Mapping concentrated solar power site suitability in Algeria

Brahim Haddad [a, *], Pilar Díaz-Cuevas [b], Paula Ferreira [c], Ahmed Djebli [a], Juan Pedro Pérez [b]

[a] Unité de Développement des Equipements Solaires, UDES, Centre de Développement des Energies Renouvelables, CDER, Bou-Ismail, 42015, Tipaza, Algeria
[b] Physical Geography and Regional Geographic Analysis, University of Seville, C/Doña María de Padilla s/n, 41004, Seville, Spain
[c] ALGORITMI Research Centre, Universidade do Minho, Guimarães, Portugal

A R T I C L E I N F O

Article history:
Received 29 July 2020
Received in revised form
17 November 2020
Accepted 18 December 2020
Available online 21 December 2020

Keywords:
Concentrated solar power (CSP)
Geographic information system (GIS)
Analytic hierarchy process (AHP)
Multi-criteria decision making (MCDM)
Energy planning

A B S T R A C T

The investment in solar thermal power technologies has become increasingly attractive, despite their still perceived high costs. Algeria presented an ambitious plan for increasing the participation of renewable energy sources (RES) in the power system, with significant investments foreseen for solar power technologies. To achieve this objective, it is necessary to identify optimal sites for the implementation of these plants, as well as others where implementation is highly inadvisable from the economic, social, or environmental points of view. The main goal of this study is to present and apply a methodology to identify adequate locations for the installation of solar power plants in Algeria. The study addressed the particular case of concentrated solar power (CSP) and proposed a hybrid approach combining multi-criteria decision making and Geographic Information System. The approach allowed mapping and visualizing unfeasible areas and ranking the feasible sites. The results showed that more than 51% of the territory of the country is unfeasible for the implementation of CSP, mainly due to criteria related to topographic aspects, water availability, and distance to the grid. The results demonstrated that relying only on Direct Normal Irradiation (DNI) values may result in a reductionist vision for energy planning and thus other criteria can play a fundamental role in the decision process. The model allowed also to identify the best regions for CSP investment and opens routes for more detailed studies for the exact site selection.

1. Introduction

The replacement of fossil fuel resources by renewable energy sources (RES) is the objective of several countries to guarantee energy supply, diversify the energy mix, and attain sustainable development goals for the short-long term. The International Energy Agency (EIA) has predicted that the worldwide capacity installation of RES can increase from 2516 GW in 2018e6369 GW by 2030 [1]. The North African countries are also struggling to invest in RES and nuclear energy to meet the high energy demand and ensure social welfare needs [2]. According to EIA [1]; the use of RES for electricity in Africa will grow from 163 TWh to 474 TWh, between 2018 and 2030, or even further if sustainable development policies are actively pursued. Supersberger and Laura [3] also evaluated the use of renewable energies and nuclear power in the North African region and showed that the integration of RES can be highly beneficial to diversify the countries' generation capacities. However, these countries would still have to rely on the importations for RES technologies. Similar occurs for nuclear energy, for which besides the importation gap other technical problems related to the size of power plants and required expertise, are also relevant. Brand and Blok [4] also studied the capacity of North African countries to achieve the transition from fossil fuel to RES under different scenarios. Their study concluded that RES increase could also lead to electricity exportation to Europe provided that integration of power markets is possible and RES production surpasses 60% of the North African electricity demand. More recently, Ouedraogo [5] analyzed the problem of RES energy development in Africa. The author concluded that Africa should review its strategy to face several factors that limit the promotion of RES such as the economic issues, the problem of institutional framework and infrastructure or unskilled labor. For the case of Algeria, Bouraiou et al. [6] concluded on the slow progress of RES integration. The authors pointed out the need the need for further incentives to

* Corresponding author.
E-mail address: haddadbrahimudes@gmail.com (B. Haddad).

https://doi.org/10.1016/j.renene.2020.12.081

encourage investment and facilitate the implementation of these projects.

Algeria is the biggest country in Africa and has a major role in the oil and natural gas market. Furthermore, the country's economy is almost exclusively based on the exportation of oil and gas and the electricity sector mainly relies on natural gas power technologies. This situation indicates the essential need that Algeria decrease its dependency on fossil fuel [7]. A new robust energy model that can extend the life of energy reserves, increase the export potential and allow the country to compete in international markets as a reliable exporter and prepare gradually for the after the oil time frame, is required. Thus, Algeria is making efforts to harness its renewable energy potential.

The government aimed to diversify the energy mix by installing around 22 GW from renewable energy sources and addressing energy efficiency measures (MEM, 2011). Due to a delay, the program objectives for RES were decreased from 22 GW to 15 GW in 2035 of which 4 GW in 2024 [8]. The potential of Algeria in renewable energy is well recognized, particularly solar and wind technologies. The country receives 2500 kWh/m² per year of solar energy, the photovoltaic (PV) potential is estimated at 27,904 TWh/year and 26,530 TWh/year for concentrated solar power [9]. According to Haddad et al. [10]; solar energy is considered the most promising energy source for the country to reach environmental and social goals. Algeria has the opportunity to become a leader in solar energy production in North Africa and, as Bailek et al. [11] recalled, the country can even deliver electrical energy to Europe.

However, the energy potential is not distributed uniformly throughout the Algerian territory. The selection of the areas with the greatest potential for the realization of these renewable energy power plants is a fundamental topic under the energy decision making problems. This selection exercise requires taking into account other specific criteria which go beyond the pure estimation of the resource potential, namely the compatibility of these facilities with other land uses, as well as guaranteeing the energy and economic efficiency of these project, and avoiding as much as possible, the potential negative impacts for the environment and population [12].

The analysis of the adequate locations for the solar power plant implementation in Algeria using a scientifically sound approach is yet far from being fully explored. The large surface area of the territory, together with the difficulty of finding adequate geospatial information of sufficient quality to carry out the analyses, has prevented analysis of this type.

The main objective of this study is to contribute to the debate on this solar-to-power strategy in Algeria, by developing a geospatial locational model to carry out an approximation to the potential of the Algerian territory for the implementation of concentrated solar power (CSP). This first analysis will then select the areas a priori with the greatest potential that can be considered future technical-economic studies of CSP projects. For this purpose, the Geographic Information System (GIS) will be combined with a Multi-Criteria Decision Making (MCDM) approach for calculating the locational model.

The present paper is divided into five sections, besides this introduction. The next section presents a literature review and analyses different approaches related to the selection of the location of RES projects. In section 3, the case of Algeria is presented, followed by a description of the data and methods used in section 4 and results and discussion in section 5. Finally, the main conclusions are summarized in the final section.

