Optimal sizing of Hybrid Renewable Energy System case study Morocco

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Abstract: - The objective of this work is to propose an optimization model to determine which configuration of Renewable Energy Systems (RES) is suitable (Wind Turbine - Battery, Panel photovoltaic - Battery or Wind Turbine - Panel photovoltaic - Battery) to power remote areas autonomously with well- defined levels of reliability and the most optimal economic costs. In this regard, and to validate the proposed model we studied four specific location in Morocco, based on the real weather data (wind and temperature) and the various technical and economic data to determine the optimal model (suitable generator). According to the results of optimization and simulation algorithm, it is concluded that the hybrid systems including WT and PV with battery backups are less expensive compared to the other, Moreover, we found that among non-hybrid systems, in all regions studied except Zagora WTs are more economical than PVs.

Key-Words: - Hybrid Renewable Energy system, Photovoltaic, Wind turbine, Optimization

1 Introduction

The application of wind and photovoltaic energy in electric power systems is growing rapidly due to enhanced public concerns to adverse environmental impacts and escalation in energy costs associated with the use of conventional energy sources. Electric power from wind or photovoltaic energy is quite different from that of conventional resources. The fundamental difference is that the wind or solar power is intermittent and uncertain. Therefore, it affects the reliability of power system in a different manner from that of the conventional generators.

The economic advantage is another crucial issue to consider in the production of electricity from renewable energy is on the grid. In sufficient reliability of power supply costs ultimately customers much more than sufficient reliability [1]. Given the relationship between reliability and economy, it is important to determine the optimal level of reliability to the investment on improving the reliability of the system is more cost effective to reduce damage costs to the customer due to power interruptions. Several studies have examined the empirical relationship between reliability and economy. For example, Ghajar and Billinton [2] evaluated the value of the reliability of the power system by a consistent set of data cost of interruption. Kleyner and Sandborn [3] incorporated several factors related to reliability, in a global model of probabilistic cost. Georgilakis and Katsigiannis [4] implemented a total cost of reliability and value analysis for small autonomous power systems. Hamdanetal [5] used the modification of charging technology to assess the impact of the implementation of the policy on energy production, the overall cost, commercial losses and reliability. Röpke [6] compared the security of supply value with its supply costs.

The design of autonomous hybrid renewable energy systems, based on wind and solar with backup system based on battery is a crucial problem. In this context, a hybrid system, composed by several components, where each can take various sizes, there are many possible combinations .For optimizing characteristics of such a hybrid renewable energy system, first we have to generate different systems with different sizes of components. Then, their dynamic behaviors should be simulated. Finally, regarding the average energy costs, among from the investigated hybrid systems, the most economical one is selected. In order to render the obtained results applicable, the Restrictions and the requirements of both supply and demand sides must be satisfied at every moment (calculated hourly in this study) and the relationships between the components of system must be taken into consideration. To assure technical feasibility of the systems, it is required to simulate their hourly operation in various conditions. This is achieved by developing an optimization method that have simulate by java. The objective of this study is to study techno-economical feasibility of a stand-alone hybrid PV - WT - BAT system for a remote area in the four regions in Morocco with a steady demand of 10MW. The meteorological data of wind and solar radiation in these areas (Tarfaya, Essaoira, Zagora and Midelt) hour by hour is collected for a year analysis period,, along with the average temperature which is necessary for the calculation of the efficiency of photovoltaic systems. The Paper is organized as follows: Section 2 discusses System Structure of System and mathematical model of hybrid system Studied. Section 3 describes the proposed optimization model; simulations run, with Java language, are presented in Section 4. Conclusion is presented in section 5.

2 System structure, modeling of HREs

2.1 System structure.

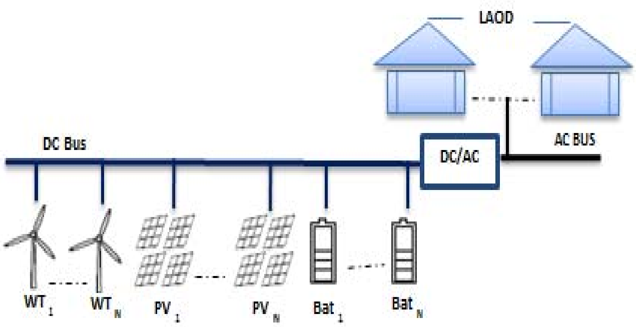

Fig. 1 - Schematic diagram of the Hybrid Renewable Energy system (HREs).

