nominal output power of the PV panel, G is the solar radiation in W/m^2, STC represent the standard condition, G_{stc} is the solar radiation at STC equal to 1000 (W/m^2), T_{stc} is the cell temperature at STC equal to 25 °C, k define the temperature coefficient, T_{cell} is the cell temperature, T_{amb} is the ambient temperature of air (°C), and finally the NOCT represent the normal operating cell temperature (°C).

3.2 Wind turbine model

The wind turbine's output power can be explained as a function of wind speed as:

$$\begin{aligned} &P_{WT} = C_p(\lambda, \beta)\frac{\rho A}{2}V_{wind}^3 \\ &V_{cut-in} \le V_{wind} \le V_{cut-out} \end{aligned} \tag{3}$$

C_p is called power coefficient, it is a function of Lambda and Beta, and their corresponding relation is expressed by the following equation [15]:

$$\begin{aligned} C_p(\lambda, \beta) = 0.35 - 0.0167 \cdot (\beta - 2) \cdot \sin\left(\frac{\pi \cdot (\lambda + 0.1)}{14.34 - 0.3 \cdot (\beta - 2)}\right) \\ - 0.00184 \cdot (\lambda - 3)(\beta - 2) \end{aligned} \tag{4}$$

where P_{WT} represent is the output power (mechanic) of the wind turbine, C_p represents performance coefficient, ρ is the air density, A is the swept area of WT, λ is the tip speed ratio β is the blade pitch angle, and finally, $V_{cut\text{-}in}$, $V_{cut\text{-}out}$, are respectively the cut-in, the cut-out wind speed.

3.3 Batteries model

To remedy the fluctuation of renewable energy sources E_p, batteries can store excess energy up to their capacity limit, and provide it when needed by load demand energy E_l. Batteries help to regulate the intermittency of the renewable sources by ensuring power reliability until its discharges.

The charging mode can be explained by the following Eq. (5) where is describing the available capacity at t hours [16]:

$$SOC(t) = SOC(t - 1) * (1 - \sigma) + \left[E_p(t) - \frac{E_l(t)}{\eta_{inv}}\right]\eta_{bat\_char} \tag{5}$$

E_p represent the produced energies from the renewables sources and E_l is the load demand of the LP. SOC(t), and SOC(t − 1) represent the batteries charge levels of times t and t − 1, the self-discharge rate is described hourly by σ.

The discharging mode can occur when the load demanded to exceed the produced energy of the renewables sources; in this case, batteries compensate the energy difference between production and consumption.

$$SOC(t) = SOC(t - 1) * (1 - \sigma) + \left[\frac{E_l(t)}{\eta_{inv}} - E_p(t)\right]/\eta_{Bat\_dischar} \tag{6}$$

η_{bat_char}, $\eta_{Bat\_dischar}$ represent the efficiency of batteries charge and discharge respectively, and η_{inv} is the efficiency of the used inverter [17].

4 Weather assessment of the referee cities

The main objective of sizing an HS is providing an optimal PV panel and wind turbine size for each potential location which can power the laboratory prototype. Moreover, the optimized configuration must ensure the uninterruptible power supply of the load demand. The adopted sizing method is the deterministic approach which is performed by analyzing the dynamic simulation of the output energy performance obtained by TRNSYS/Matlab. In this work, deterministic procedure witch use metrological data (1 h interval) helps to estimate the performance and provides the feasibility of the HS, then, time-series metrological data is containing the hourly physical rate of solar irradiation, wind-speed, and temperature to achieve the simulation for all probable system configuration [18]. The chosen locations are the six referee cities of the Moroccan weather area (Fig. 2).

Referring to numerous study and analyses of Moroccan weather, A government agency specialized in

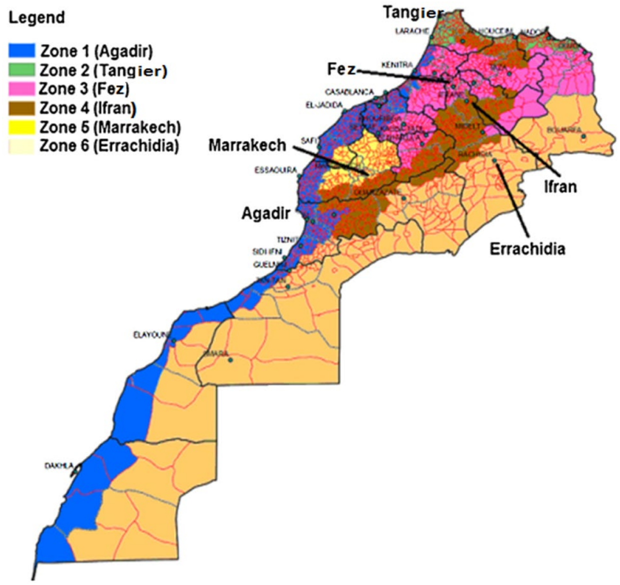

Fig. 2 The six referee cities of the Moroccan weather area

renewable energy and efficiency (NADREEE) [19] has defined a weather area. Each climatic zoning is represented by referee cities see (Table 1).

The hourly solar irradiations on a horizontal surface (W/m^2), and wind speed (m/s) of the six referee cities are illustrated respectively in following (Figs. 3, 4, 5, 6, 7, 8) [20].