2. Literature review

Finding the best location to install solar power plants has been the objective of several studies in different countries. This problem is frequently tackled using a MCDM approach and a GIS software to analyze the data of the geographic areas and to identify the best area to install RES power plants. There is an extensive number of reviews addressing MCDM for RES (see for example [13,14], or GIS for RES mapping (see for example [15] or [16]. The combined MCDM-GIS approach was also reviewed by Al-Garni and Awasthi [17] for site selection for the photovoltaic plants.

Table 1 presents some recent studies that used a hybrid MCDM-GIS approach in different countries and regions to find the best location for RES power plants. The majority of the studies are dedicated to photovoltaic and/or wind power plants but the CSP power plants are becoming increasingly attractive given the high energy demand and new future programs promoting this type of energy.

Although far from being exhaustive this set of studies clearly showed that choosing suitable areas to install RES power plants is a non-trivial task, given the number and diversity of criteria involved in the choice. The problem comprises multi-dimensional conflicting criteria and generally requires three main steps:

- Defining unsuitability criteria and adding restrictions to the criteria to eliminate the unsuitable areas for installing solar power plants.
- Defining the appropriate criteria to select the best sites for installing power plants.
- Ranking the range of suitable areas using the criteria weights involving the judgments of experts in the field.

The analytical hierarchy method -AHP- [48] is one of the most popular methods used in this MCDM-GIS approach, as shown in Table 1. This goes in line with Al-Garni and Awasthi [17] review as the authors also concluded that AHP is the most used method for the ranking of photovoltaic site alternatives.

In North Africa, Morocco is one of the most important investor countries in the CSP. Tazi et al. [33] evaluated the potential of Morocco to host solar power plants from CSP and PV technologies. Four criteria (climate, orography, location and water resource) and eight sub-criteria (Direct Normal Irradiation eDNI-, slope, distance from residential, distance from road and railway network, distance from the electricity grid, distance from waterways, distance from dams and distance from underground water) were selected to analyze the problem. Then, restrictions were applied to each sub-criteria and the excluded are were obtained. The AHP method was implemented to determine the importance of each criterion. Lastly, the final suitability ranking map for the solar power plants was obtained. Alami-Merrouni et al. [32] assessed the suitability of the Eastern Morocco region to install CSP power plants. Criteria similar to Tazi et al. [33] were considered to analyze the CSP technology location and the constraints layer was created to find the unsuitable areas. GIS and the MCDM (AHP method) were combined for the evaluation of dry and wet cooling techniques. The DNI criterion resulted in the most relevant factor the best CSP sites selection. Finally, two suitability maps for CSP power plants with dry and wet cooling techniques for the region were obtained.

In rural areas of West Africa, Yushchenko et al. [30] analyzed the PV and CSP potential using GIS and the AHP method. Restrictive criteria (urban settlements, land cover, risk areas, protected areas, land slope, population density) were used to get the non-suitable areas for solar power plants. In the second step, solar irradiation (DNI for CSP), distance to electricity grid lines, distance to roads and distance from settlements factors were weighted using the AHP approach to assess the suitability of the area for energy production from these solar power plants.

Aly et al. [41]; analyzed the solar (CSP and PV) power potential of Tanzania using GIS and AHP tools. Protected areas, land cover,

Table 1
Studies using combined MCDM-GIS for RES planning.

Authors name	Method	Technology	Country
[18]	GIS-AHP	PV	Egypt
[19]	GIS-AHP	PV	Malatya, Turkey
[20]	GIS-AHP	PV	Brazil
[21]	GIS-AHP	Wind farm	Iran
[22]	GIS-AHP	Wind, PV and biomass	Malaga, Spain
[23]	GIS-AHP	PV-hydrogen	Algeria
[24]	GIS-AHP	PV	Southern Morocco
[25]	GIS-AHP	PV	Istanbul, Turkey
[26]	GIS-AHP	PV and CSP	Unit of Rethymno, Greece
[27]	GIS-AHP	PV	Croatia
[28]	GIS-AHP	Wind energy	Andalusia, Spain
[29]	GIS-AHP	CSP	United Arab Emirates
[30]	GIS-AHP	CSP and PV	West Africa
[31]	GIS- Boolean-Fuzzy Logic Model	PV	Iran
[32]	GIS-AHP	CSP	Eastern Morocco
[33]	GIS-AHP	CSP and PV	Morocco
[34]	GIS- Fuzzy AHP	Solar farms (PV)	Mekkah, Saudi Arabia
[35]	GIS-AHP	Wind energy	Nigeria
[36]	GIS-AHP and Boolan model	Landfill	Haryana, India
[37]	GIS-AHP	PV	Saudi Arabia
[38]	GIS-AHP	PV and Wind	Tehran, Iran
[39]	GIS-AHP	PV and Wind	Philippines
[40]	GIS-(AHP, ELECTRE, TOPSIS and VIKOR)	PV	Anatolian, Turkey
[41]	GIS-AHP	CSP and PV	Tanznia
[42]	GIS- Weighted Linear Combination and AHP	Solar farms (PV)	Legionowo District Poland
[43]	GIS- Boolean logic	Wind farm	Western Iran
[44]	GIS-AHP/Weighted Linear Combination	Wind farm	Silesia, Poland
[45]	GIS-AHP	PV	Karapinar, Konya/Turkey
[46]	GIS-AHP	PV	Southern Morocco
[47]	GIS-AHP and TOPSIS	PV	South-eastern Spain

topography, water bodies, urban expansion, and low solar radiation were the integrated criteria to find unsuitable areas. AHP method was applied to calculate the importance of each criterion. The resulting map was designed according to a four range scale from the highest to the lowest suitable area.

In the Middle East countries, Alqaderi et al. [29]; worked on the suitability map for CSP power of the United Arab Emirates (UAE). Solar irradiation (DNI), land slope, protected areas, land use, proximity to water bodies, power grid and the roads were the criteria used to identify the excluded areas for CSP projects according to the restrictions of each criterion. The AHP method was applied to rank the criteria and suitability of areas.

In summary, and according to these sample of studies, some exclusion criteria can be highlighted as the most used ones, namely solar resource availability, the topography of the site, location and water resource, electricity grid, distance from water resources, population density and land. In the first stage, constraints are usually applied to these criteria in order to dismiss the undesirable areas for installing solar power. Following this exclusion stage, a MCDM method (AHP, Fuzzy AHP, TOPSIS, ANP and others) is then applied to assess suitable sites against a variety of criteria. As illustrated in Table 1, the AHP method is the most used technique to rank the importance of criteria. GIS software (ArcGIS, QGIS) is frequently used to map the data (DNI, roads, electricity grid, waterways, population density, and slope), analyze and show the ranking of suitability range zones. Combing MCDM with GIS tool allows classifying the areas into different ranges of suitability.

