Estimating the Renewable Energy Potential in Morocco: solar energy as a case study

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Abstract. The issue of climate change is expanding over the world. Thus, the interest in renewable energies is growing to minimize the effect of this phenomenon. Environmental policies are changing in different countries (including Morocco); they focus more on the integration and the development of renewable energy projects. The aim of this paper is to assess the potential of Morocco to host solar power plants from both technologies: Concentrated Solar Power (CSP) and Photovoltaics (PV). To have an accurate study, we need to choose the right criteria pursuing a specific methodology. For this reason, four selection criteria were chosen: climate, orography, location and water resource. To calculate the weight/importance of each one of the criteria the Analytical Hierarchy Process (AHP) has been used. Once obtained, the weights are applied on the map of each criteria to generate a final ranking map which classifies the regions according to their potential. Results show that Morocco possesses high potential in both technologies and especially in the south. Finally, this work is the first in its field to include all Morocco in the study area.

1. Introduction

The Conference of Parties, held in Morocco November 2016, sorted out the Marrakech Action Proclamation which underlines its task of moving forward to reduce greenhouse gas emissions and to encourage adaptation measures [1].

Morocco is aware of the importance of enhancing renewable energy investments and encouraging sustainable development. Thus, the Kingdom shows its willingness to increase the share of renewable energies from 42% of the installed capacity for 2020 to 52% for 2030 [2]. In solar, for instance, the capacity production will increase to reach 4560 MW.

The present study aims to estimate the solar potential in Morocco by elaborating a map highlighting the most suitable sites to host solar power plants. As the combination of the Multi-Criteria Decision Making (MCDM) and Geographic Information System (GIS) tools became an effective method [3] to
do so, our results will represent a tool for the decision support in the Moroccan renewable energy strategy.

2. Criteria selection

2.1. Methodology

To realize a map of the correct potential of our study area, it is imperative to follow certain steps. According to the literature, the most used methodology is a combination of one of the Multi-Criteria decision making (MCDM) and Geographic Information System (GIS) software. The used steps are: the definition of the weight of each criterion, the development of exclusion maps, the combination of the restriction maps with the resource maps and the development of the technical resource potentials.

In the process, the criteria must be chosen wisely and their weight should be calculated. In this study to calculate the weights we used pair comparison matrix based on the analytical hierarchy process (AHP) method.

The following figure (Figure 1) resume the methodology used.

![Figure 1](image)

**Figure 1.** The architecture of the methodology. [4]

To make a decision over the criteria, we assembled all the values and choices of each case in the table below:
Table 1. Values of the criteria for PV.

| Criteria                  | Sub-criteria                               | Limited suitability | Suitable | highly suitable | Excellent |
|---------------------------|--------------------------------------------|---------------------|----------|----------------|-----------|
| Location                  | Distance to urban areas (km)               | >40                 | 20       | 15             | 10        |
|                           | Distance from road and railway network (km)| >20                 | 10-20    | 05-10          | 5         |
|                           | Distance for electricity grid (km)         | >20                 | 15       | 10             | 5         |
| Orography                 | Slope (°)                                  | 10°-45°             | 5°-10°   | 3°-5°          | 1°-3°     |
| Climate                   | Temperature (°C)                           | >45                 | 30-45    | 15-30          | 0-15      |
| Water source              | Distance from water ways (km)              | >15                 | 15       | 10             | 5         |
|                           | Distance from dams (km)                    | >25                 | 15-25    | 10             | 5         |

Table 2. Values of the criteria for CSP.