The referee cities have a significant yearly average irradiation along the year with exceptions for December and January. It should be noted that Tangier knows an enormous wind field in comparison with other cities. Important data can be deduced from the dynamic simulation which concerns the average annual of irradiation, temperature and wind speed (Table 2).

The weather data analysis is based on a specific resource data file called TMY2. Each location understudy has a specific TMY2 file, it can be generated form Meteonorm software [21], or downloaded from the National Renewable Energy Laboratory (NREL), TMY2 files contain the time series weather data such as solar radiation and meteorological element during 1 year period with 1 h step. In other hand, TMY2 files are used as input for a developed TRNSYS design where the PV panel and WT are modeled. This TRNSYS design allows generating the time series energy output for each or both RES during 1 year period. These times series energy output is used on a Matlab program as input to decide the appropriate size of renewable energy sources able to satisfy the ELD of the LP. Dynamic simulation of the time series energy output of generated sizing solution is analyzed

Table 1 Weather characteristics of Moroccan referee cities

Weather area	Referee city	Coordinates	Altitude "m"	Weather characteristic
Z1	Agadir	301250 N 1360 W	31	Subtropical-semiarid
Z2	Tangier	351460 N 51480 W	20	Mediterranean hot
Z3	Fez	341030 N 41580 W	403	Mediterranean/continental
Z4	Ifrane	331320 N 51060 W	2019	Humid temperate climate
Z5	Marrakech	311370 N 81000 W	457	Semiarid
Z6	Errachidia	311550 N 41250 W	1041	Hot desert

