Deep Analysis on Sizing a Renewable Energy System at 12 Locations in Morocco Using Particle Swarm Optimization

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Abstract- This study provides an in-depth analysis of the optimal sizing of a renewable energy system, consisting of both photovoltaic (PV) and wind energy, for twelve cities located throughout the Kingdom of Morocco. The objective of the study is to determine the most appropriate combination of wind and PV-based renewable energy systems with a capacity under 20 kWp that can achieve an annual output greater than 5000 kWh/year in each of the twelve cities. To attain this objective, the study employs the particle swarm optimization algorithm and the levelized cost of energy (LCOE) as the objective function to be minimized. The LCOE is calculated as the average cost of generating each kilowatt-hour of energy over the lifetime of the system, taking into account the initial capital cost, maintenance costs, operating costs, annual output, discount rate, and degradation rate. Three different scenarios were considered in this study. As a matter of fact, the first scenario includes the case where no excess energy is sent to the grid. In the second scenario, only 10% of excess energy is sent to the grid. In the last scenario, any excess energy available is sent to the grid. The results of the analysis show that integrating excess energy into the grid has a positive impact on the LCOE, with the lowest value (0.08$/kWh) achieved in Laayoune and Dakhla in the third scenario where all the excess of energy is sent to the grid.

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Keywords RE Renewable energy, LCOE Levelized cost of electricity, photovoltaic, Particle Swarm Optimization.

1. Introduction

Due to their environmental and social benefits, renewable energy (RE) sources have known a significant global rise over the past few years all over the world [1, 2, 3]. On the other hand, Morocco enjoys a high level of solar and wind energy potential. In order to benefit from this characteristic, the Moroccan government intends to have 52% of its energy mix from RE sources by 2030 [4, 5] In fact, the installed capacity of solar and wind energy rises between 2018 and 2020 from 700 MW to 2000 MW and 1215 MW to 2000 MW, respectively [6].

In order to promote the use of RE, the Moroccan government released a new Draft Law No. 82.21 regarding the self-production of electrical energy. Users could generate electricity for personal use and inject the excess into the grid under this law [7]. In the same context, the government has also set up different sites that could receive RE projects [8].

The Intermittent character of RE and the characteristic of the site (weather and climatic conditions), dictate the use of hybrid systems. Photovoltaic (PV) and wind energies are the most suitable combination [9, 10, 11]. As mentioned above, the significant potential of ER in Morocco favours the deployment of these technologies in standalone and grid-connected systems due to the gradual decline in the cost of wind turbines and solar PV, as well as the enormous improvements in technological development. This capacity has to be matched with an economic evaluation of hybrid PV-wind systems [12, 13, 14]. In this context, The Net Present Value (NPV), Internal Rate of Return (IRR), Discounted Payback Time (DPBT), and Levelized Cost of Electricity (LCOE) are often the employed techniques for economic analysis of hybrid renewable energy systems (HRES). Nevertheless, when assessing different technologies with various scales of operation, investment, or operating time, the LCOE method is most frequently used.

In fact, the LCOE is a metric in $/kWh for analysing the economics of power production systems that have been developed and widely accepted [1]. The major inputs required to calculate LCOE are capital cost, operations and maintenance cost, energy performance, degradation rate, and discount rates.

Researchers, investors, project managers, and policymakers are using LCOE to make techno-economic analysis for RE systems [15]. Some researchers have adapted basic LCOE methods to improve their accuracy, especially for RE systems [1], such as Stefan Reichel stein and Anshuman Sahoo by proposing a correction factor (Co-Variation coefficient) to cover intermittency which is usually ignored in life-cycle for PV and wind [15]. Also A. Vazquez a, G. Iglesias have designed a new tool in order to assess the LCOE by taking into account capital costs, operating costs, and technological specifications which vary by location [16].

The LCOE employed in this work will be the same as used by Jia Liu and Meng Wang to optimize the techno-economic design of integrated renewable energy applications for high-rise residential buildings in Hong Kong[17]. Then, it will be optimized by a modern intelligent optimization algorithm. This latter should be powerful and designed to solve complex and multi-objective problems [18].

The majority of sizing studies for hybrid systems based on RE between 2011 and 2021 are using HOMER, genetic algorithms (GA) and particle swarm optimization (PSO) [19]. Wei ET al found that the PSO algorithm gives better results with a high convergence than an analytic algorithm for sizing calculations [20]. Also, in a comparative analysis of sizing RE using HOMER PRO and three meta-heuristic algorithms which are Artificial Bee Colony (ABC), GA, and PSO, among this methods the PSO algorithm was found to be the best performing in terms of results and convergence by achieving the lowest LCOE (0.162 $/kWh))[20].

PSO is one of the best techniques for a system's optimal search, as compared to the GA, which is better suited for complicated problems and has a slow convergence rate [21, 22].

PSO characterized by their highest level of efficiency and excellent calculation accuracy [18, 23, 24] In fact, PSO algorithm has a good convergence speed compared to other algorithms like Gray wolf optimization (GWO), Whale optimization algorithm (WOA), Sine–cosine algorithm (SCA), PSO achieved competitive results [21, 25].