| Criteria                  | Sub-criteria                               | Limited suitability | Suitable | highly suitable | Excellent |
|---------------------------|--------------------------------------------|---------------------|----------|----------------|-----------|
| Climate                   | Solar radiance values (DNI) (kWh/m²/year)  | 1800 - 2000         | 2000 - 2300 | 2300 - 2500 | 2500 - 2800 |
| Orography                 | Suggested values of slopes (°)             | >2.1                | 1.5-2.1  | 1 - 1.5       | 0.5-1     |
| Location                  | Distance from cities and urban areas (km)  | 30.0 - 200.0        | 20.0 - 30.0 | 15.0 - 20.0 | 10.0 - 15.0 |
|                           | Distance from road and railway network (km)| > 40                | 10.0 - 40.0 | 5.0 - 10.0   | 5.0       |
|                           | Distance from airports (km)                | 2.0 - 3.0           | 3.0 - 4.0 | 4.0 - 5.0    | 5.0 - 6.0 |
|                           | Distance from Electricity grid (km)        | >200                | 100 - 150 | 50 - 100     | 1.0 - 50.0 |
| Water resources           | Distance from water ways (km)              | >15                 | 10 - 15  | 5 - 10        | <5        |
|                           | Distance from dams (km)                    | > 25                | 15 - 25  | 10 - 15       | <10       |

2.2. Methodology

Before conducting any Solar plant project, a pre-feasibility study needs to be done taking into account some different criteria. A criterion is a standard we take to make a judgment and decision. For both PV and CSP technologies the same criteria have been selected in this paper. Those criteria are climate, orography, water resources and location [5]. However, the difference between CSP and PV resides in the sub-criteria (like temperature, GHI and DNI [6]) and their weights. In what follow we will discuss the selected criterions:

- **Climate**: For this study, this criterion takes a big part in estimating the potential of PV and CSP in Morocco. For PV, two sub-criteria are evaluated: temperature and global horizontal irradiation. As for CSP, one criterion is needed which is the Normal Direct Irradiation (DNI). The efficiency of the panels and therefore the yield of solar plant is mostly affected by the irradiation.

- **Orography**: It is the study of the reliefs and elevation or in other words the terrain’s slope analysis. For economic reasons, the lower the slope is the lower investment cost will be. Each of the technologies has its sensibility to the land slope, but the CSP is the most sensitive one to the angle of the slope and it requires a maximum slope value of 2.1% to work efficiently.

- **Water resource**: This resource is important for both technologies especially in arid regions. Indeed, soiling affects considerably the productivity of a solar plants and thus it need to be cleaned. Additionally, CSP power plants require water for cooling the steam turbines. In our study two sub-criteria were used: the distance from water ways and the distance from dams.

- **Location**: This criterion regroups three sub-criteria: the distance to urban areas, the distance from road and railway network and the distance for electricity grid. During the installation of a solar plant, the transportation of the materials as well as the labors are needed.
Consequently, the plant should be as close as possible to the roads to minimize the construction expenses. Also the best scenario is to have plant close to the electricity grid, to inject the produced electricity.

3. The analytical hierarchy process

3.1. Multi-Criteria Decision Making (MCDM)
Evaluating the potential of Morocco to host solar power plants, and classifying regions according to the suitability level needs to take into account many criteria as well as applying decision-making methods.

MCDM methods are often divided to multi-object decision making (MODM) and multi-attribute decision making (MADM). The difference between them is the domain of alternatives, while MODM concerns a continuous, MADM works with a discrete domain of alternatives. [4]

The AHP approach, which is adopted in this study, is a MADM method. It is one of the most commonly used MCDM methods despite the debate around it. This method has demonstrated its capacity at resolving many decision-making problems in several fields and renewable energy analysis is among them.

The AHP method, developed by Saaty in 1977[5], is a process of comparing the importance of a group of criteria and sub-criteria so as to reach a certain aim. Ours is to determine the most suitable sites for CSP in Morocco.