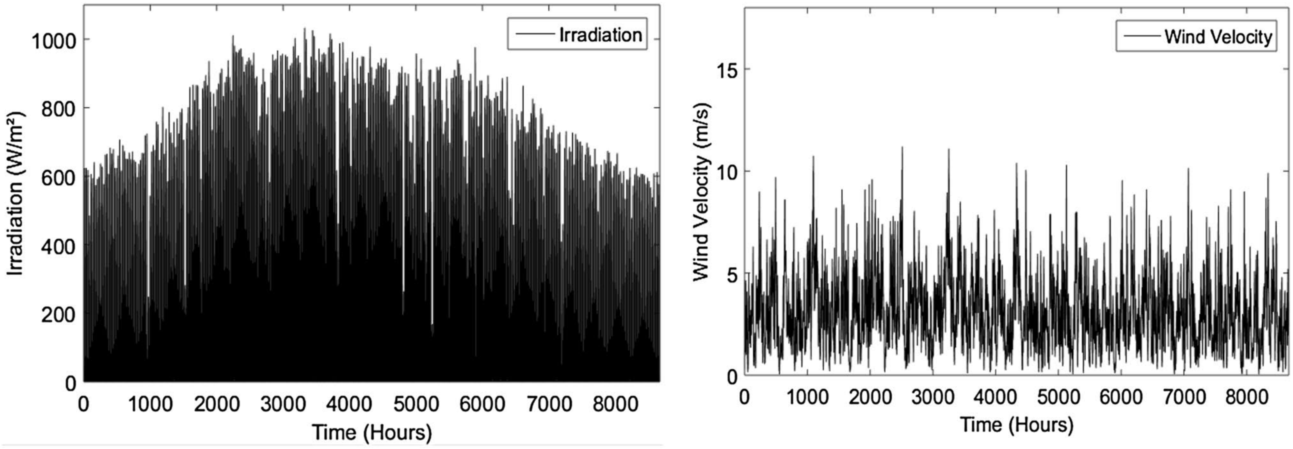

Fig. 3 Hourly solar irradiations and wind speed of Agadir City

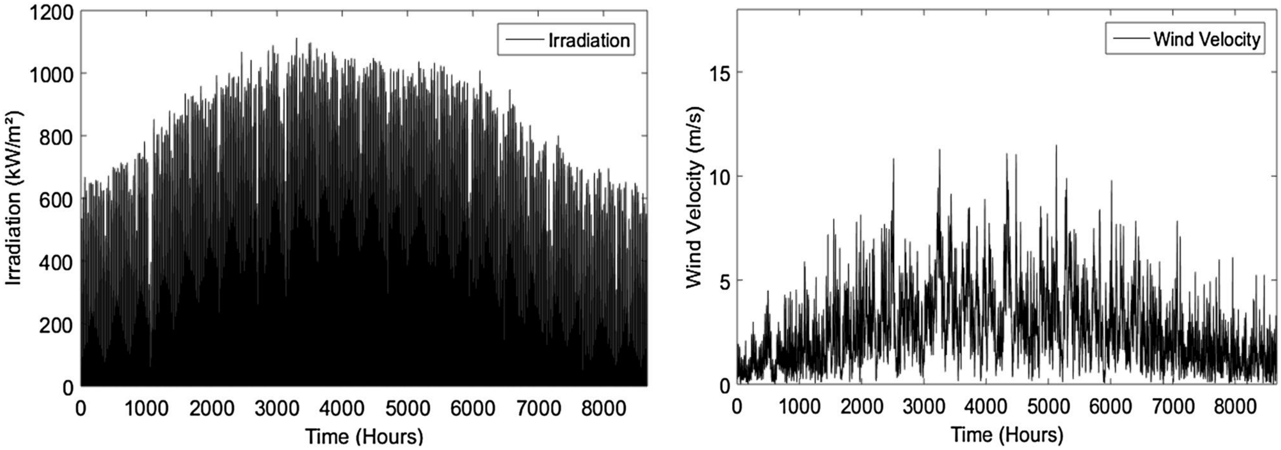

Fig. 4 Hourly solar irradiations and wind speed of Errachidia City

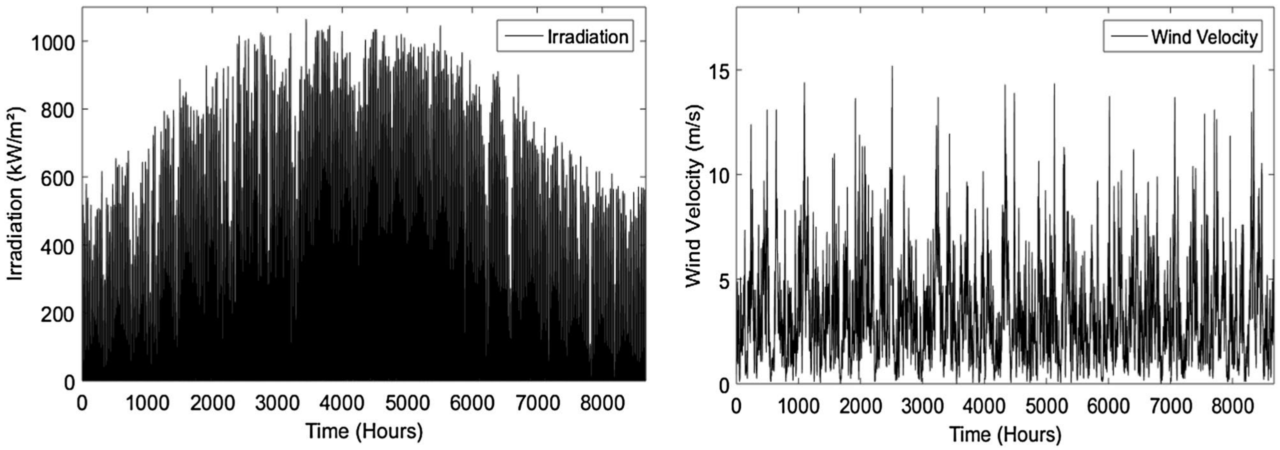

Fig. 5 Hourly solar irradiations and wind speed of Fez City

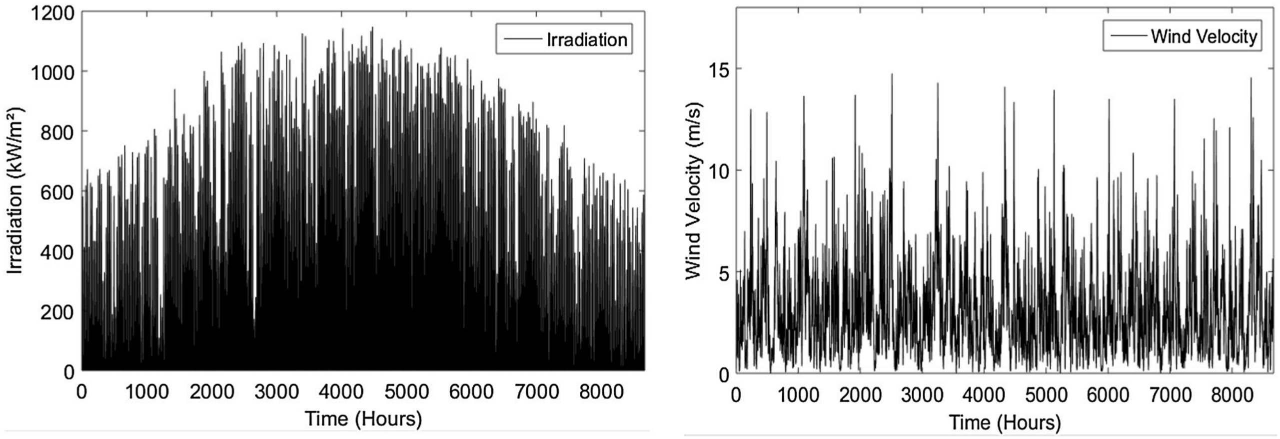

Fig. 6 Hourly solar irradiations and wind speed of Ifran City

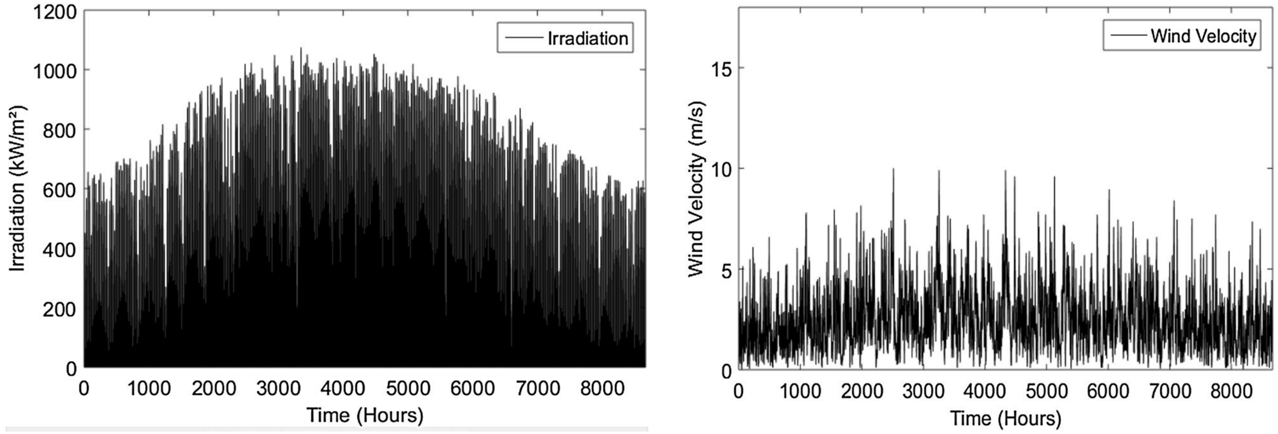

Fig. 7 Hourly solar irradiations and wind speed of Marrakech City

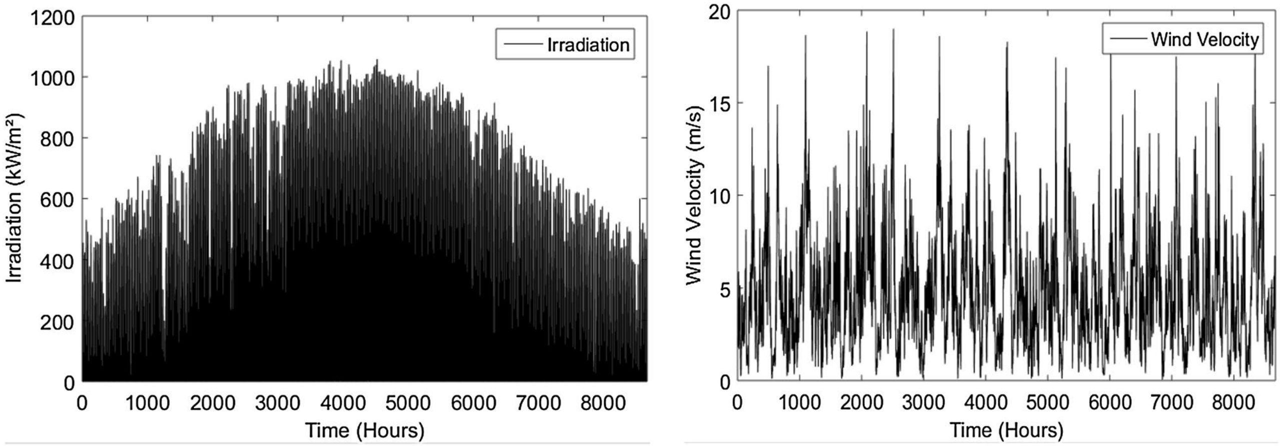

Fig. 8 Hourly solar irradiations and wind speed of Tangier City

Table 2 Annual average values of the referee cities

Average value/ cities	Irradiation “W/m^2”	Temperature “°C”	Wind velocity “m/s”
Agadir	828.36	19.29	3.15
Errachidia	914.46	20.60	2.60
Fez	802.41	17.53	3.37
Ifran	810.03	15.11	3.14
Marrakech	858.74	20.33	2.49
Tangier	823.40	18.15	4.90

technically and economically to decide the appropriate hybrid configuration solution for each location under study and time-series energy output of HS configuration following the six referee cities are presented in (Fig. 9).