Many studies about RE sizing use the PSO algorithm to find the optimal LCOE. For example, Omar et al. optimize a RE system based on wind, tidal, PV, and batteries to supply a remote area in Bretagne, France; the LCOE achieves 0.09 $/kWh using only wind energy [26]. Also, Poonam Singh et al compare traditional solve methods and PSO using LCOE as the objective function to size PV/wind/diesel generator/battery system. Including all types of studied generations, the lowest LCOE was 0.24 $/kWh using PSO [27].

Yekini et al. compare various scenarios using various algorithms in the Nigerian state of Nasarawa. By using the PSO algorithm, they found that the lowest LCOE is 0.145 $/kW for the system composed of wind-PV-battery bank [9]. By evaluating several objective functions and finding the best possible scenario, Ali et al. in Iran optimized a RE system based on solar and geothermal energy. They discovered that when using energy efficiency and LCOE as objective functions to be minimized by PSO, LCOE reached 0.350 $/kW [28].

In order to avoid under sizing or oversizing of RE systems, the main objective of this work is to determine the appropriate type and size of a RE system less than 20 kW based on wind and PV energy with an annual output superior than 5000 kWh/year, in various locations throughout the Kingdom of Morocco. In order to achieve this goal, the PSO algorithm is used. As mentioned above, it is well known by its ability to solve complex and multi-objective problems with a high-speed convergence and a good accuracy compared to other algorithms. For the analysis and comparison purposes, LCOE is used as an objective function. Moreover, the impact of connecting the RE system to the grid on the LCOE is evaluated. This assessment will be done by discussing three scenarios. The first scenario discusses the case where there is no sell back. In the second scenario, only 10% of the energy excess is supplied to the grid, and in the third scenario, all the surplus of the production is supplied to the grid.

2. Methodology

2.1 LCOE

As mentioned above, the LCOE is a standard metric used to assess the economics of power production systems. In more detail, it represents the present value of total costs (fixed and variable)[29, 30]. The major inputs required to calculate LCOE are resumed in table 1 [1].

The mathematical equation of the LCOE is formulated by equation (1).

$$\mathrm{LCOE} = \frac{\mathrm{Pcosts}}{\sum_{n=1}^{n=N}\left(\frac{\mathrm{E}\times(1-\delta)^{n-1}}{(1+i)^{n}}\right)} \tag{1}$$

where Pcosts is defined in equation (2),

$$\mathrm{Pcosts} = C_{ini} + \sum_{j=1}^{j=J}\left(\frac{C_{rep}}{(1+i)}\right)^{j-N} + \sum_{n=1}^{n=N}\frac{C_{ini}\times f_{mai}}{(1+i)^{n}} \tag{2}$$

C_{ini} is the initial cost, C_{rep} is the replacement cost, J is the total number of replacements during lifetime, j is number of replacement of a specific compenents, the total annual output E is defined in equation (3).

$$\mathrm{E}=\mathrm{Epv}+\mathrm{Ew} \tag{3}$$

Where Epv and Ew represents respectively, the annual energy generated by PV and wind energy system

The value of the LCOE parameters differs from one country to another. Table 2 summarizes information about the RE components used in our study [12]. In this paper, the LCOE optimization is done by using the PSO algorithm. The next paragraph discusses the modelling of the objective function which is in our case the LCOE.

2.2 Modelling

In this study PV and wind power capacities are considered as 'x' and 'y' variables respectively. In order to build our objective function which is the LCOE, all parameters (capital cost 'C', operations and maintenance cost 'O', annual output energy 'E', converter cost 'Cconv') are modelled using 'x' and 'y' variables as shown in table 3, where $C_{PV} = 0.6 \frac{\$}{W}$, $C_W =$

0.7 \$/Wp are the costs of 1Wp of PV power and wind power, respectively [25, 9]. e_{PV} and e_W represents respectively, the predicted annual output produced from 1Wp of the PV system and 1 Wp of the wind energy system in the studied sites. It should be noted that the initial data will be extracted by HOMER PRO Software (Hybrid Optimization Model For Electric Renewables) which is developed by the National Renewable Energy Laboratory (NREL) of the United States [32].

The main objective is to extract the best sizing, which will be the values of 'x' and 'y' that give the lowest LCOE.

Table 1. major inputs used in LCOE calculation

Inputs	designation	Explanation
Capital cost	C	Present value of the all-investment costs.
Operations and Maintenance cost	O	Refers to the annual operating cost for the operation and maintenance of the installed system.
Energy performance	E	Total generated energy in one year.
Degradation rate	δ	The degradation rate is defined to show the decrease of plant efficiency with increasing age.
Discount rate	i	The discount rate is used to evaluate the time value of money.
Lifetime	N	Project lifetime is the total time that an energy system is available to produce electricity.
Maintenance coefficient	f_{mai}	refers to the coefficient multiplied by the total cost to determine the maintenance cost

Table 2. information about the RE components

Components	Price	Lifetime (years)
PV panels	0.6 \$/W	25
Wind turbine	0.7 \$/W	25
Converters	0.41 \$/W	10
f_{mai}	0.004	
Degradation rate	1 %	
Discount rate	7 %	

Table 3. LCOE inputs modeling.