3. Study area

Algeria is the biggest country in North Africa as well as in the continent, with an area of more than two million km^2, with two-thirds of it covered with deserts [49]. The country had 43 million inhabitants in January 2019, with a growth rate of 1.9% compared to 2018 [50]. The forecasts indicate that the population of the country will attain 51 million in 2030 [51].

In terms of territorial organization, Algeria is divided into 48 provinces as shown in Fig. 1. The southern provinces of Tamanrasset (11), Adrar (1) and Illizi (33) occupy almost 58% of the country's total area. Nevertheless, according to the spatial distribution of the population, most densely populated cities are located on the Mediterranean coast and in the northern region of the country while the south and the deep Sahara are less populated.

The energy consumption of Algeria as a whole has been multiplied in recent years. The total consumption of the country was around 65 million tons of oil equivalents (TOE) in 2018 with a growth of 7.7% comparing to 2017 [52] and should reach 91.54 million TOE by 2030 [53]. The exportation of energy products is decreasing and the internal energy consumption is increasing for the last years. The volume of hydrocarbon exports in 2018 reached 101.4 million TOE, compared to 108.8 million TOE in 2017, reflecting a decrease of 7.0% [52].

The final energy consumption of the country increased from 44.6 million TOE in 2017 to 48.1 million TOE in 2018 and it is mainly based on fossil energy as petroleum products (45%) and natural gas (42%) (IEA, 2017). The residential sector is still the highest consuming sector representing 46.5% of the final energy consumption (residential, agriculture and other related activities), followed by transportation (31.7%) and the industrial sector (21.8%) [52].

In the year 2018, national gas consumption reached 4.5 billion m^3 with a growth rate of 8.7% comparing to 2017. Regarding electricity, its use reached 66.8 TWh representing an increase of 2.9% against the previous year [52]. The increasing and massive use of air conditioning and other cooling devices, pumping water for consumption and agricultural irrigation needs due to high heat as well as public lighting have significant repercussions on the electricity network, causing high peaks in electricity consumption.

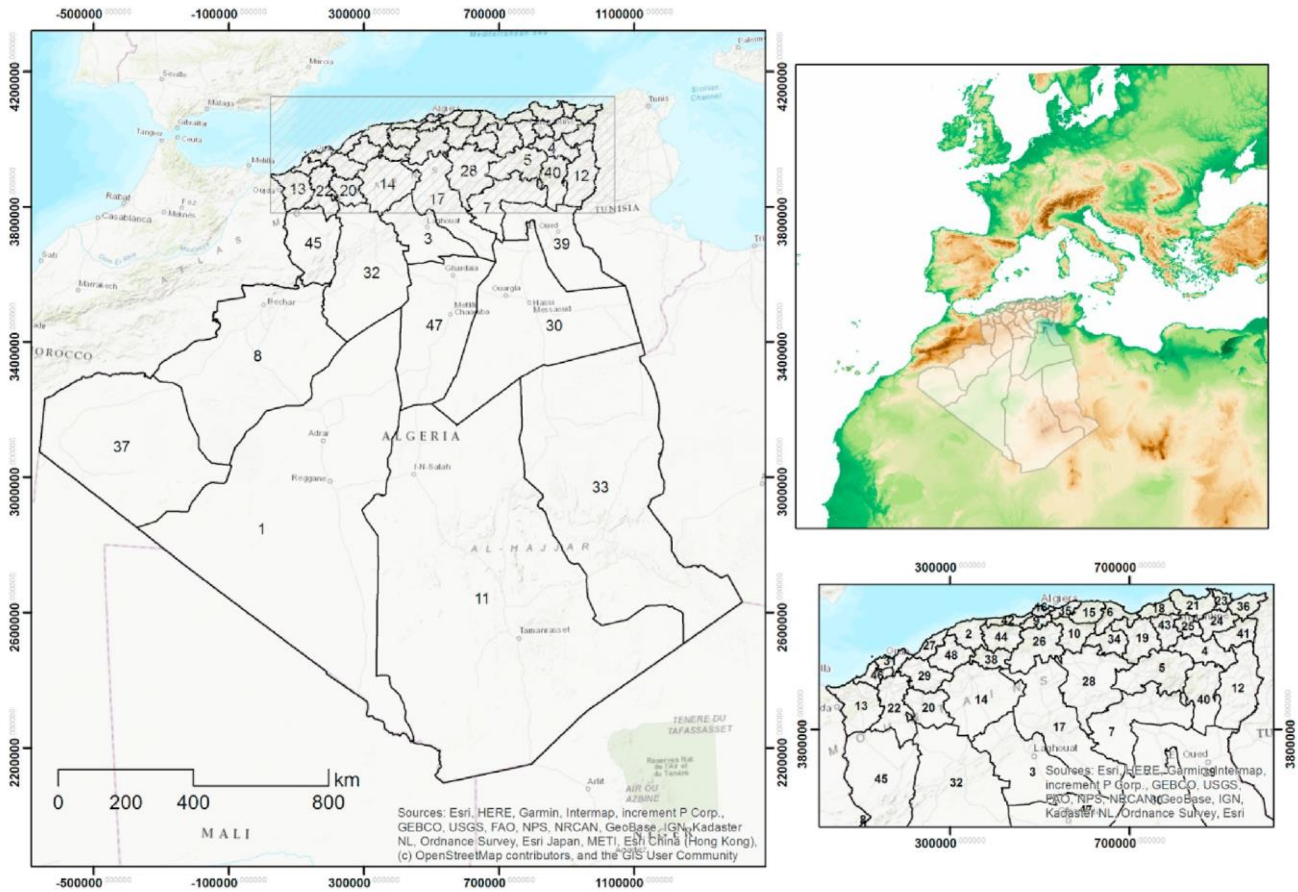

Fig. 1. Study area.

The total installed power electricity capacity reached 20,964 MWat the end of 2018, representing an increase of 7.7% when compared to 2017 [52]. The government targets to install 15 GW from RES up to 2035. The installed power of RES in 2018 was around 354.3 MW (without hydroelectric), divided between 344.1 MW for photovoltaic technology, and 10.2 MW for wind power plants. Unfortunately, only a small amount of the program of RES has been accomplished (small units in the far south). At this rhythm, it is almost impossible to reach half of the RES target. This is due to several reasons, such as the lack of information, poor staff training, and the absence of legal and regulatory framework and lack of skilled labor [6]. As such most of the electricity is still coming from single-cycle and combined cycle gas turbines technologies and RES represented only 1% of the total production in 2018.

The rationalization of the consumption of electrical energy is, therefore, becoming an emergency to reduce energy losses, increase energy efficiency and promote the use of renewable energies. To meet the evolution of the national electricity demand and to take into account the program of decommissioning of the means of production arrived at end of life, the needs for construction of new means of electricity production must be analyzed by region. The Algerian renewable energy program foresees then the development of RES power plants in the country. During the first stage, a strong emphasis will be put on photovoltaic, wind power and to less extent on biomass, and in the second stage, additional technologies will be considered, including CSP. However, to the best of the authors' knowledge, a strategy for mapping RES resources is still not defined. As such, we aim to contribute to this debate by presenting a methodology combining MCDM-GIS to support CSP locational planning in Algeria.