5 Result and discussion

5.1 The assumption on the energy demand

According to specifications of the considered industrial prototype, the temperature of bitumen must be maintained at 160 °C. Thus, allowing the quality of bitumen to be conserved and ensuring bitumen viscosity for pumping. Otherwise, by compensating the heat losses of the bitumen tank during a day work, the temperature can be maintained at the desired value, the idea is to calculate the thermal energy of the heat losses, adding other electric consumption (sensors, commutator, regulator, and agitator) during a day to express the behavior of the electric load demand of the LP.

The procedure used determines the heat losses from a vertical-cylindrical storage tank seated on the Ground-like the one in Fig. 9. It includes the effects of

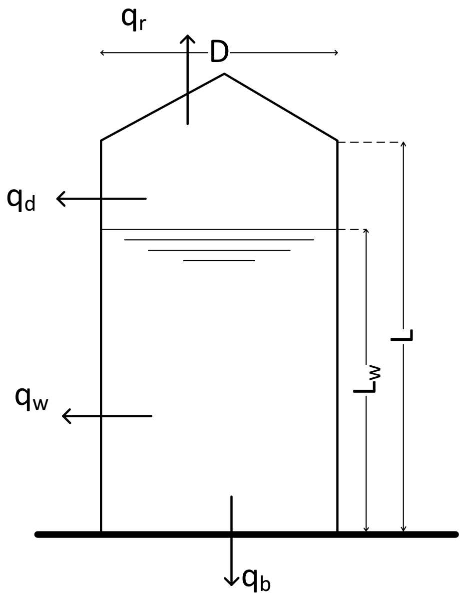

Fig. 9 Typical vertical-cylindrical tank

tank configuration, ambient temperature, wind speed, and temperature variations within the tank and between air and ground. The approach is to develop equations for calculating the heat loss from each of the four surfaces, and get the total heat loss. Thus:

