Selection of suitable concentrated solar power farm's locations A Case study: Fez-Meknes Region, Morocco

Abdelkhiar Ait Ali[1,*], *Laila Ouazzani Chahidi*[1], *Abdellah Mechaqrane*[1], *Mohammed Charroud*[1], *Youssef Ouahzizi*[1] *and Jaouad Choukrad*[1].

1, Intelligent Systems, Georesources and Renewable Energies Laboratory (SIGER), Faculty of Sciences and Techniques of Fez, Sidi Mohamed Ben Abdellah University, PO. Box 2202, Fez, Morocco.

Abstract. Nowadays, the transition to green energies becomes a necessity in the worldwide. In order to have an optimal yield, the selection of the adequate site for a given technology is required. In this study, the geographical environment of Fez-Meknes region, Morocco, is explored to select suitable location for concentrated solar power plants (CSP). For this purpose, a combination of a geographic information system (GIS) and the multi-criterion decision-making (MCDM) method is used for this aim. Various factors are taken into consideration, namely climate conditions, environment, water resources and location. These criteria are calculated and weighted using the Analytical Hierarchy Process (AHP) approach. The findings indicate that the Fez-Meknes region is a viable location for the implementation of CSP plants. Thus, the most suitable site represents 12% of the total region area. These suitable areas are located in the southern and southeastern part of the region with an irradiation value of about 6.57 kWh/m^2/yr.

1. Introduction

Energy is a key element for the worldwide development. The depletion of fuel reserves and their increasing price, as well as growing environmental concerns, have led to a growing interest in renewable energy [1][2] . The capacity of renewable energies has increased rapidly in recent years. As such, the hydropower presents the largest share, pursued by wind and solar energy's respectively [3]. Although, solar energy is the best known and most popular renewable energy source [4].

The selection of the right site for solar energy plants implementation is a complex task. Different criteria and sub-criteria must be considered, e.g., the potential of solar energy in this area, the proximity to infrastructure, unused land, and many others. Several researches were devoted to this task.

In the Kingdom of Morocco, different studies have been conducted for some regions. Tahiri et al. 2015 [5] evaluated the potential of the site of Ouarzazat to host a photovoltaic farm. In another Moroccan region, Alami et al. 2017 and 2018 [6] [7] identified the adaptability of the Eastern region for hosting photovoltaic and concentrated solar power plants.

The geographical location of the Kingdom of Morocco plays an important role in the abundance of different renewable energy sources. However, it should be noted that each Moroccan region has its specificity. Thus, the implementation of any renewable energy technology must be preceded by a site validity assessment. The present study aims to highlight the appropriate areas for the installation of concentrated solar power plants in Fez-Meknes region. In this respect, GIS and MCDM method are combined using high spatial resolution data inputs: solar energy potential, infrastructure, water resources, land use, protected areas, and electric lines grid. The choice of Fez-Meknes region is based on the fact that this region has a large repartition and is one of the important economic areas in Morocco. The results of this work are very useful for the governors and the investors interested in the field of energy.

The paper is organized as next: first, the target area and the collected data are described. Then, the methodology of the study is explained. Finally, the suitable locations for CSP farms are selected and the results are presented.

2. Materials and Methods

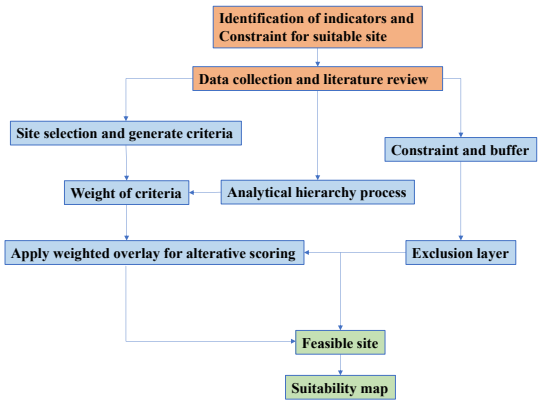

Fig 1. Flowchart of study's approach.

* Corresponding author: abdelkhiar.aitali@usmba.ac.ma

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Figure 1 summarizes the methodology adopted in this study. To select and identify the suitable sites for CSP farms in the region of Fez-Meknes, Morocco, four main steps are followed: (1) literature review and data collection (2) determination of the decision criteria and constraint factors (3) description and weighting of the criteria (4) combination of the constraints and weighted criteria to identify the proposed site selection.

2.1. Case Study Region and Data Description

In this study, Fez-Meknes region (figure 2) is considered. This region is located in the center north of the Kingdom of Morocco and extends over an area of about 40,075 km² that represents 5.7% of the total Kingdom area with a population density of 105.7 inhabitants per square kilometer. Figure 3 is a graphical presentation of the data used in this study [8].