4. Data and methods

The first approximation for identification areas with the greatest potential for the implementation of CSP power plants has been carried out through the consecution of two methodological phases (Fig. 2): 1) Excluding and mapping unsuitable areas map and 2) Ranking and mapping suitability areas. Based on these two phases, the outcome will be the mapping of areas classified according to their potential for CSP installation.

These are common phases in works linked to the use of GIS and MCDM methods for select the best places for RES installation and will be addressed separately in the following sections.

4.1. Calculate unsuitable areas

The calculation of the unsuitable areas will be carried out in two stages: 1) definition of the unsuitability criteria and 2) calculation and mapping of unsuitability criteria and unsuitable areas.

4.1.1. Definition of unsuitability criteria

The criteria to identify the unsuitable areas for locating solar power plants have been established according to the literature and taking into account the specificities of the country [14,32,33]; among others). Table 2 lists a set of criteria to find the unsuitable areas and the restrictions for each criterion. Each of them will be commented hereupon:

- Direct normal irradiation (DNI) factor is a crucial criterion to determine the suitable areas to install CSP technologies. The solar potential of Algeria is around 2500 kWh/m² per year [10].

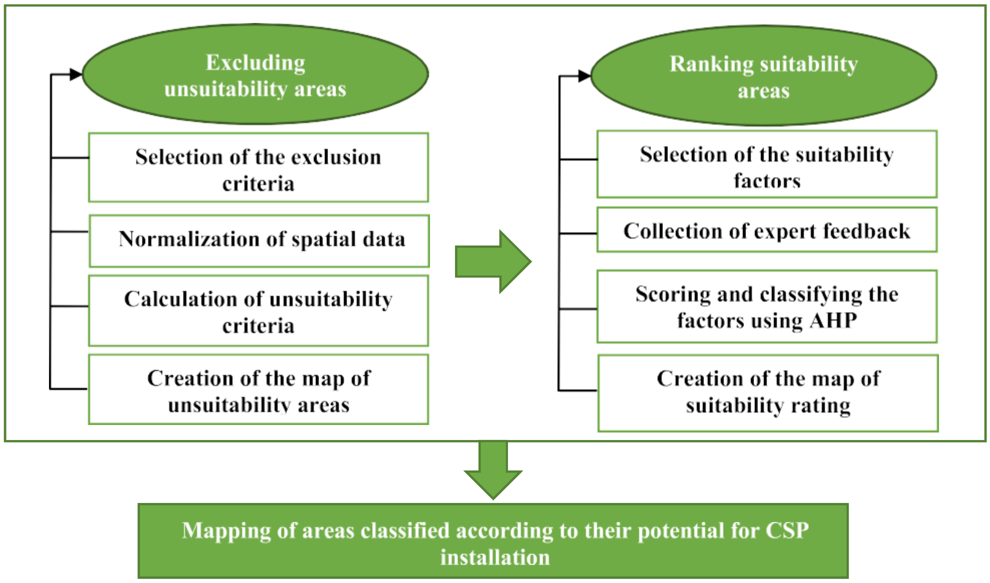

Fig. 2. Methodology of the study.

Table 2
Exclusion criteria and the values assumed in this study.

Element of database	Exclusion criteria	Remarks
Annual direct solar irradiation	DNI < 1800 kWh=m^2	
Roads and railways	Distance <100 m Distance >40 km	Zones located more than 40 km from a road or railway are excluded.
Density population	Population areas. Distance > 200 km	Zones located more than 200 km from populated areas are excluded.
Electricity grid	Distance > 200 km	Zones located more than 200 km from the grid are excluded.
Slopes	Slope > 2:1%	Zones with a slope higher than 2.1% are excluded
Protected areas	Not in this areas	/
Airports	Not in this areas	/
Water availability	Distance > 30 km	Zones located more than 30 km from rivers, streams or dams are excluded

This places Algeria as one of the countries with the highest potential in the North African and Mediterranean regions. The DNI potential is considered to be economically feasible above 1800 kWh/m² [54], so areas under 1800 kWh/m² were excluded.

- The distance from the electricity grid is an important criterion to optimize the electricity production cost. The closest the power plant is to the electricity the less costly it will be to inject the produced electricity into the grid. The length of the national electricity transmission system was around 29,233 km in 2017 for all levels of voltages (60e400 kV). To avoid electricity transmission losses and additional grid extension costs, areas located more than 200 km from the electricity grid (line or substation) were excluded.
- The same argument, avoid energy losses, and facilitated distributions and supply, justify that the areas located more than 200 km from populated zones were excluded. Also, spaces occupied for population nuclei were excluded.
- The proximity to transport networks is an important factor to be considered for solar power plant implementation site selection, as building new roads and railways networks bring significant additional costs to the project. To avoid this, areas located more than 40 km from the transport network were excluded. Areas less than 100 m from a road or railroad were also excluded to avoid negative impacts on the transportation network.
- Protected areas must be excluded from the implementation of large RES plants, to ensure their preservation. Following the ProtectedPlanet.net website, the number of protected areas in Algeria is 78 with a total area of 174,219 km² representing around 7.5% of the total area of the country.
- For safety reasons, the airport areas were not considered to install power plants [35,55].
- Topography variables are of extreme importance to ensure the required technical conditions to install thermal solar power plants. Cylindrical Parabolic Trough and Linear Fresnel Reflectors technologies require a site with a slope of less than 2%. In the case of solar towers and Dish, the allowable slope of the terrain could be 5% [56]. However, the lower slope can generally reduce the investment cost and especially for the CSP power plants that are very sensitive to this factor [33]. According to The World Bank [57]; the maximum value of the slope is usually set between 1% and 3% for CSP. Given the variability of values, for this study, a conservative approach was followed and a maximum slope of 2.1% was considered to be acceptable [33,41].

Also, some authors identified as unfeasible for CSP plants, the areas that are not oriented to the south in the northern hemisphere and the north in the southern hemisphere [32]. Adequate locations to capture maximum solar energy are then facing to the south, south-east and south-west in the northern hemisphere exposed to radiation all year round, in particular during the daily middle hours. Nevertheless, although a south-facing zone would have better results, it does not mean that CSP cannot be implemented in the

Table 3
Data sources.