$$\text{For-dry-sidewall} \quad q_d = U_d A_d \left(T_v - T_{amb}\right) \tag{7}$$

$$\text{For-wet-sidewall} \quad q_w = U_w A_w \left(T_L - T_{amb}\right) \tag{8}$$

$$\text{For-tank-bottom} \quad q_b = U_b A_b \left(T_L - T_G\right) \tag{9}$$

$$\text{For-tank-roof} \quad q_r = U_r A_r \left(T_v - T_{amb}\right) \tag{10}$$

$$\text{Total} \quad Q = q_d + q_w + q_b + q_r \tag{11}$$

The electric load demand of the LP combines thermal and electric component. The thermal component expresses the heat losses to be compensated by an electric heater during 1 day period for 1 tonne of the bitumen storage tank. The heat losses during the night are more significant: superior to 0.8 kW/h (influenced by the drop in temperature during the night), compared to those during the day time (inferior to 0.8 kW/h), these losses are equal to an average of 20.6 kWh/day (see Fig. 10).

In another hand, to well handle and to control the properties of the bitumen during the day work, some electric equipment is required such as electric agitator, electric valve, sensors, and controller. These operations can generally be involved between 9 and 17 h which express an energy demand of 0.62 kW/h. While these operations are not required in the other period especially during the night, only sensor and controller are operating. Therefore, the energy demand is equal to 0.2 kW/h. As a result, the electric consumption during the day/night is estimated to 8.9 kWh/day. The total energy request by LP is composed of thermal and electrical part, and it is illustrated in figure bellowing (Fig. 10).

5.2 Time series simulation result

Numerous HS configuration for different size has been investigated in order to reach the power reliability, and the system costs constraints through performing numerous dynamic simulations using a designed TRNSYS/Matlab model for each referee city. Table 3 regroups the optimized HS configuration of each referee cities. The optimized HS configuration depends on several factors, the potential of solar deposit and wind field of the chosen location, the behavior of the electric consumption and the cost of the material. These configurations can ensure the load demand of the LP which is estimated around 10,522.85 kWh/year. The optimized

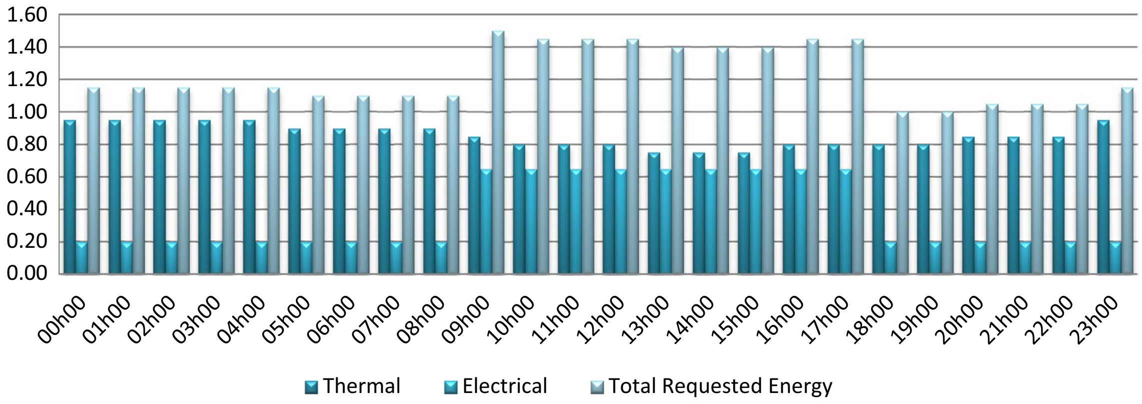

Fig. 10 Electric load demand of the laboratory prototype (kWh vs. h)

Table 3 Optimized HS configuration

Referee city	Installed PV "kWp"	Yearly production "kWh"	Installed wind turbine "kW"	Yearly production "kWh"	Yearly HPWS production "kWh"
Agadir	9	9896.69	1	1695.60	11,592.29
Errachidia	8	9711.43	1	1399.54	11,110.97
Fez	9	9586.66	1	1814.02	11,400.68
Ifran	9	9677.70	1	1690.22	11,367.91
Marrakech	8	9252.42	1	1340.33	10,592.75
Tangier	3	3279.14	3	7912.80	11,191.94

configuration is practically closed for five cities with 1 kWp less in the cities of Marrakech and Errachidia, but for Tangier, which knew in a significant potential of the wind deposit of 4.9 m/s compared to the other cities, the optimal HS is (PV = 3 kWp, WT = 3 kW).

According to the designed HS model, many simulation results are presented concerning the long-term output of hybrid produced energy versus load demand (Fig. 11). The green curve represents the energy output from the HS for each 1-h witch concerns PV Array and Wind Turbine, while the orange curve illustrates the ELD. The excess of energy production is serving to charge the battery bank as first, and then inject the rest in the grid. The batteries can provide the necessary energy to cover a limited period relating to its capacity, the grid can be connected if the HS and batteries have not sufficient energy to power the ELD.