2.2 Wind Turbine (WT) and Panel photovoltaic (PV) models

WT and PV represent the control units of the wind turbine and the photovoltaic panel, respectively. As the wind turbine and the photovoltaic panel operate at a low levelized cost, in the principle of maximizing the use of renewable energy,

The output power characteristics of the wind generator can be expressed as [7]:

$$\begin{cases} P_{WT}(t) = P_n \dfrac{V^k(t) - V_d^k(t)}{V_n^k - V_d^k} & V_d < V(t) < V_n \\ P_{WT}(t) = P_n & V_n < V(t) < V_c \\ P_{WT}(t) = 0 & elsewhere \end{cases} \tag{1}$$

The output powers of the wind turbine in function of the wind speed are given by Equation (1). Where $V(t)$, V_d , V_n and V_c respectively represent the instantaneous wind, start, nominal and cut off speed. P_n is the aerogenerator nominal power; k is the form factor (without any dimension characterizing the Weibull distribution dissymmetry). The definition and the values of Aerogenerator parameters used in the simulation are given in Table 1.

TABLE 1- PRESENTS THE CORRESPONDING USED IN THIS PAPER

WT data	
Capital cost $	2000 $/KW
O&M Cost	2% of the capital
Cost life	25 years
Cut-in speed (m/s)	4
Rate wind speed (m/s)	12
Rate power (MW)	2.5
Hub height (m)	90

The output power model of the PV module is determined by solar radiation and environ-mental temperature [10], as follows:

$$P_{PV}(t) = A_{PV} . G(t) . \eta_{PV}(t) . \eta_{inv} \tag{2}$$

Where A_{PV} (m2) is the area of the PV panel exposed to solar radiation, $G(t)$ (W/m2) is the value of solar radiation, $\eta_{PV}(t)$ is the energy conversion efficiency of the PV module, and η_{inv} is the conversion efficiency of the inverter. $\eta_{PV}(t)$ is influenced by environmental temperature:

$$\eta_{PV}(t) = \eta_{ref} \cdot \left[1 - \beta . \left(T_C(t) - T_{cref}\right)\right] . A_{PV} \cdot G(t) . \eta_{inv} \tag{3}$$

$$T_C(t) - T_{ambiant} = \frac{T_{rated}}{800} . G(t) \tag{4}$$

η_{ref} is the reference energy conversion efficiency of the PV module under a standard temperature, β is the influence coefficient of the temperature for energy conversion efficiency, $T_c(t)$ is the temperature of the PV module at t, and T_{cref} is the reference standard temperature of the PV module, $T_{ambiant}$ is the ambient temperature, and T_{rated} is the rated temperature of the PV module. The definition and the values of photovoltaic panel parameters used in the simulation are given in Table II.

The output constraints of equipment can be expressed as:

$$0 \le P_{WT}(t) \le P_{WT}^{max} \quad (5)$$

$$0 \le P_{PV}(t) \le P_{PV}^{max} \quad (6)$$

Where $P_{WT}^{\max}$ and $P_{PV}^{\max}$ are the upper power output limit of wind turbine and the photovoltaic panel.

TABLE 2- USED DATA FOR SIMULATION OF CRYSTALLINE PVS.

PV data	
Rated module efficiency (ηr)	15 %
Temperature coefficient of efficiency (β)	0.0045
Normal operation cell temperature(NOCT)	55 °c
Temperature of rated efficiency (Tr)	25 °c
Solar radiation in NOCT(INOCT)	88 W/m2
Life	25 years

2.3 Battery model

2.3.1 State of charge and discharge.

Energy storage system is necessary because the generation of renewable energy is inherently intermittent. The stored energy can supply the load when there is a lack of electricity, and store surplus power when the generated power exceeds the load. State of charge is basically the opposite of depth of discharge. State of charge is how much power is left in the battery. Depth of discharge is how much power was used from the battery. A battery at 70% state of charge is at 30% depth of discharge. The state of charge at the moment t can be obtained using the following equation [7]:

$$\text{Charge:} \quad \mathrm{soc}(t) = soc(t-1)(1-\sigma) + \frac{P_{Ch}\,\Delta t\,\eta_{Ch}}{\mathrm{E}_{Bat}} \quad (7)$$

$$\text{Discharge:} \quad \mathrm{soc}(t) = soc(t-1)(1-\sigma) + \frac{P_{Dis}\,\Delta t}{E_{Bat}\,\eta_{Dis}}\Delta\,\mathrm{t} \quad (8)$$