A matrix is generated after setting a goal and the number n refers to the number of criteria, which are set for comparison. The procedures are as following [7]:

- The matrix (P) is a (n x n) one where pij describes the importance of the criterion i to the criterion j. The relative importance is set according a numerical scale from 1 to 9.
  - pii=1
  - We assume that pji=1/pi
- For weight calculation, we need to normalize the matrix(P) by following these steps:
  - Sum the values of each column,
  - Divide each entry by its column sum [8],
  - Average across rows to get the relative weights. [5]
- To control the consistency of the calculated weights in case a problem arises, the consistency ratio (CR) is calculated as following:
  - Calculation of the eigenvector and the maximum eigenvalue for each matrix.
  - Calculation of an approximation to the consistency index (CI):
    \[ CI = \frac{\lambda_{max} - n}{n-1} \]  
    Where \( \lambda_{max} \) is the maximum eigenvalue for each matrix.
- To ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR that is:
  \[ CR = \frac{CI}{RI} \]
  Where RI is the random consistency index. The RI values for different numbers of n are shown in [4]. If CR≤0.10, the degree of consistency is satisfactory. If CR>0.10, there are serious inconsistencies. In this case, the pairwise comparison should be recalculated.

4. Results:
After using the AHP method, we obtained the following weights of each criterion.
Table 3. The weights of the criteria for PV.

| Criteria       | Weight | Sub-criteria                       | Weight |
|----------------|--------|------------------------------------|--------|
| Location       | 6%     | Distance to urban areas (km)        | 1,62   |
|                |        | Distance from road and railway     | 0,66   |
|                |        | network (km)                       |        |
|                |        | Distance for electricity grid (km)  | 3,72   |
| Orography      | 19%    | Slope (°)                          | 19,00  |
| Climate        | 62%    | GHI (kWh/m²)                       | 62,00  |
| Water source   | 13%    | Distance from water ways (km)       | 10,4   |
|                |        | Distance from dams (km)             | 2,6    |

Table 4. The weights of the criteria for wet cooling CSP.

| Criteria       | Sub-criteria                        | Detailed weights | Global weights |
|----------------|-------------------------------------|------------------|----------------|
| Climate        | Solar radiance values (DNI) (kWh/  | 57,7%            | 57,7%          |
|                | m²/year)                            |                  |                |
| Orography      | Suggested values of slopes (°)      | 25,6%            | 25,6%          |
| Water resources| Distance from water ways (km)       | 9,36%            | 11,7%          |
|                | Distance from dams (km)             | 2,34%            |                |
| Location       | Distance from cities and urban areas (km) | 1,4%            | 5,0%           |
|                | Distance from road and railway      | 0,5%             |                |
|                | network (km)                        |                  |                |
|                | Distance from airports (km)         | 0,6%             |                |
|                | Distance from Electricity grid (km)  | 2,6%             |                |

After obtaining the weights, we applied them on the criterion of each technology. As a result, we generated the ranking maps below.
**Figure 2.** The ranking map of PV.

**Figure 3.** The ranking map of wet cooling CSP potential.
5. Conclusion
Energy is a key factor to development whether it is social, economic, or environmental. While fossil fuels are running out, renewable energy resources suggest clean alternatives to them. The sun is a powerful source of energy since solar energy can be used for generating electricity, heating, lighting and cooling buildings etc….

This paper shows an application of combining AHP with GIS for site selection of solar farms in Morocco. The AHP is used to evaluate the importance and determine weights of criteria. The AHP methodology integrated with GIS are very important for the effective estimation of the solar farms sites. Finally, a ranking map will be created combining all criteria that will provide a decision support to choose the most suitable solar farms sites.

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Nomenclature
CSP: Concentrated Solar Power
PV: Photovoltaic
AHP: Analytical Hierarchy Process
MCDM: Multi-Criteria Decision Making
GIS: Geographic Information System
GHI: Global Horizontal Irradiation
DNI: Direct Normal Irradiation
MODM: Multi-object decision making
MADM: Multi-attribute decision making
Pii: describes the importance of the criterion i to the criterion i in the matrix
Pji: describes the importance of the criterion j to the criterion i in the matrix
Pij: describes the importance of the criterion i to the criterion j in the matrix
CI: Consistency Index
N : Number of the criteria
CR : Consistency Ratio
RI : Random Index
λmax: Eigenvalue of the pairwise comparison matrix