5.3 Economic assessment

The economic study helps to evaluate the investment cost of the HS configuration. Each chosen location required a particular system component (Table 4). For the same ELD, the optimized HS configuration may be differenced according to the chosen referee cities.

The cost of HS installation consists of all service provision relating to several tasks such as providing PV modules and their support, wind turbine and its support, and even the necessary components such as equipment for the protection, disjunction, and signalization.

After analyzing these economic results, it is deductible that each chosen location has a specific configuration requirement as an optimal solution to the sizing problem, and even. This optimal size could be cheaper compared to conventional energy sources (Table 4). The lowest installation cost appears in Tangier with 14,645.00 €, it showed the power of hybridization of various renewable energy sources as a realistic form of electrical power energy.

5.4 Return on investment and impact of the environment

Evaluating a renewable energy project taking into account Return on investment and environment benefice remind necessary, indeed, in this study, payback period (Eq. 12) is evaluated as an essential parameter in return on investment as well as CO_2 reduction (Eq. 13) as environment benefice.

$$PBP = \frac{\ln\left(\frac{C_s i_f}{E_s C_f} + 1\right)}{\ln\left(1 + i_f\right)} \tag{12}$$

Kalogirou [23] proposed a mathematical formula (Eq. 12) to calculate the payback period of the renewable energy project, this equation takes into account, C_s the capital cost of the system (€) which is detailed in Table 4, E_s the total energy saving during a year (kWh) which is detailed in Table 3, C_f Cost of electricity 0.097 (€/kWh) and i_f electricity inflation (8%).

By analyzing the payback period of a susceptible installation of one of the referee cities (Table 5), Tangier present the minimum period of 9.36 years to recover all investment cost of the renewable power plant. In another hand, even if the investment cost is lower (14,845.00 €) compared by other cities, Marrakech presents the longer payback period 9.82 year, it can be explained by lowest total value of energy-saving during a year period (10,592.75 kWh), the hot temperature registered in Marrakech except the winter season influence the PV energy production.

$$Q_{\text{emission mitigated}} = CE_s \tag{13}$$

where C is the emission factor and E_s is the energy saved during the year. The quantity of CO_2 reduction by each configuration is summarized in the following (Table 6).