Element of database	Source
Annual direct solar irradiation	Global Solar Atlas and published by the World Bank Group. The Data has been downloaded in GeoTIFF format and the resolution data is 250 m.
Roads and railways	Road network and railroad spatial data has been obtained in shapefile format for 2004 from International Steering Committee for Global Mapping and The National Institute of Cartography and Remote Sensing, Algeria.
Density population	Population density for each 100 m × 100 m grid square has been obtained from Pop World. A general view of the data is available in Tatem et al. [60] and the description of the methods used can be found in Stevens et al. [61].
Electricity grid	Electricity Transmission Network of 2017 of Algeria available in the dataset of the World Bank. This dataset is classified as public under the Access to Information Classification Policy. The file is downloaded in json. Using this file and the map of electricity grid data of Algeria from the Ministry of Energy and Mines of Algeria [52], the electrical network (lines and substations), have been digitalized.
Slopes	Slopes have been calculated from Digital Elevation Model obtained from Shuttle Radar Topography Mission (SRTM 90m Digital Elevation Database v4.1) [62,63].
Protected areas	Data have been downloaded for March 2020 from ProtectedPlanet.net. Boundaries of some protected areas have been digitized from Google Maps.
Airports	Airports spatial data has been obtained in shapefile format for 2004 from the International Steering Committee for Global Mapping and The National Institute of Cartography and Remote Sensing, Algeria./
Permanent rivers, streams or dumps	Permanent rivers, streams or dumps spatial data were obtained from International Steering Committee for Global Mapping.

northern hemisphere. As such, in this paper, orientation was not considered as an exclusion criterion.

On the same hand, the CSP power plant requires water for its cooling and cleaning which poses important questions for effective water management in the country. Water scarcity is a fundamental concern in Algeria in general and in the Sahara region in particular [58]. Following Ziuku et al. [59] areas locate more than 30 km from water bodies were excluded. Data from waterways and dams, lakes and irrigated areas of Algeria are obtainable via the International Steering Committee for Global Mapping for all rivers including both intermittent and permanent flows. However, the number of digitized streams in an arid country like Algeria, makes this information uncertain. In fact, the spatial data were checked by the authors with satellite images and a large number of digitized streams were linked to intermittent, dry streams. Therefore, only remote areas from permanent rivers, streams, damps and irrigated areas have been taken into account as an exclusion criterion. This is because the spatial information linked to them, are more accurate.

4.1.2. Calculation and mapping of unsuitability criteria and areas

Table 3 shows data sources used for calculating and mapping the unsuitability criteria. All these data search and standardization has been carried out in this paper. To this end, the use of GIS, capable of integrating and normalizing spatial information of different nature, has been fundamental.

Once the spatial information has been determined, it was normalized. The same spatial resolution and the same coordinate system were assigned to them. The coordinate system used was the WCGS84, projected in use 31 N (EPSG25830) and the spatial resolution was 100 m^2. The ArcGIS 10.3 software was used for spatial analysis. Following this, criteria have been calculated and mapped, assigning the value of 0 to incompatible zones and 1 to compatible zones. This was carried out using three ArcGIS parameters: *Reclassify*, *Slope* and *Distance*.

Reclassification is an operation that assigns different values to the input data according to certain criteria. Regarding to DNI, the DNI raster values have been reclassified assigning the value of zero to those pixels whose DNI values are lower than 1800 kWh/m^2. The value of 1 has been applied to the rest of the pixels as presented in equation (1).

$$\begin{cases} \text{If } DNI_{(i,\dots,n)} < 1800; & DNI_{(i,\dots,n)} \text{ then } Z_{DNI\,(i,\dots,n)} = 0 \\ \text{If } DNI_{(i,\dots,n)} \geq 1800; & DNI_{(i,\dots,n)} \text{ then } Z_{DNI\,(i,\dots,n)} = 1 \end{cases} \tag{1}$$

Where $DNI_{(i,\dots,n)}$ = DNI value for pixel (i, …,n) and $Z_{DNI\,(i,\dots,n)}$ is the reclassified value for each pixel (i, …,n) for DNI criterion.

The slope is calculated through the ArcGIS *slope*[1] function. This parameter calculates the rate of maximum change in z-value from each pixel of a raster surface. In this case, the raster surface used is SRTM 90m Digital Elevation Database v4.1. Once the slope for each pixel has been calculated, the *Reclassify* parameter has been used to assign values of 1 to the cells with slopes lower than 2.1% and 0 to the rest, as presented in equation (2).

$$\begin{cases} \text{If } S_{(i,\dots,n)} > 2.1; & S_{(i,\dots,n)} \text{ then } Z_{S\,(i,\dots,n)} = 0 \\ \text{If } S_{(i,\dots,n)} \leq 2.1; & S_{(i,\dots,n)} \text{ then } Z_{S\,(i,\dots,n)} = 1 \end{cases} \tag{2}$$

Where $S_{(i,\dots,n)}$ = Slope value for pixel (i, …,n) and $Z_{S\,(i,\dots,n)}$ is the reclassified value for each pixel (i, …,n) for Slope criterion.

Regarding the remaining of the criteria, firstly a distance map has been generated for each of them (distance to: electricity network, population nuclei, roads and railroad lines, natural protected areas and airports). The ArcGIS parameter used to calculate the distance has been *Euclidean distance*[2] that results in a map of distance from each pixel in the raster to the closest source. Once the distance to each of the criteria has been calculated, the reclassification orders have been carried out, as presented in equation (3).

$$\begin{cases} \text{If } Dp_{(i,\dots,n)} > R; & Dp_{(i,\dots,n)} \text{ then } Zi_{(i,\dots,n)} = 0 \\ \text{If } Dp_{(i,\dots,n)} \leq R; & Dp_{(i,\dots,n)} \text{ then } Zi_{(i,\dots,n)} = 1 \end{cases} \tag{3}$$

Where $Dp_{(i,\dots,n)}$ is criterion Dp value for each pixel (i, …,n) and R is restriction values for each criterion (for example, R value is 200 km for population density and electricity network) and $Zi_{(i,\dots,n)}$ are the reclassified values for each pixel (i, …,n) for "i" criterion.

Once the exclusion criteria have been calculated and mapped, these criteria have been multiplied to generate the map of incompatible zones, as presented in equation (4).

$$Za_{(0;1)} = \left(Zi_{(0;1)} * \dots * Zn_{(0;1)}\right) \tag{4}$$

Where the $Za_{(0;1)}$ are the final incompatible values, and Zi-n are incompatible values for each criterion for each pixel.

Finally, an analysis of the number of incompatibility criteria met by each pixel has been carried out. For this, reclassification values have been reversed. Therefore, the value of 1, has been applied to incompatible pixels and value 0 to compatible ones. Finally, each

[1] See ArcGIS 10.3 Help (https://pro.arcgis.com/es/pro-app/tool-reference/spatial-analyst/how-slope-works.htm).