Inputs	Modeling
Capital cost (\$)	$C = C_{PV} \times x + C_W \times y + C_{conv}$
Operations and maintenance cost (\$)	$O = f_{mai} \times (x + y)$
Annual output energy (kW)	$E = e_{PV} \times x + e_W \times y$
Converter cost (\$)	$Cconv = 0.41 \times (x + y)$

2.3 Renewable Energy System

As shown in Fig. 1, RE systems can be categorized as grid-connected or standalone (off grid) systems [33]. The standalone systems require the purchase of backup batteries to provide an uninterrupted supply of electricity which is not the case in grid-connected systems where the energy is fed directly from the national grid if the supplied energy from RE sources couldn't satisfy the energy demand [34, 35]. In this case study, all of the RE systems are grid-connected.

2.4 Sites Description

Morocco is characterized by a very interesting RE potential, especially solar and wind resources as shown respectively in Fig. 2 and Fig. 3. It has a daily average of irradiation superior to 5 $kWh/m^2/day$ [36], and a considerable potential of wind energy, specifically in the north and south of the country [10]. In order to cover the entire Moroccan territory, this study includes 12 locations throughout Morocco which are: Kenitra, Oujda, Laayoune, Agadir, Marrakech, Al Hoceima, Errachidia, Dakhla, Tangier, Fez, Meknes, Sidi Ishak.

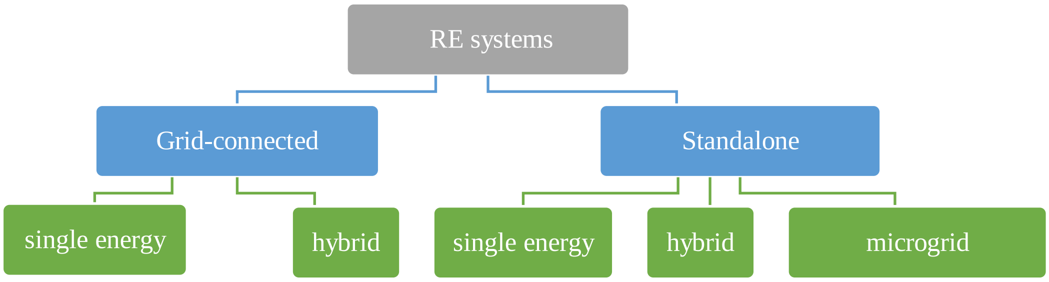

Fig. 1. Kind of RE systems

Fig. 2. Solar potential in Morocco

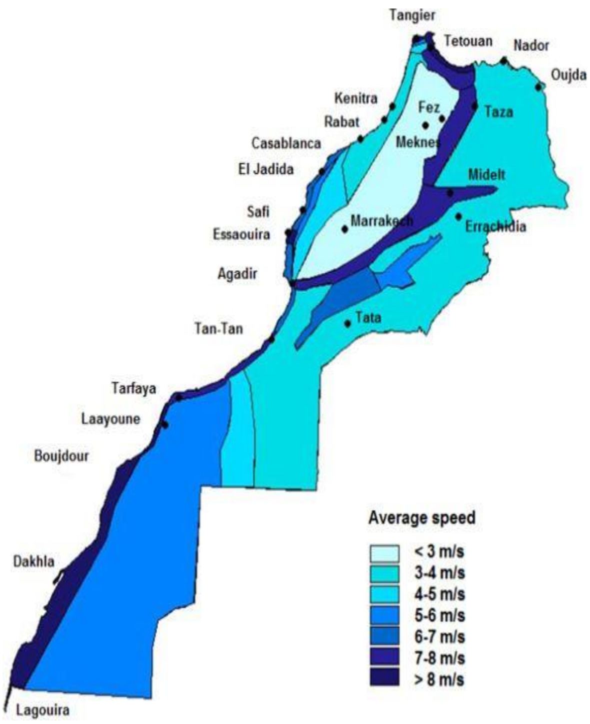

Fig. 3. Average wind speed in Morocco

2.5 Draft Law No. 82.21 and scenarios

According to the draft law N° 82.21 concerning the self-production of electrical energy, anyone can produce energy for their own use or to supply the grid, even at the low-voltage level. Knowing that the main objective is to select the best type and size of a hybrid system based on RE, we will evaluate the impact of this law on the LCOE by proposing three scenarios which are detailed in table 4.

In the first scenario, the excess of energy can't be integrated to the grid. The two other scenarios are proposed with energy sell back. In fact, in the second scenario, only 10% of the total produced energy can be injected into the grid which is in good agreement with the draft law No. 82.21 (clause N° 12). In the last scenario, all the energy excess is sent to the grid. On the other hand, the grid power is purchased at 0.10 $/kWh and sold at $0.050 kWh.

2.6 HOMER PRO model and the initial results

HOMER PRO is used to extract the initial data. These latter include the estimated annual output energy produced by an installed RE of 1 W in each location. The obtained results are reported in table 5. Fig. 4 shows a schematic of the HRES under study in HOMER PRO.