Where $soc(t)$ is the battery state of charge after t ; σ is the self-discharge ; P_{Ch} and P_{Dis} are the charge and discharge powers of the battery in t, respectively ; Δt : is the length of t, η_{Ch} and η_{Dic} are the charge and discharge efficiencies of the battery, respectively and E_{Bat} is the maximum capacity of the battery.

The battery state of charge must be kept in a reasonable range:

$$\mathrm{SOC}_{min} \le \mathrm{SOC}(t) \le \mathrm{SOC}_{max} \quad (9)$$

Where SOC_{min} and $SOC_{\max}$ are minimum and maximum of battery capacity.

2.3.2 Life cycle of a battery

The modeling of the life cycle of a battery will affect the calculation of total system cost. The present study adopts the method [7], which estimates cycles to failure of batteries by calculating the number of charge and discharge within an interval of several discharge depths . The calculation method is as formula 10:

$$Life_{bat} = \frac{\eta_T\,\Delta t}{8760 \times \sum_{t=1}^{\eta_T}\sum_{m=1}^{M}\frac{N_m(t)}{CF_m}} \quad (10)$$

Where $Life_{bat}$ is the failure cycle of the battery (year); Δt is the length of the statistical cycle length (h); η_T is the total number of time intervals of the simulation; $N_m(t)$ is the times of charge and discharge of the battery; CF_m is the total cycles of charge and discharge. Thus, the usage cycle of the battery CF_{Bat} is not greater than its life cycle CTF_{Bat} :

$$CF_{Bat} \le CTF_{Bat} = \min\{Life_{Bat}, Life_{float}\} \quad (11)$$

$Life_{float}$ in the equation is the float cycle of the battery which is provided by the manufacturer.

The specifications for a typical battery are presented in Table 3.

3 System optimization

Due to stochastic and intermittent characteristics of renewable energy sources, evaluating the reliability of these systems has become questionable. For this, the economic study on the type of suitable source is a critical issue to consider in the production of electricity from renewable energy on the grid. Given the relationship between reliability and economic study, it is important to determine the optimal system to which the investment on improving system reliability is more profitable. In this study, the optimization of renewable energy system (RES) components is explained through introducing the balancing constraints and the objective function. For this purpose, a reliability index should be defined and surveyed during the simulation. Calculation of the system reliability can be done using different indexes [8, 9, and 10]. In the present study the Loss of Energy Expectation index, LOEE, and the Loss of Load Expectation index, LOLE, are used. The former index calculates the cost of energy short age while the latter is used to identify and select the acceptable combinations. These indexes are defined in equations (12) and (13).

TABLE III- USED DATA FOR SIMULATION OF BATTERY.

Battery data	
Maximum charge depth (%)	70
Rated capacity (MW h)	3
Maximum power (MW)	1.5
Charge/discharge efficiency (%)	0.9/0.95
Capital cost	130 $ / KWh
Life	5 years
Scarp salvage value of capital cost	10%
BRE	80%
BDOD	75%

$$LOEE = \frac{\sum_t \varphi(t) \times LOE_t}{\sum_t E_t} \quad (12)$$

$$\varphi(t) = \begin{cases} 1 \; if \; P_{RES}(t) < P_{Load}(t) \\ 0 \end{cases}$$

Or

$$LOLE = \frac{\sum_t LOL_t}{8760} \quad (13)$$

Where LOE_t is the amont loss of energy, E_t is the demand of energy in step t and LOL_t is the amount loss of charge.