[2] See ArcGIS 10.3 Help (https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/euclidean-distance.htm).

criterion has been added, obtaining, for each pixel, the total number of criteria that this pixel does not meet, as presented in equation (5).

$$Zb_{(0;1)} = (Zi_{(i;1)} + :::::::: + Zn_{(0;1)}) \quad (5)$$

Where $Zb_{(0;1)}$ the final unfeasibility values and Zi-n are incompatible values for each criterion.

4.2. Ranking suitable areas

Once the incompatible areas have been identified, compatible areas must be ranked according to their suitability for installing CSP power. Three stages were carried out for this purpose: 1) Selection of suitability factors; 2) Application of weights; 3) Calculation and mapping of potential areas.

4.2.1. Selection of suitability factors

The most relevant factors (or criteria) used for the case of the Algeria region and other countries are summarized in Fig. 3. They are based on the work of Tazi et al. [33]; Alami-Merrouni et al. [32] and Shao et al. [14]. These are designed to guarantee maximum productivity (areas with greater radiation and orientation of the slope) as well as greater energy and territorial efficiency of the installation.

4.2.2. Factor weighting

Once the factors (or criteria) have been identified, it has been considered that not all of them contribute in the same sense and have been weighted. For the weighting, the Analytic Hierarchy Process (AHP), has been used. AHP is one of the most used methods to choose the best locations of RES power plants as shown in the precedent Table 1.

Saaty [48] proposed the AHP approach and the principal advantage of this method is its inherent ability to handle intangible and less cumbersome mathematical calculations. This method is structured in three main steps:

Step 1 Define the problem and fix the goal.
Step 2 Build the hierarchical diagram of the MCDM problem as shown in Fig. 2.
Step 3 Experts consultation to weigh the importance of criteria to evaluate site suitability. A linguistic scale may be used and the pairwise comparison of criteria concerning the objective is attempted. Then, the expert judgments are converted to numeric values using Saaty [64] scale presented in Table 4.

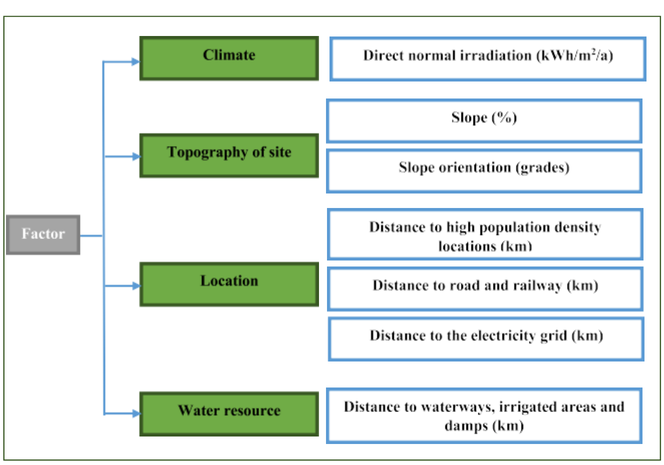

Fig. 3. Relevant criteria used to select the appropriate site.

A face-to-face meeting with each expert was favored and if this meeting was not possible phone meetings were organized. In this study, twelve experts were consulted to evaluate the appropriateness of the criteria for the site for CSP site selection in Algeria according to seven criteria presented in Fig. 3.

The consulted experts have been working for more than fifteen years in this field, the group may be divided into two expertise areas. One area includes experts holding a PhD in different disciplines (mechanical, electrical and environmental engineering). They are currently working as researchers in solar thermal energy projects for the case of Algeria and most of them are leaders of research groups of the Renewable Energy Development Center (CDER) of Algeria. The other group includes engineering practitioners (mechanical, electrical) working on a power plant from an international company operating in Algeria. Some of these experts worked also in the installation of the CSP plant of Hassi r'mel in Algeria.

Each expert made an individual decision and then all decisions were integrated into in-group decision to obtain the one final decision [65].

The pairwise comparison matrix is elaborated to present the relative importance of the factors as illustrated in Fig. 4 [66]. In this figure, a pair-wise comparison matrix is shown for n criteria labeled as Ci presented on the top and left side of the matrix.

The pair-wise matrix is normalized by dividing each value in the pair-wise comparison matrix by its column sum. Following, the values of the rows of the normalized matrix are summed and divided by the number of factors (in this case 7), to obtain the priority vector, that shows the relative importance of the compared factors (W). The sum of all elements in the priority vector should be 1.

As the weighing process for the comparison matrix tends to have a subjective nature, a consistency test is required. The Eigenvalue λ_i and consistency index (CI) test of the pairwise comparison is calculated using Eq. (6) and Eq. (7) respectively. Finally, the consistency index (CR) of the matrix comparison is calculated using Eq. (8).

$$\lambda_i = \frac{\sum_{j}^{n} \sum_{i=1}^{n} (A_{ij} w_j)}{A_{ij}} \quad (6)$$

Consistency test,

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (7)$$

Consistency ratio,

$$CR = CI/RI \quad (8)$$

The random index (RI) is selected from Table 5 for each pairwise matrix comparison. The judgment matrix may be considered consistent, and consequently, the comparison matrix may be acceptable, if the CR does not exceed 0.1. In case of inconsistency, the expert should be contacted and the evaluation must be repeated until an acceptable matrix is reached.

When a set of experts is involved, different approaches may be used for the aggregation (see for example [67,68]. For the sake of simplicity, arithmetic mean was used to aggregate the final weights provided by each expert, as shown in equation (9).

Table 4
Crisp value of preference scale for AHP.

Scale of importance for comparison pair $A(a_{ij})$	Numeric Rating	Reciprocal (decimal)
i is extremely more important than j	9	1/9 (0.111)
i is very much important than j	7	1/7 (0.143)
i is much important than j	5	1/5 (0.200)
i is moderately more important than j	3	1/3(0.333)
i is equally important than j	1	1 (1.000)

$$A_{ij} = \begin{array}{c|cccc|} & C_1 & C_2 & \cdots\cdots\cdots & C_n \\ \hline C_1 & a_{11} & a_{12} & \cdots\cdots & a_{1n} \\ C_2 & a_{21} & a_{22} & \cdots\cdots & a_{2n} \\ . & . & .. & \cdots\cdots\cdot & a_{3n} \\ . & . & . & \cdots\cdots & . \\ C_n & . & & & \\ & a_{2n} & . & \cdots\cdots & a_{nn} \end{array}$$

Fig. 4. The pair-wise comparison matrix
Where:
$n =$ Criteria number to be evaluated
$C_i =$ i^{th} Criteria
$a_{ij} =$ importance of criteria i^{th} compared to criteria j^{th}
$a_{ij} =$ importance of criteria i^{th} compared to criteria j^{th}
For all i and j it is necessary that.
$a_{ij} =$ 1 Reflects equal importance
$a_{ji} = \frac{1}{a_{ij}}$ Reflects reciprocity in judgment

Table 5
Random consistency index for matrices of size n.