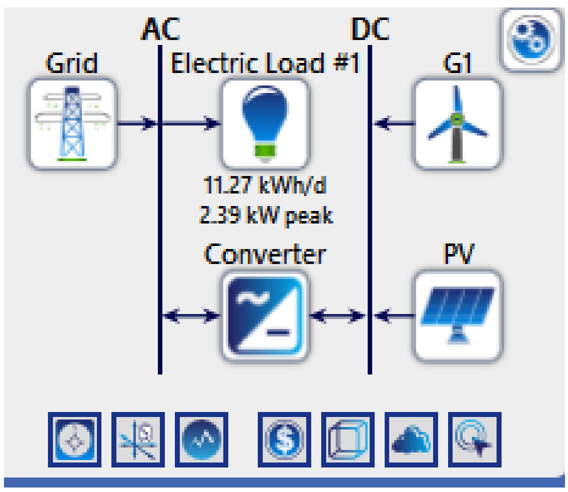

Fig. 4. schematic of the studied hybrid RE system

Table 4. proposed scenarios

N	Scenario	Designation	Tariff ($)	Overproduction
1	Without sell back	The excess of energy can´t be injected to the grid	Grid: 0.10 ; Sold: 0	0
2	With 10% sell back	Only 10% of the total produced energy can be injected into the grid	Grid: 0.10 ; Sold: 0.05	Annual output -5000
3	With 100% sell back	All the excess of energy can be injected to grid	Grid: 0.10 ; Sold : 0.05	Annual output -5000

Table 5. predicted annual output produced by 1 W

	City	Predicted annual output produced by 1 Wp	
		Epv (kWh)	Ew (kWh)
A	Al Hoceima	1.831	1.171
B	Kenitra	1.796	1.9265
C	Oujda	1.691	1.9354
D	Marrakech	1.800	1.185
E	Errachidia	1.884	2.193
F	Agadir	1.908	1.858
G	Laayoune	2.017	4.45525
H	Dakhla	1.863	4.635
I	Tangier	1.722	2.679
J	Fez	1.693	1.361
K	Meknes	1.783	1.067
L	Sidi Ishak	1.8	2.14

2.7 PSO algorithm and optimization

PSO is a population-based optimization algorithm that was first introduced by James Kennedy and Russell Eberhart in 1995. It is based on the collective behavior of a group of particles, where each particle represents a potential solution to the optimization problem.

The algorithm iteratively updates the position and velocity of each particle based on its own best known position and the best-known position of the entire [18, 37]

All the best global positions as shown in Fig. 6 will be filtered to extract 'x', 'y', which respects all desired constraints and had minimum LCOE. Fig. 5 resumes the details of the adopted method.

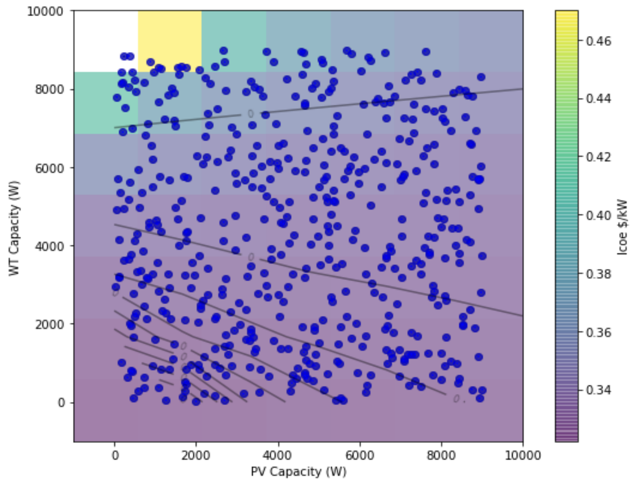

Fig. 5. PSO particles in first iterations

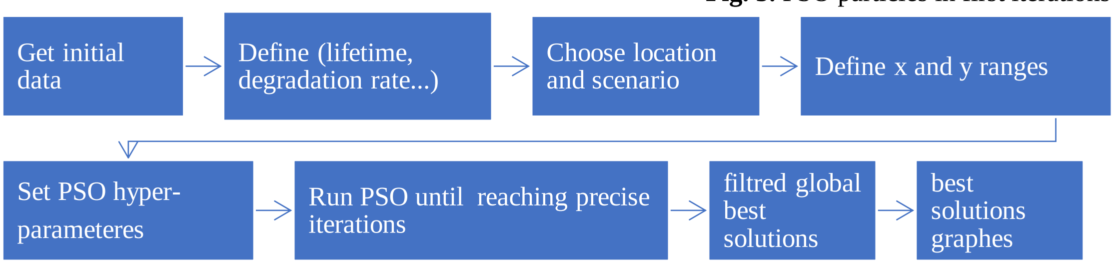

Fig. 6. RE optimization methodology

3. Result and Discussion

As mentioned above, the main goal is to determine the suitable type and size of a RE system less than 20 kWp based on wind and PV in different locations across Morocco. In this context, the PSO algorithm is adopted. In fact, the LCOE is set as the objective function for three scenarios on 12 different locations in Morocco. The PSO algorithm is implemented in Python language. This latter is a high-level programming language that is widely used for web development, scientific computing, data analysis, artificial intelligence, and more. It is known for its readability and ease of use, and has a large and supportive community[38, 39].PSO offers many solutions found at the global best positions, which will be filtered as the desired constraints considering 'x' and 'y' variables according to the lower LCOE. Fig. 7, Fig. 8 and Fig. 9, show respectively the best sizing and LCOE found by PSO in scenarios 1,2 and 3.