3.1 The constraints and the objective function

The constraints and the objective (cost) function of our problem are given as follows.
The constraints outfits in this studies
In this study, several constraints were used in different parts of the study. The most significant constraints in this study are: to ensure the balance between supply and demand of energy at every moment and increase the life of batteries equation (14) and (9). The side of the energy supply contains the energy produced by renewable energy sources and batteries as the energy application contains the energy demand in research centers, the surplus energy stored in battery (SESB).

$$P_{PV} + P_{WT} + P_{BAT} + LOE = Energy\ Demand + SESB \quad (14)$$

Another constraint in this study is the reliability of the systems. To this end, LOLE should be less than 2%.

$$LOLE \leq 2\% \quad (15)$$

3.2 The objective function:

To minimize the total energy costs, the optimization algorithm searches the possible solution spaces, specified by the constraints, and selects the combination with the lowest cost.
The objective function consists of investment costs, O&M costs, all replacement costs and unmet demand costs excluding scrap salvage value. Other used data is presented in Table 4. The annual real interest rate has an important role affecting the results, which is related to the nominal interest rate by equation (16)

$$i = \frac{i_0 - f}{1 - f} \quad (16)$$

Where i is the real interest rate, i0 is the nominal interest rate (the rate at which the banking system could offer a loan), and f is the annual inflation rate. In Morocco, the annual i0 is about 25% (currently there are opportunities for very low-interest loans for RES) and f is around 21%, leading to a real interest rate of 5.06%. The well Libor1 has dropped considerably in the recent decade, regarding the simultaneous economic conditions of the country, we assumed to equal 5%.

TABLE 4- USED DATA IN OBJECTIVE FUNCTION.

Used data in objective function	
The annual real interest rate	5 % per year
Cost of energy shortage	5,6 $/kWh

Given the information provided, the goal of this optimization problem is minimized The cost of energy production over the long term it is defined as being the ratio of the sum of capital expenditures, operating and sum of net electricity production, the formula is:

$$Min\ COE = \frac{(CRF \times SII) + O\ \&\ MCost - (USFW \times SV) + (Cost\ LOE \times Sum(LOE))}{365 \times 24 \times Demand\ Load - Sum(LOE)} \quad (17)$$

Where SII is the system initial investment, CRF is the Capital Recovery Factor and USFW is the "Uniform Series of a Future Worth".
Figure.2 shows the steps of our iterative algorithm that searches the possible solution space for an optimal solution. The simulation of a sample system behavior is presented in Figure. 3.

Step 1: initialization (t=1)
Step 2: While (1<= t <= (365*24h=8760 h)
Calculate PWT and PPV.
Calculate PRE= PWT + PPV.
If (PRE >= PLoad)
If (PRE >= PLoad)
If (SOC >= SOCmax) Charge battery and calculate new SOC.
If not Go to step 2.
If not (PRE = PLoad) Go to Step 2.
If not
If SOC > SOCmin Go to step 2.
If not Recalculate LOE and LOL
End While

Fig.2 - Optimization algorithm.

Step 1: initialization
Step 2: Find the WT capacity with a loop increasingly
Step 3: Searching PV capacity with decreasing loop
Step 4: Searching battery capacity with decreasing loop
Step 5: Simulation system (figure. 2)
Step 6: if (LOLE < 0.02) Calculate of COE (cost of energy equation.17)
If (COE > COS previous cost of system)
Select this combination as the optimal system
If not
If (there's another combination unstudied)
Go to step 4
If not
Select this combination as the final optimal system
If not Go to step 3.

Fig.3 - Step of simulation.

4 Results and analysis

The simulation results are given for three modes, a hybrid system (WT- PV- Battery), a system without WT (PV– Battery), and a system without PV (WT - Battery). The obtained results indicate that the optimum system (corresponds to a minimum cost of energy) is the hybrid mode in all regions except Zagora. Figure.3 present the optimization results of the four studied regions for all modes, Comparing the cost of the energy (COE) obtained for the three modes in all regions shows that the hybrid system corresponding to the minimum cost in the all studied regions, except Zagora whose photovoltaic system has the minimum cost. The proposed model takes into account the life span of Battery.
To evaluate the system reliability, the results of the reliability indices (LOEE) are displayed in Figure. 4. All the indicator values of reliability show that the hybrid mode in all regions is inferior to other modes in terms of system reliability. Comparing the loss of energy expectation index (LOEE) obtained for the two other modes in all regions we shows that WT system corresponding to the minimum LOEE in the all studied regions compared to PV system ,except Zagora