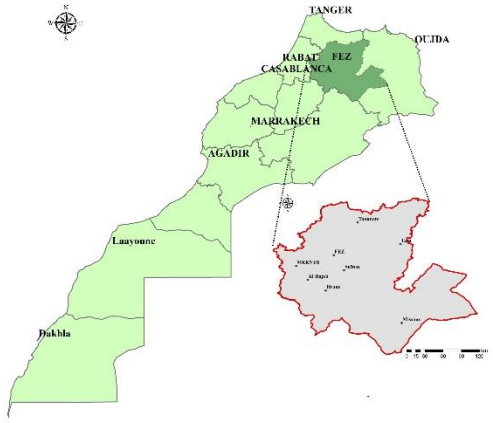

Fig. 2. Geographical location of Fez-Meknes Region, Morocco.

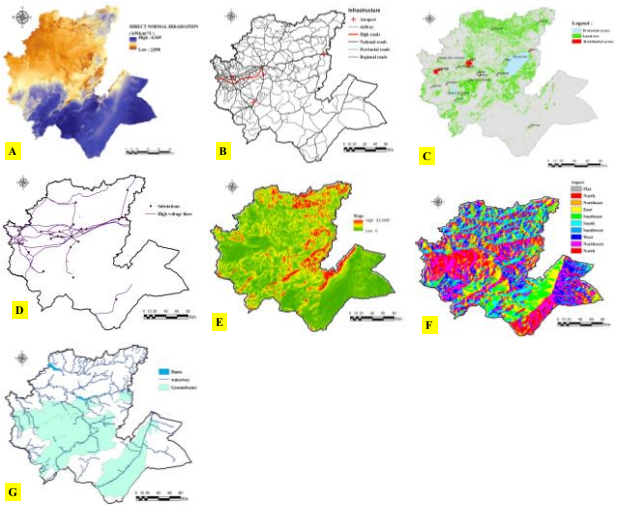

Fig. 3. Data used in this study, A: Direct Normal solar Irradiation, B: Infrastructures, C: Land use, D: Electricity grid, E: Slope, F: Aspect and G: Water resources.

2.2. Multi-Criterion Decision-Making Method

The AHP is a mathematical method created by Thomas Saaty in 1987 [9]. Which the objectives, alternatives, and criteria should be specified at the start of the AHP process. It is a valuable method for checking the consistency of the decision [10], thus decreasing the bias in the decision-making process. Then, M (eq. 1) It is possible to construct a pairwise comparison matrix. The matrix M of size (n × n) where (p, r & q) represent the relative relevance of each criterion to the others. A numerical scale from 1 to 9 is used to determine relative importance.

$$M = \begin{vmatrix} 1 & p & q \\ 1/p & 1 & r \\ 1/q & 1/r & 1 \end{vmatrix} \quad (1)$$

After assigning the value of the interest of each criterion to the other, the criteria's weights are calculated. To normalize the matrix M, many procedures are taken: The sum of each column's values is calculated first. Following that, each entry is divided by the sum of its columns. The relative weights are then determined by taking the average of all rows. After that, the consistency ratio CR is calculated (eq.2), that presents the ratio of the consistency index CI (eq.3) devised by the random value RI (Table 1). λmax is the maximum eigenvalue for each matrix and n is the criteria number.

$$CR = \frac{CI}{RI} \quad (2)$$

$$CI = \frac{(\lambda max - n)}{(n - 1)} \quad (3)$$

In this study, four criteria (climate, environment, location, and water resources) and ten factors have been defined to solve this problem. Different factors are considered to select the suitable area in Fez-Meknes region, Morocco, for implementing the CSP technology.

Table 1. Assigned RI values.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3. Results and Discussion

The AHP is used to create the pairwise comparison matrix, and the results are displayed in Table 2. The results of the pairwise comparisons are very well and consistently done, as the consistency ratio (CR) is equal to 1.8%, or less than 10 %. The criteria with their relative constraints are presented in table 3.

Table 2. Pairwise comparison matrix.

	Climate	**Environment**	**Water resource**	**Local**
Climate	1	3	5	9
Environment	1/3	1	2	5
Water resource	1/5	1/2	1	2
Local	1/9	1/5	½	1
Weight	0.5927	0.2352	0.1155	0.0564

Table 3. Study criteria and constraint.