- For the first scenario, as it is clear in Fig.7:

Wind energy is the suitable type of energy that should be used in Laayoun (G), Dakhla (H) and Tangier (I).
PV energy is the adequate kind of energy to use in Fez (J).
A hybrid system is suitable for: Al Hoceima (A) Kenitra(B),Oujda(C),Marrakech(D),Errachidia(E), Agadir(F), and Meknes (K) and Sidi Ishak

- For the second scenario as shown in Fig. 8:

Wind energy remains the suitable RE to be used in Laayoun (G), Dakhla (H) and Tangier (I) also Errachidia (E) and Sidi Ishak (L) becoming single energy based on wind.
PV energy is now the adequate RE to be installed in Marrakech(D), Meknes and Al Hoceima(A) while the adequate system was hybrid in the first scenario for these locations. Also, PV energy remains the suitable RE to be used in Fez.
A hybrid system is suitable for: Kenitra (B) Oujda (C) and Agadir (F).

- For the third scenario as shown in Fig. 9:

Wind energy is still the most suitable for Laayoun (G), Dakhla (H) and Tangier (I).
PV energy continues to be the kind of RE system that should be employed in Al Hoceima (A), Marrakech (D), Fez (J) and Meknes (K).
The hybrid system is appropriate for Kenitra (B) Oujda (C) Agadir (F) the same as the second scenario while Errachidia (E) was single energy based on wind and became hybrid.