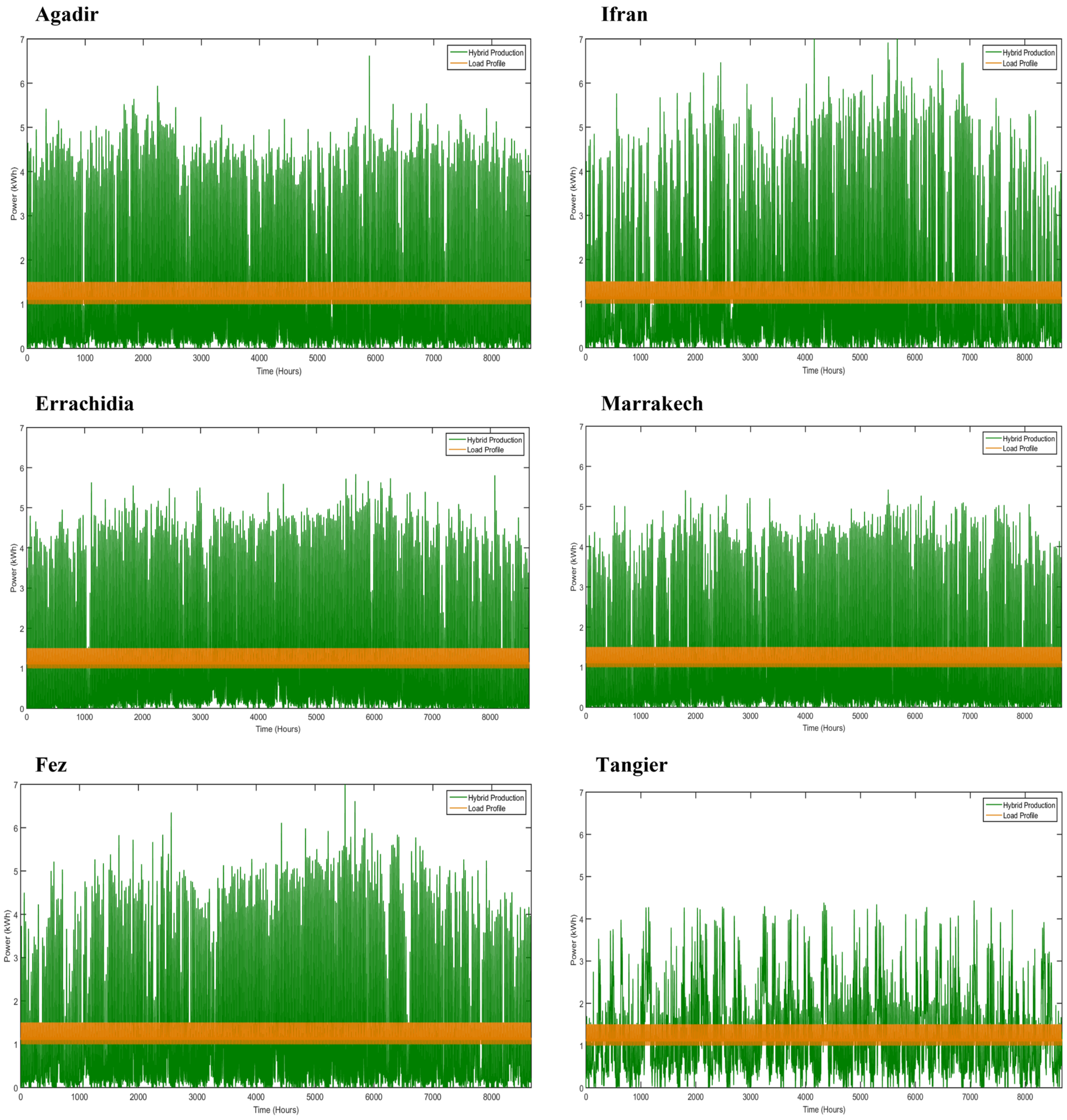

Fig. 11 Energy production and consumption during a year (1-h step)

6 Conclusion

In this paper, the authors are focusing on sizing and integrating HS based of photovoltaic and wind turbine to power load demand of industrial laboratory prototype, The target of this sizing study is providing an optimized configuration (PV and Wind size), which ensures electrical supplying of the laboratory prototype with the cheaper installation cost. Six referee cities have been chosen for potential integration of the laboratory prototype. TRNSYS and Matlab have been used to execute a simulation of energy exchange of the HS configuration of the cities understudies. First of all, a Weather assessment has been released to determine the potential of solar irradiation and wind speed of these cities. As a result, it appears after a data analysis that each location is characterized by a specific weather parameter such as solar radiation, temperature, humidity, and only Tangier has a significant potential of wind speed compared to other cities. The

Table 4 The cost of HS installation [22]

	Agadir	Errachidia	Fez	Ifran	Marrakech	Tangier
Estimated number of 250 Wp PV panel	36.00	32.00	36.00	36.00	32.00	12.00
PV panel unit "250 W"	155.00 €	155.00 €	155.00 €	155.00 €	155.00 €	155.00 €
PV array	5580.00 €	4960.00 €	5580.00 €	5580.00 €	4960.00 €	1860.00 €
Wind turbine	2000.00 €	2000.00 €	2000.00 €	2000.00 €	2000.00 €	5250.00 €
Battery storage of 15kWh	2235.00 €	2235.00 €	2235.00 €	2235.00 €	2235.00 €	2235.00 €
Inverter of 5 kW	2800.00 €	2800.00 €	2800.00 €	2800.00 €	2800.00 €	2800.00 €
Installation and service	3300.00 €	2850.00 €	3300.00 €	3300.00 €	2850.00 €	2500.00 €
Total cost of HS	15,915.00 €	14,845.00 €	15,915.00 €	15,915.00 €	14,845.00 €	14,645.00 €

Table 5 Technical and economics comparison result

	Agadir	Errachidia	Fez	Ifran	Marrakech	Tangier
Cost of HS (€)	15,915.00	14,845.00	15,915.00	15,915.00	14,845.00	14,645.00
Ener saving (kWh)	11,592.29	11,110.97	11,400.68	11,367.91	10,592.75	11,191.94
Ener cost (€/kWh)	0.10	0.10	0.10	0.10	0.10	0.10
Ener inflation (%)	8.50	8.50	8.50	8.50	8.50	8.50
Payback (years)	9.68	9.50	9.79	9.81	9.82	9.36

Table 6 Energy-saving and CO_2 mitigation

	Agadir	Errachidia	Fez	Ifran	Marrakech	Tangier
E_s by PV (kWh)	9896.69	9711.43	9586.66	9677.70	9252.42	3279.14
E_s by wind (kWh)	1695.60	1399.54	1814.02	1690.22	1340.33	7912.80
Total E_s (kWh)	11,592.29	11,110.97	11,400.68	11,367.91	10,592.75	11,191.94
Tones reduced CO_2	8476.42	8124.47	8336.31	8312.35	7745.54	8183.68

potential of solar ration remains approximatively the same except the cities of Tangier, Fez, and Ifran where the solar radiation drops during rainy winter season. Moreover, various dynamic simulations had been performed in order to visualize the long-term electrical production vs load demand of laboratory prototype for a possible HS configuration, after that between these HS configurations, the lowest one has been chosen, and its dynamic simulation of time series energy output of HS is done to assess their power reliability during a year. From these HS configurations sizes, the lowest in cost investment is choosing. Finally, for each selected configuration, an economic evaluation has been made in order to estimate the cost of HS solution integration and even to calculate the return on investment and the environmental impact. After analyzing these economic results, it is deductible that each chosen location has a specific configuration requirement as an optimal solution to the sizing problem, and even. This optimal size could be cheaper compared to conventional energy sources. The lowest installation cost appears in Tangier with (14,645.00 €), it showed the power of hybridization of various renewable energy sources as a realistic form of electrical power energy. A combination of photovoltaic and wind turbine with batteries presented excellent opportunities to integrate these renewable energy sources in such industrial application, and especially when reducing integration prices, and improving the return on investment time.

Acknowledgements The authors would like to thank IRESEN (Moroccan Institute for Research in Solar Energy) for the financial support granted to the project "MCS Bitume", and to all those who have contributed from near and far to the success of this publication.