Criteria	Factors	Description	Constraint	Sources
Climate	Solar radiation (kWh/m²/yr)	Long-term yearly average of Direct Normal irradiation (DNI), from 1994 to 2018.	----------	Solargis [11]
Location	Residential area	Population density	Distance < 3 km (for small cities) and 5 km (for big cities)	Glovis [12]
	Infrastructure	Road and railway	Distance < 0.1 km	Street map and topography map [13]
		Airports	Distance < 3 km	Datashare [14]
	Electricity grid	Electric line transmission	Distance < 0.1 km	Energydata [15]
	Administrative boundaries	Region and common boundaries	----------	ArcGIS [16]
Environment	Slope and Aspect	Slope and aspect orientation	> 5° for slopes and North for orientation	DEM (USGS) [17]
	Land use	Agricultural land, national parks, protected areas…	Distance < 0.5 km	Street map and topography map [13]
Water source	Dams	Lac and dams	Distance < 0.5 km	Street map and topography map [13]
	Groundwater	Groundwater	----------	ArcGIS [18]
	Waterway	Rivers	Distance < 0.5 km	Street map and topography map [13]

According to the AHP weight analysis (Table 4), the climatic criterion is the most dominating, accounting for 59.2 percent of the total weight. This makes sense because the amount of solar irradiation is precisely proportional to the amount of power produced. As a result, optimal locations for CSP farms should be in well-irradiated locales to be competitive in the solar market.

Table 4 shows the importance of each criterion and its value after the multi-criterion analysis, so the restriction values fit in the whole study.

Table 5 and figure 4 show the result of the CSP ranked suitability map, after the exclusion of all inadequate areas. The result demonstrates that the most suitable area is located in the south and southeastern of Fez-Meknes region. Areas of about 4365.00 km² can be considered as the most suitable site, 4347.77 km² as moderately suitable, 1874.04 km² as suitable, 331.56 km² as marginally suitable and 26852.41 km² as unsuitable. These areas are accounting, respectively, for 12%, 12%, 5%, 1% and 71% of the total land area of Fez-Meknes region.

Table 4. Summary of surface areas and suitability indexes for the Fez-Meknes region.

	Planimetric Area (km²)	Percentage
Unsuitable	26852.41	71%
Marginally suitable	331.56	1%
Suitable	1874.04	5%
Moderately suitable	4347.77	12%
Highly suitable	4365	12%

Table 5. Criteria, weight factors and global weight factors.

Criteria	Weight	Factors	Weight factor	Global weight
Climate	0.592772	Normal direct Irradiation (kWh/m²/yr)	1	0.592772
Environment	0.235243	Slope (°)	0.626703	0.147427
		Aspect	0.279683	0.065793
		Land use	0.093613	0.022022
Location	0.05647	Distance from the road and rail networks (km)	0.635	0.035858
		Distance from residential (km)	0.287	0.016207
		Distance from the electricity grid (km)	0.078	0.004405
Water source	0.115514	Distance from waterways (km)	0.783743	0.090533
		Distance from dams (km)	0.134944	0.015588
		Distance from groundwater (km)	0.081313	0.009393

The unsuitable areas are very large. This can be explained by the fact that the region is occupied by very fertile land (essentially the plain of Saiss, and the central and northern parts of the region), two large National Parks that of Tazzeka and that of Ifrane in addition to a large forest cover. The suitable area is situated in Boulemane Province, more precisely in the Enjile zone.

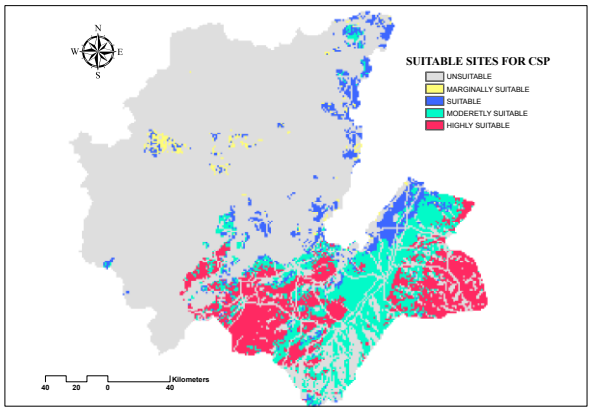

Fig. 3. The site suitability map for the installation of CSP power in Fez-Meknes region.

4. Conclusion

This work presents an integrated methodology for locating potential options for large-scale concentrated solar power installations (CSP) systems by combining GIS and MCDM-AHP methodologies. Four criteria were used for this aim. Their weights were estimated, and maps of suitability for CSP plant location were established.
The obtained results show that. The Fez-Meknes region can be considered as a good place for the implementation of concentrated solar power plants, with a large continuous suitable area with a proportion of 12% from the total area extends over the south and southeastern of the region.

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