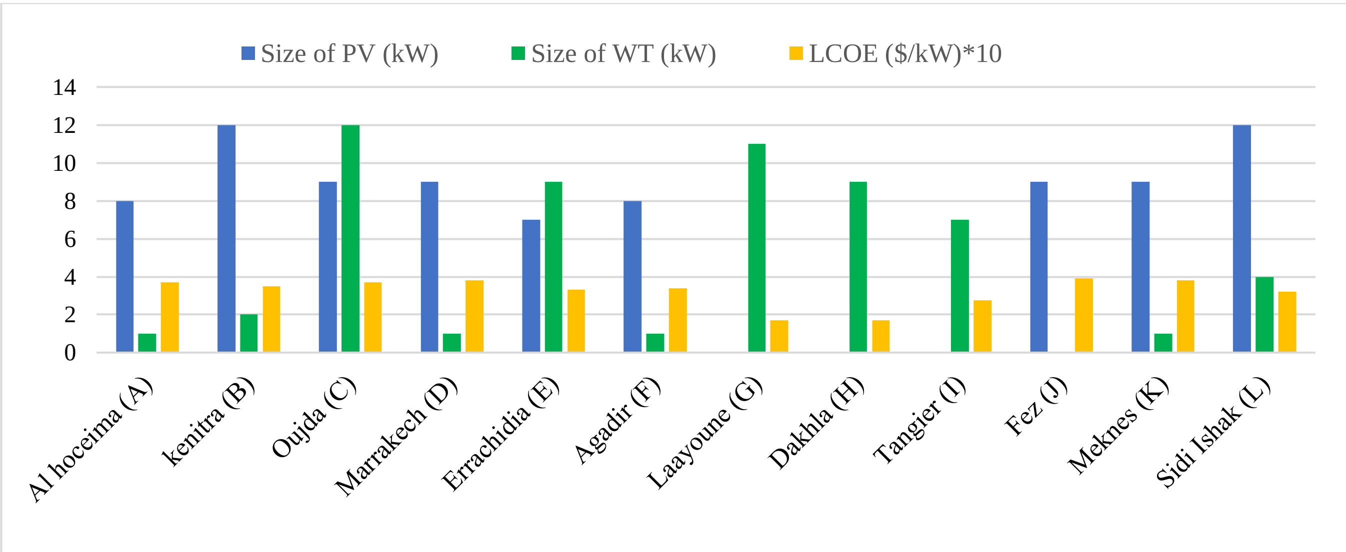

Fig. 7. Best solutions without sell back

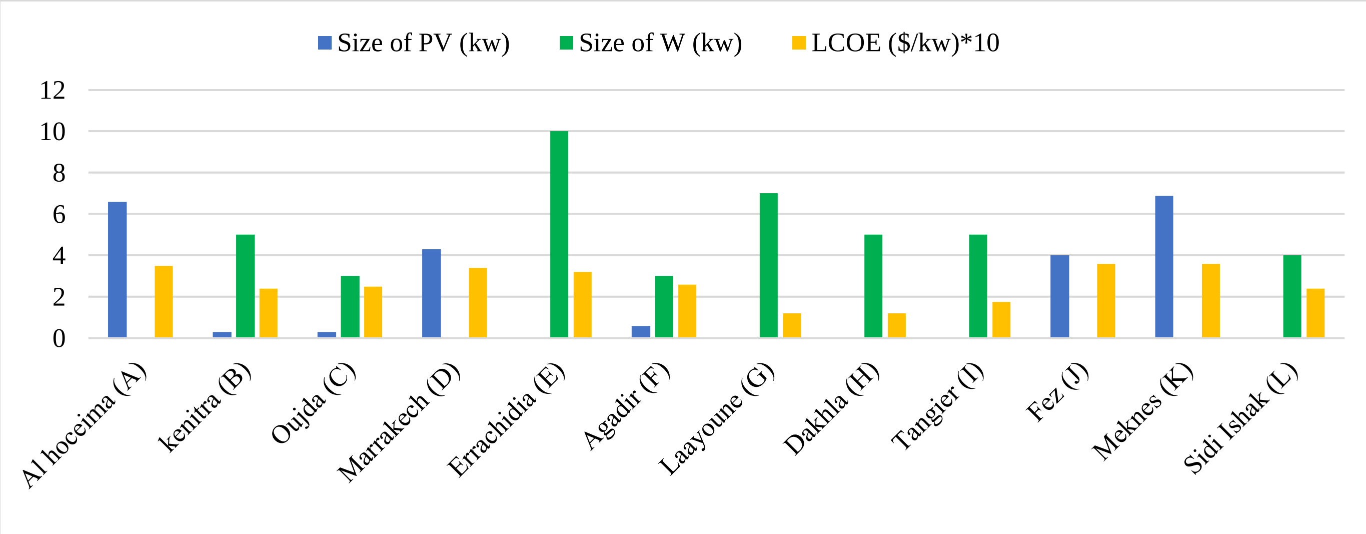

Fig. 8. Best solutions including 10% sell back

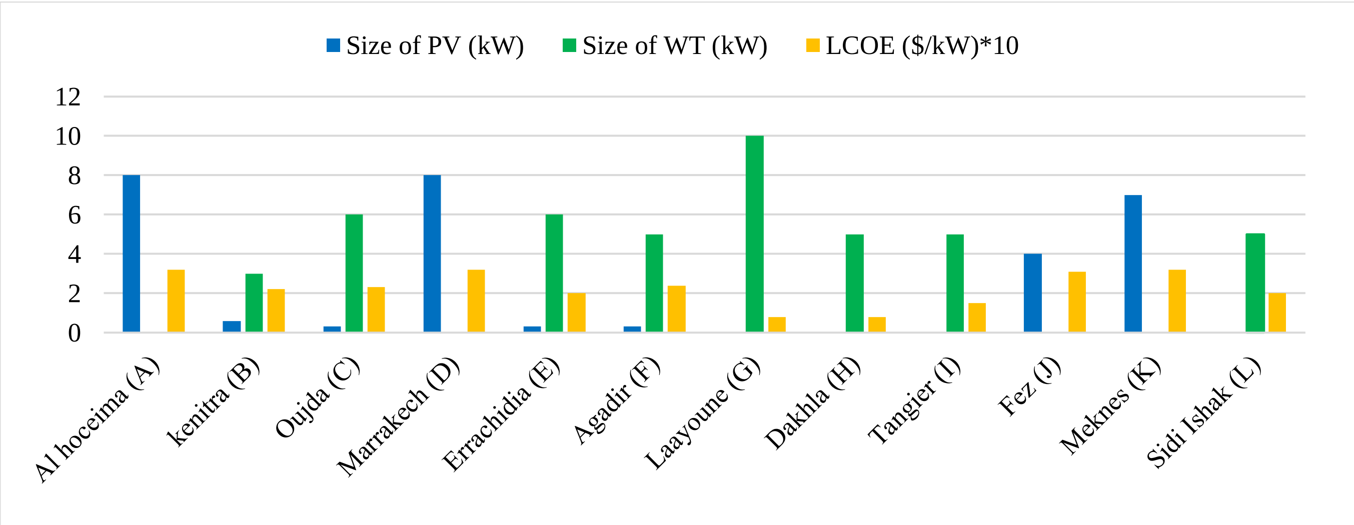

Fig. 9. Best solutions with 100% sell back

The best solutions obtained from the global best positions founded by PSO across these scenarios in each city are summarized in table 6. It is remarkable that a lot of cities in Morocco have great potential and a competitive LCOE, which encourages consumers to become producers and produce electricity from the RE system. In fact, sell back can reduce LCOE and also optimize the sizing which means reducing net present cost. On the other hand, integration of the electrical energy to the main grid should be controlled in order to keep a balanced electrical grid where the grid managers should exploit at maximum the overproduction of the RE system in a way that takes into account neighbors needs and ensure the electrical grid balance. Fig. 10 shows the obtained LCOE for the studied cites in each scenario. It is remarkable from these results that the draft Law No. 82.21 can improve the feasibility of RE generation by decreasing LCOE. This latter can reach 0.17 $/kWh in scenario 1 and 0.12 $/kWh in scenario 2 using single energy systems based on wind energy (5 kWp) in Laayoun (G) and Dakhla (H) (7 kWp). By adopting this draft law, the LCOE could be reduced by 0.1 $/kWh in Kenitra (B) and Oujda (C). In scenario 3 where all the overproduction is injected into the grid (without making limits such article 12 in the draft law), the lowest LCOE is 0.08 $/kWh in Laayoune (G) and Dakhla (H). In comparison with scenario 1, the LCOE can be reduced by more than 0.1$/kWh in 8 cities which are Kenitra (B), Oujda (C), Errachidia (E), Agadir (F), Laayoune (G), Dakhla (H), Fez (I), Sidi Ishak (L).