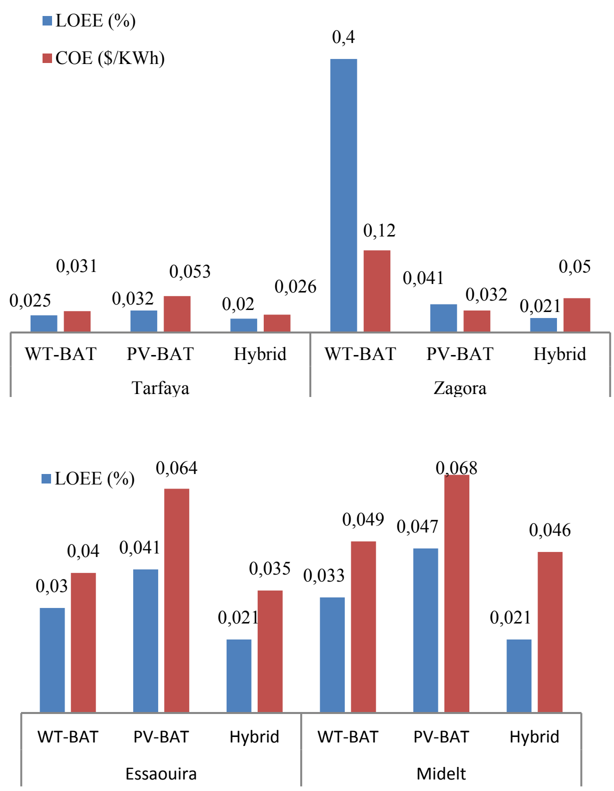

Fig.4 - The results of optimization ($/KWh).

Additionally, Figure. 5 present behavior of the optimum hybrid System for four sample days in Midelt. In all the four pictures, during the day time, WT and PV systems meet the energy demand and charge the battery bank. During the night time, WT system and battery bank help system to provide the energy demand.
Figure. 6 shows the hourly energy generation of PV and WT systems as components of the optimal hybrid system in Midelt for four sample days during

summer. As expected, generated power by WT system is more regular than generated power by PV system. On the other hand, energy generation in WT system is continues at day time and night time but PV system only generates at day time. Then use of these systems together can help to reduce COE and increase the reliability.