N	1e2	3	4	5	6	7	8	9
RI	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

$$P_i = \sum_{i=1}^{n} \frac{w_i}{N} \quad (9)$$

Where P_i is the final aggregated priority assigned to criterion i.

The AHP method calculation was elaborated using Excel software and performed to compute scores and rank the suitability rating of the site according to the well-established mathematical methodology [69].

Table 6 summarizes the aggregate expert assessment. DNI, electricity and population density were highlighted as crucial factors for choosing the location of CSP plants. Not surprisingly, the potential of solar energy (given by DNI) was selected as the most important factor to be considered. DNI is of course fundamental for the techno-economic viability of these projects as was already debated in the literature [33]. Both the distance to the electricity grid and to locations with high population density are considered to be highly relevant. The high weight assigned to the distance to the grid and big consumer centers indirectly demonstrate the importance given to the grid losses and related cost concerns.

Table 6
Weights assigned to each factor (criterion) for evaluation of CSP installation.

Factors	Weight (%)
Direct normal irradiation (DNI)	27.05
Distance to roads and railways	05.31
Distance to high population density	22.95
Distance to the electricity grid	23.00
Distance to waterways and damps	12.51
Slope	05.48
Slope orientation	03.70

Also, water resources were considered decisive for selecting the best site for CSP power plants. The country is facing a big problem of water availability and the water management challenge seems to be well understood by the experts. Finally, distance to roads, railways, slopes and orientation of slope were judged less important compared to other criteria.

The final ranking of the alternatives was then computed based on the weights assigned to each factor (or criterion), as explained in the next section.

4.2.3. Calculation and mapping of potential areas

Once the suitability factors and the weights to be applied to each of them have been identified, these have been calculated and mapped using ArcGIS. The sources used are those indicated in Table 3.

The orientation has also been calculated from SRTM 90m Digital Elevation Database [62,63]. For this, the parameter *Aspect*[3] from ArcGIS has been used. The same digital elevation model was used to calculate the slope. Also, data from waterways (permanent rivers of first and second order, that due to their width are easier to obtain) and damps, lakes and irrigated data of Algeria are obtainable via International Steering Committee for Global Mapping. This issue is considered in this step assuming it as a positive criterion by means to prioritize as better areas those located close to damps, and water in lands. Once the factors have been calculated, they have been normalized between 0 and 5, using the quantiles as classification methods (Fig. 5).

This means that for each criterion the areas cataloged with 0 are unfeasible areas, the areas assigned, by means of *Reclassify function*, a value of 1 to represent those that obtain 20% of the lowest values and the areas cataloged with a value of 5 represent 20% of the highest values, and therefore, better suited for the installation.

It is necessary to mention the case of the slope orientation factor that has been normalized in the following way: value 5 for south orientation, value 3 for SW or SE orientation, value 1 for the remaining areas. Fig. 5 shows the maps of the reclassified factors. It is possible to find out how some areas with higher DNI values (Fig. 5f) are considered unsuitable due to the water availability pending (5d), and the higher slopes (5f).

Also, Fig. 5 shows how despite the highest population densities (5a) and therefore the most developed road and electricity transport network (5c and 5b) in the northern areas of the country, these areas have been cataloged as unsuitable. This is due to the Atlas Mountains Range, resulting in the highest slope (5g) and lowest DNI values (5f) given the shadow effect.

The suitability index was calculated following the equation (Eq. (10)).

[3] See ArcGIS 10.3 Help (https://desktop.arcgis.com/es/arcmap/10.3/tools/3d-analyst-toolbox/how-aspect-works.htm).

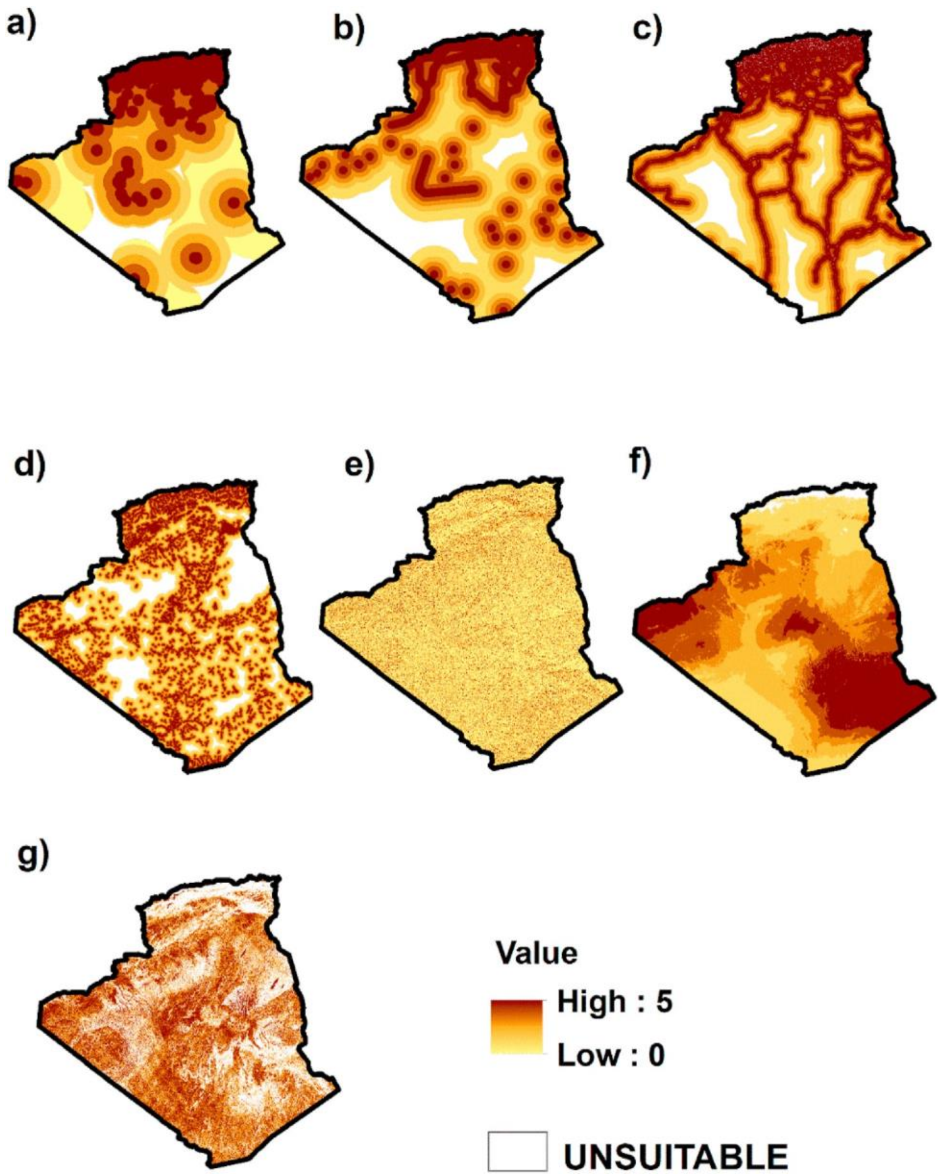

Fig. 5. Normalized maps for each factor: a) Distance to higher density nuclei; b) Distance to the electric grid; c) Distance to the road and railway network; d) Distance to permanent rivers, damps and water inlands; e) Orientation; f) DNI and g) Slope.

$$S_i = S_{ip} \times Za_{(0;1)} \tag{10}$$

Where Si is Suitability Index, Sip is Partial Index value for each pixel and $Za_{(0,1)}$ are final incompatible value for each pixel.