In comparison with other research works that has been done in Morocco, Hassan et al. used the modified electric system cascade analysis (MESCA) to design a hybrid renewable energy system in remote areas. The optimal system is composed of 25 kWp of PV Panels, a 5-kWp wind turbine, and a battery bank. The obtained results show that it is possible to have a LCOE of 0.25 euro/kWh under the conditions of this remote area in Oujda [40]. Latifa et al. found the same LCOE (0.25 euro/kWh) by the use of a parabolic trough solar power plant [41]. It should be noted that in this case study the power plant has a size of 60 MW. Also Mohammed et al used the electric system cascade extended analysis to find the optimal size of hybrid renewable energy system. The LCOE achieves

0.22 \$/kWh by a combination of 79.8 % PV and 20,2% of wind where ($C_{PV} = 0.4\ \$/kwh\ C_w = 0.45\ \$/kwh$ in our study's third scenario, Oujda's (C) LCOE was 0.23 \$/kWh with 0.3 kWp of PV and 6 kWp of wind [42].

In India, Ambati et al tried to determine the optimal combination of the PV, wind, and pumped storage hydropower energy station by using the improved search space reduction algorithm. The obtained LCOE is between 0.187-0.24 \$/kWh using 17,349 of PV panels 355 Wc and 588 wind turbine of 10 kWp [43].

In a detailed analysis of the LCOE for a real RE system installed in a remote area in Morocco (Sidi Ishak (L), it was found that the LCOE for the standalone hybrid system with a power rating of 5 kWp for the wind generator and 7.2 kWp of PV was 0.32 \$/kWh. The same LCOE value was also achieved for two different combinations in scenario 1 in the same area, one with an 8 kWp wind generator and 0.7 kWp PV and the other with a 12 kWp wind generator and 4 kWp PV [12].

HOMER PRO was used in a lot of research to extract RE optimal size. e.g., Ravi et al have done a techno-economic study for hybrid RE system feasibility and they found that PV-Diesel generator-battery (197.38 kWp PV, 50 kWp diesel generation 599.76 kWh battery, and 80.61 kW converter) gave the lowest LCOE which is 0.19\$/kWh [44].

Actually, in addition to the power plant size, the LCOE is also directly impacted by the values of the discount rate, the degradation rate, the cost of PV panels and wind turbines. When comparing methods according to LCOE, the value of these parameters should be taken into consideration by selecting a similar or close value.