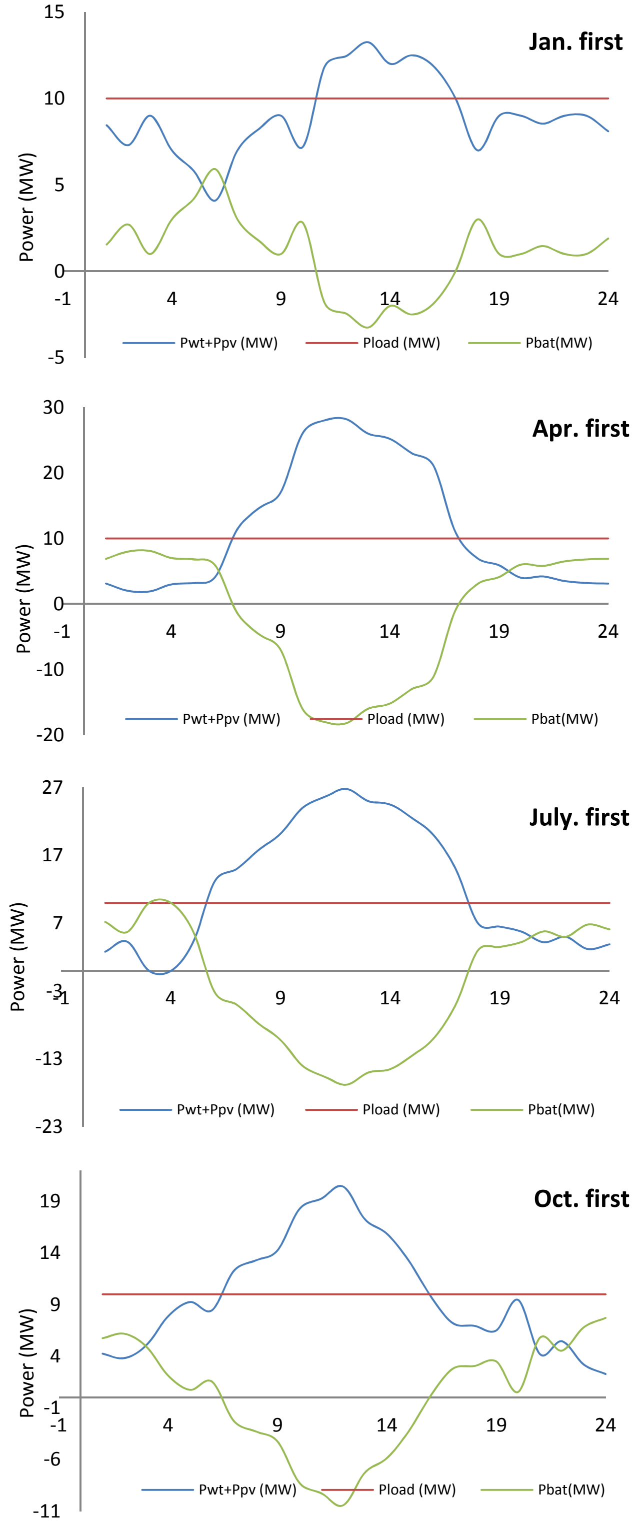

Fig.5 - The simulation results of hybrid system for four days.

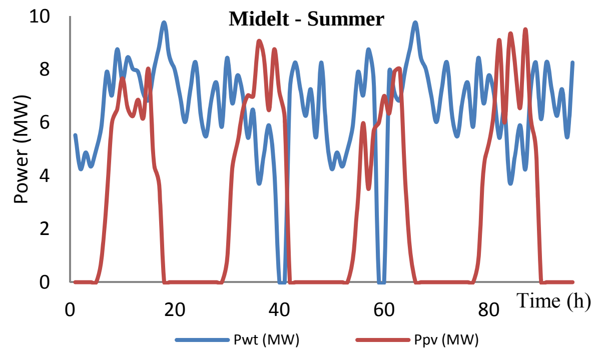

Fig.6 - The simulation of WT and PV in Midelt.

In order to make a coherent assessment of the economy and reliability, it is necessary to assess the economic value to achieve a specified level of system reliability. The COE (cost of energy) is used to compare the total expenditure under all anticipated revenues. Indeed, and according to the results obtained we can conclude that, in many parts of the hybrid system is more economical than other systems. Table 5 summarizes the results of optimization of the various modes in the study areas.

According to the calculation results in Table 5, the energy management system proposed in the paper can reduce operating costs and amortization of the system. This part of the cost is used to prolong the life of the batteries based on the optimization of the charging and discharging of the batteries.

TABLE 5 - OPTIMIZATION RESULTS.

Region	PV capacity (MW)	WT capacity (MW)	Battery capacity (MW)	LOEE (%)	COE ($/KWh)
WT system					
Zagora	0	36	1296	4	0.12
Tarfaya	0	15	194.4	2,5	0.03
Essaouira	0	21	496.8	3,3	0.04
Midelt	0	24	648	3,2	0.05
PV system					
Zagora	147.8	0	237	4,1	0.032
Tarfaya	179.9	0	864	3,2	0.053
Essaouira	184.42	0	1101.6	4,1	0.064
Midelt	292.3	0	1123.2	4,6	0.068
Hybrid system					
Zagora	135	3	216	2,12	0.050
Tarfaya	74.97	15	96.12	2	0.022
Essaouira	147	175	237.6	2,102	0.035
Midelt	153.38	24	540	2,117	0.047

5 Conclusion

The present research studied optimization of hybrid renewable energy systems (HRES), where WT and PV functioned as generation systems and battery banks for storage. A computer program was used to simulate dynamic behavior of these components. By this program, the different combinations of these components were taken into consideration, so that the system with the minimum costs and the acceptable reliability would be selected as the best combination for HRES. The simulation and optimization were carried out for Tarfaya, Essaouira, Zagora and Midelt, and it was shown that among different systems, the hybrid ones are more economical for an off-grid usage, and among the regions Tarfaya has the best COE equal to 0.026 $/KWh, Essaouira are the next regions. According to the results, hybrid systems are made of combinations of WT and PV systems in which the batteries are employed to store surplus energy mostly for night time. In the non-hybrid systems, especially in PV systems, the capacity of battery bank heavily increases and O&M costs of battery banks in remote area will be a serious problem. Among the non-hybrid systems, due to the appropriate potential and relatively regular nature of the wind, less capacity is required for both WT modules and battery banks, compared to photovoltaic. As a result, WT systems are more economical than PV systems in the studied regions of Morocco except Zagora. Nevertheless, the PVs can be used as a complementary system, covering the weaknesses of WT systems, reducing costs of the produced energy.

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