Compliance with ethical standards

Conflict of interest The authors that the present work (manuscript) does not present any conflict of interest with any institution, organization or person; and that the work was done in our laboratories in consultation with other authors and laboratory directors.

References

1. Sanajaoba S, Fernandez E (2016) Maiden application of Cuckoo Search algorithm for optimal sizing of a remote hybrid

renewable energy system. Renew Energy 96:1–10. https://doi.org/10.1016/j.renene.2016.04.069

2. Anoune K, Bouya M, Ghazouani M, Astito A, Abdellah AB (2016) Hybrid renewable energy system to maximize the electrical power production. Int Renew Sustain Energy Conf 2016:533–539. https://doi.org/10.1109/IRSEC.2016.7983992
3. Siddaiah R, Saini RP (2016) A review on planning, configurations, modeling and optimization techniques of hybrid renewable energy systems for off grid applications. Renew Sustain Energy Rev 58:376–396. https://doi.org/10.1016/j.rser.2015.12.281
4. Ismail MS, Moghavvemi M, Mahlia TMI, Muttaqi KM, Moghavvemi S (2015) Effective utilization of excess energy in standalone hybrid renewable energy systems for improving comfort ability and reducing cost of energy: a review and analysis. Renew Sustain Energy Rev 42:726–734. https://doi.org/10.1016/j.rser.2014.10.051
5. Anoune K, Bouya M, Astito A, Abdellah AB (2018) Sizing methods and optimization techniques for PV-wind based hybrid renewable energy system: a review. Renew Sustain Energy Rev 93:652–673. https://doi.org/10.1016/j.rser.2018.05.032
6. Tina G, Gagliano S (2011) Probabilistic analysis of weather data for a hybrid solar/wind energy system. Int J Energy Res 35:221–232. https://doi.org/10.1002/er.1686
7. Yang HX, Lu L, Burnett J (2003) Weather data and probability analysis of hybrid photovoltaic-wind power generation systems in Hong Kong. Renew Energy 28:1813–1824. https://doi.org/10.1016/S0960-1481(03)00015-6
8. Anoune K, Laknizi A, Bouya M, Astito A, Ben Abdellah A (2018) Sizing a PV-wind based hybrid system using deterministic approach. Energy Convers Manag 169:137–148. https://doi.org/10.1016/j.enconman.2018.05.034
9. TRNSYS. http://sel.me.wisc.edu/trnsys/. Accessed May 2019
10. Quesada B, Sánchez C, Cañada J, Royo R, Payá J (2011) Experimental results and simulation with TRNSYS of a 7.2 kWp grid-connected photovoltaic system. Appl Energy 88:1772–1783. https://doi.org/10.1016/j.apenergy.2010.12.011
11. Mondol JD, Yohanis YG, Norton B (2009) Optimising the economic viability of grid-connected photovoltaic systems. Appl Energy 86:985–999. https://doi.org/10.1016/j.apenergy.2008.10.001
12. Panayiotou G, Kalogirou S, Tassou S (2012) Design and simulation of a PV and a PV-Wind standalone energy system to power a household application. Renew Energy 37:355–363. https://doi.org/10.1016/j.renene.2011.06.038
13. Bakic V, Pezo M, Jovanovic M, Turanjanin V, Vucicevic B (2012) Technical analysis of photovoltaic/wind systems with hydrogen storage. Therm Sci 16:865–875. https://doi.org/10.2298/TSCI120306132B
14. Bakić V, Pezo M, Stevanović Ž, Živković M, Grubor B (2012) Dynamical simulation of PV/Wind hybrid energy conversion system. Energy 45:324–328. https://doi.org/10.1016/j.energy.2011.11.063
15. El Azzaoui M, Mahmoudi H, Boudaraia K (2016) Backstepping control of wind and photovoltaic hybrid renewable energy system. Int J Power Electron Drive Syst 7:677–686
16. Belfkira R, Zhang L, Barakat G (2011) Optimal sizing study of hybrid wind/PV/diesel power generation unit. Sol Energy 85:100–110. https://doi.org/10.1016/J.SOLENER.2010.10.018
17. El Kafazi I, Bannari R (2018) Optimization strategy considering energy storage systems to minimize energy production cost of power systems. Int J Renew ENERGY Res 8:2199–2209
18. Zhou W, Lou C, Li Z, Lu L, Yang H (2010) Current status of research on optimum sizing of stand-alone hybrid solar-wind power generation systems. Appl Energy 87:380–389. https://doi.org/10.1016/j.apenergy.2009.08.012
19. ADEREE. National agency for the development of renewable energy and energy efficiency. http://www.amee.ma/index.php/en/ . Accessed May 2019
20. Anoune K, Bouya M, Astito A, Abdellah AB (2018) Design and sizing of a hybrid PV-wind-grid system for electric vehicle charging platform. In: MATEC web conference, vol 200, p 00008. https://doi.org/10.1051/matecconf/201820000008
21. Meteonorm. http://www.meteonorm.com/. Accessed May 2019
22. Amine A. Voltrom energy. http://www.voltra.ma/installation/index.php. Accessed May 2019
23. Kalogirou SA (2013) Solar energy engineering: processes and systems. Academic Press, Cambridge