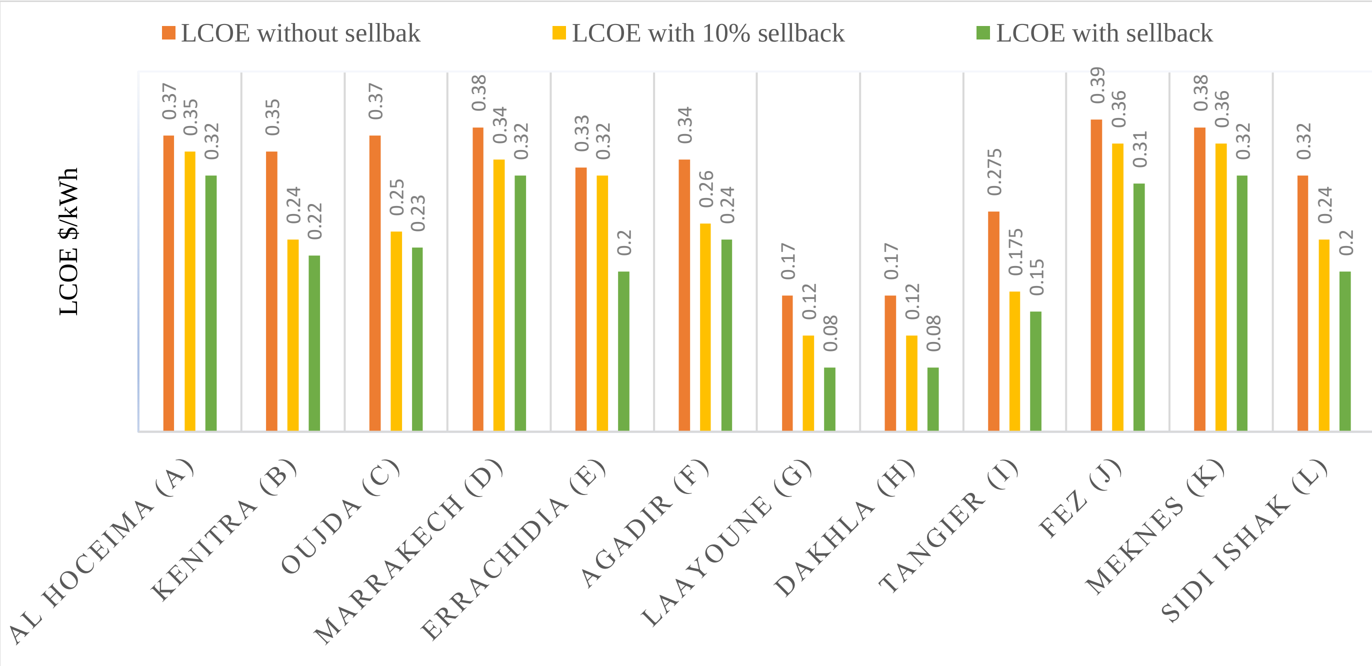

Fig. 10. best solutions LCOE found by PSO

Table 6. Best scenario comparison.

	City	Scenario	RE type	Best sizing capacity		LCOE ($/kWh)
				PV (kWp)	WT (kWp)	
A	Al Hoceima	Without sell back	Hybrid	8	1	0.37
		With a limit of 10% for sell back	Hybrid/single energy	2.7;6.6	1 ;0	0.35
		Sell back without limit	Single energy	8	0	0.32
B	Kenitra	Without sell back	Hybrid	12	2	0.35
		With a limit of 10% for sell back	Hybrid	0.3	5	0.24
		Sell back without limit	Hybrid	0.6	3	0.22
C	Oujda	Without sell back	Hybrid	9	12	0.37
		With a limit of 10% for sell back	Hybrid	0.3	3	0.25
		Sell back without limit	Hybrid	0.3	6	0.23
D	Marrakech	Without sell back	Hybrid	9	1	0.38
		With a limit of 10% for sell back	Single energy	4.3	0	0.34
		Sell back without limit	Single energy	8	0	0.32
E	Errachidia	Without sell back	Hybrid	9;6.75;7	9;12;	0.33
		With a limit of 10% for sell back	Single energy	0	10	0.320
		Sell back without limit	Hybrid	0.3	6	0.20
F	Agadir	Without sell back	Hybrid/ single energy	9;8	0;1	0.34
		With a limit of 10% for sell back	Hybrid	0.6	3	0.26
		Sell back without limit	Hybrid	0.3	5	0.24
G	Laayoune	Without sell back	single energy	0	11	0.17
		With a limit of 10% for sell back	single energy	0;0	4;7	0.12
		Sell back without limit	single energy	0	10	0.08
H	Dakhla	Without sell back	single energy	0	9	0.17
		With a limit of 10% for sell back	single energy	0	5	0.12
		Sell back without limit	single energy	0	5	0.08
I	Tangier	Without sell back	Hybrid/single energy	1;0;2	9;7;11	0.275
		With a limit of 10% for sell back	Hybrid	0.3	3	0.175
		Sell back without limit	single energy	0	5	0.15
J	Fes	Without sell back	single energy	9	0	0.39
		With a limit of 10% for sell back	single energy	4	0	0.36
		Sell back without limit	single energy	4	0	0.31
K	Meknes	Without sell back	Single energy / Hybrid	9;7.3	1;0	0.38
		With a limit of 10% for sell back	Hybrid	5	1	0.36
		Sell back without limit	single energy	7	0	0.32
L	Sidi Ishak	Without sell back	hybrid	4;0.7	12;8	0.32
		With a limit of 10% for sell back	Single energy	0	4	0.24
		Sell back without limit	Single energy	0	5	0.20

4. Conclusion

This study aimed to determine the optimal sizing of renewable energy systems in different locations in Morocco, specifically using wind and PV-based systems. To achieve this, a techno-economic and feasibility analysis was conducted in 12 cities using a PSO algorithm to minimize LCOE across three scenarios: no excess energy sent to the grid, 10% excess energy sent to the grid, and all excess energy sent to the grid.

The results of the study show that the majority of RE systems across the three scenarios are hybrid systems that integrate wind and PV systems. This combination provides a cost-effective and reliable source of RE for various regions in Morocco. Interestingly, even though hybrid systems were found to be optimal and more adequate for most of locations, the lowest LCOE was achieved in Laayoune (G) and Dakhla (H) located in the southern area using a single energy RE system based on wind. The lowest value of LCOE obtained was 0.08$/kWh in scenario 3, the capacity of wind energy was 10 kWp in Laayoune (G) and 5 kWp in Dakhla (H). Although injecting overproduction into the grid has a positive impact on the cost of energy produced by the RE system, LCOE in scenario 3 can be reduced by more than 0.1$/kWh compared to scenario 1.

Overall, this research has significant implications for policymakers and private investors in the RE sector, to accord policies and regulations that support the injection of excess energy into the grid, as it demonstrates the potential for consumers to generate electricity from RE systems and become producers. Furthermore, it is important to continue monitoring and regulating the injection of excess energy into the grid to maintain balance and ensure the stability of the electrical system.

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