Suitability Partial Index, Sip, is calculated by applying the weighted linear sum method for suitable areas (Eq. (10)), a frequent method applied with the available software that uses either *map algebra* or the weighted linear sum itself. Finally, the result will be multiplied for unsuitable values (Eq. (11)).

$$SIp = \sum_{i=1}^{n} Wi\, X_{ip} \tag{11}$$

Where SIp represents the Suitability Partial Index for cell p (land portion); Wi the weight of criterion i (from Table 6); and Xip the normalized value of the cell p (land portion) for the criterion i. Finally, suitability values have been categorized by deciles intervals, so that the value 10 corresponds with areas that have obtained the 10% of the highest values.

5. Results

5.1. Unsuitable area

Fig. 6 shows the areas of the Algerian country characterized as incompatible for the implementation of CSP. A total of 1,195,800 Km^2 (almost 51.6%) of the territory is considered incompatible with the implementation of CSP power plants.

Considering the incompatible surface by criteria, slope, constitute the criterion that excludes most of the territory (39%), followed by the water availability and distance to the grid. These two last aspects highlight important challenges of the country with a high impact on energy planning: water scarcity and the vast geographical extension.

Regarding the number of unmet criteria (Fig. 7), 90% of inappropriate areas failed to meet between one and three criteria: one—61%; two—29%; three—8%- The remainder of inappropriate areas fail to meet multiple criteria (between 4 or 6).

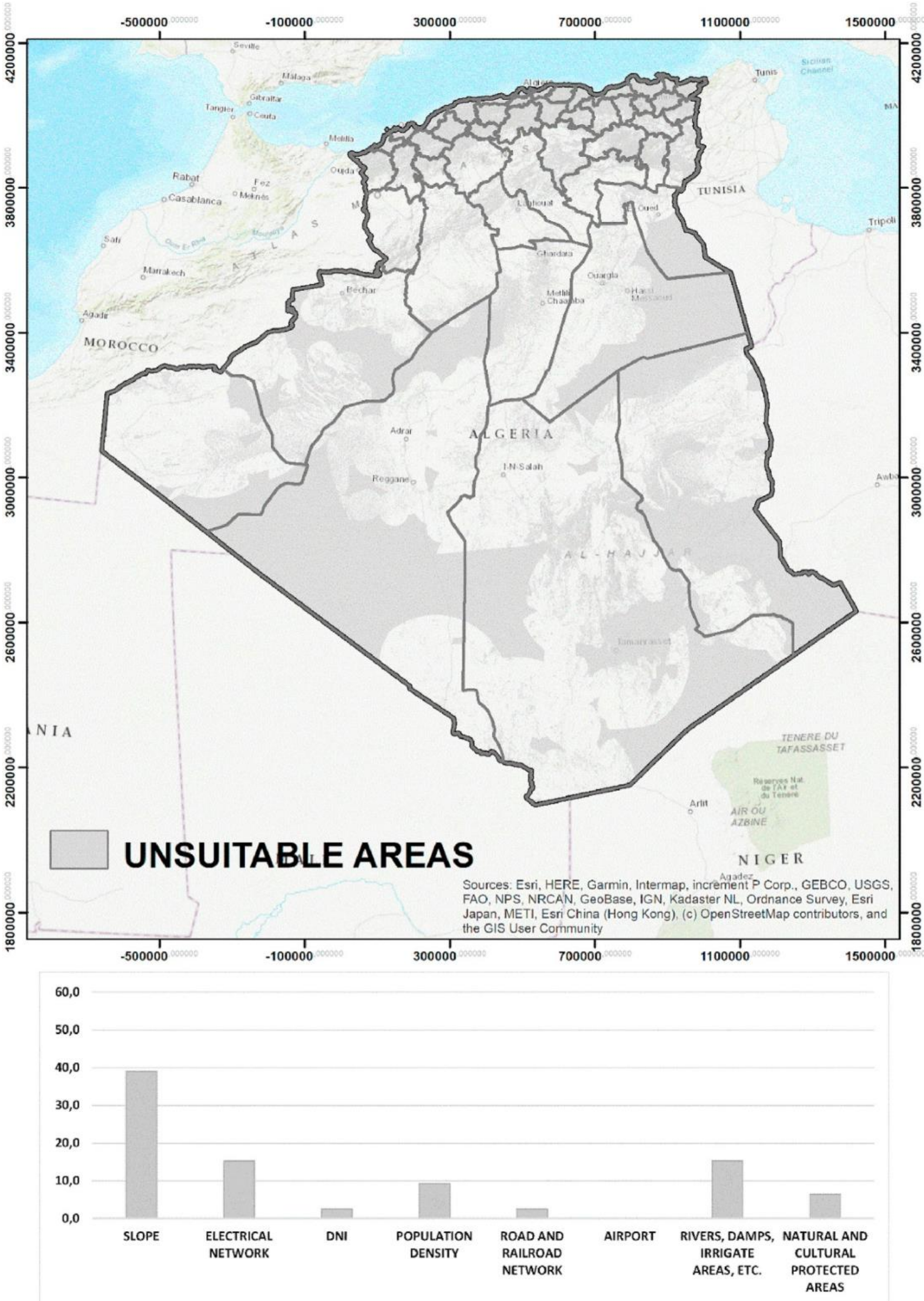

Fig. 6. Unsuitable areas and unsuitable areas rendering to each unmet criteria.

5.2. Suitability areas rank

As for the suitable areas, Fig. 8 shows areas classified according to their potential for CSP installation. The suitability indicator values ranged between 1.3 and 6.7 in the country, categorized by deciles (quantiles). The highest potential values (10% of highest values) are located in the highlands areas that are near to the highest population density, electricity grid, and water resources and with acceptable solar energy availability. These areas represent the best locations for CSP and should be considered for further analysis including additional variables that are costly and difficult to obtain for large areas. It is worth highlighting that, although there are higher solar potential areas in the Sahara, most of this area is unsuitable for installing CSP given the distance from the

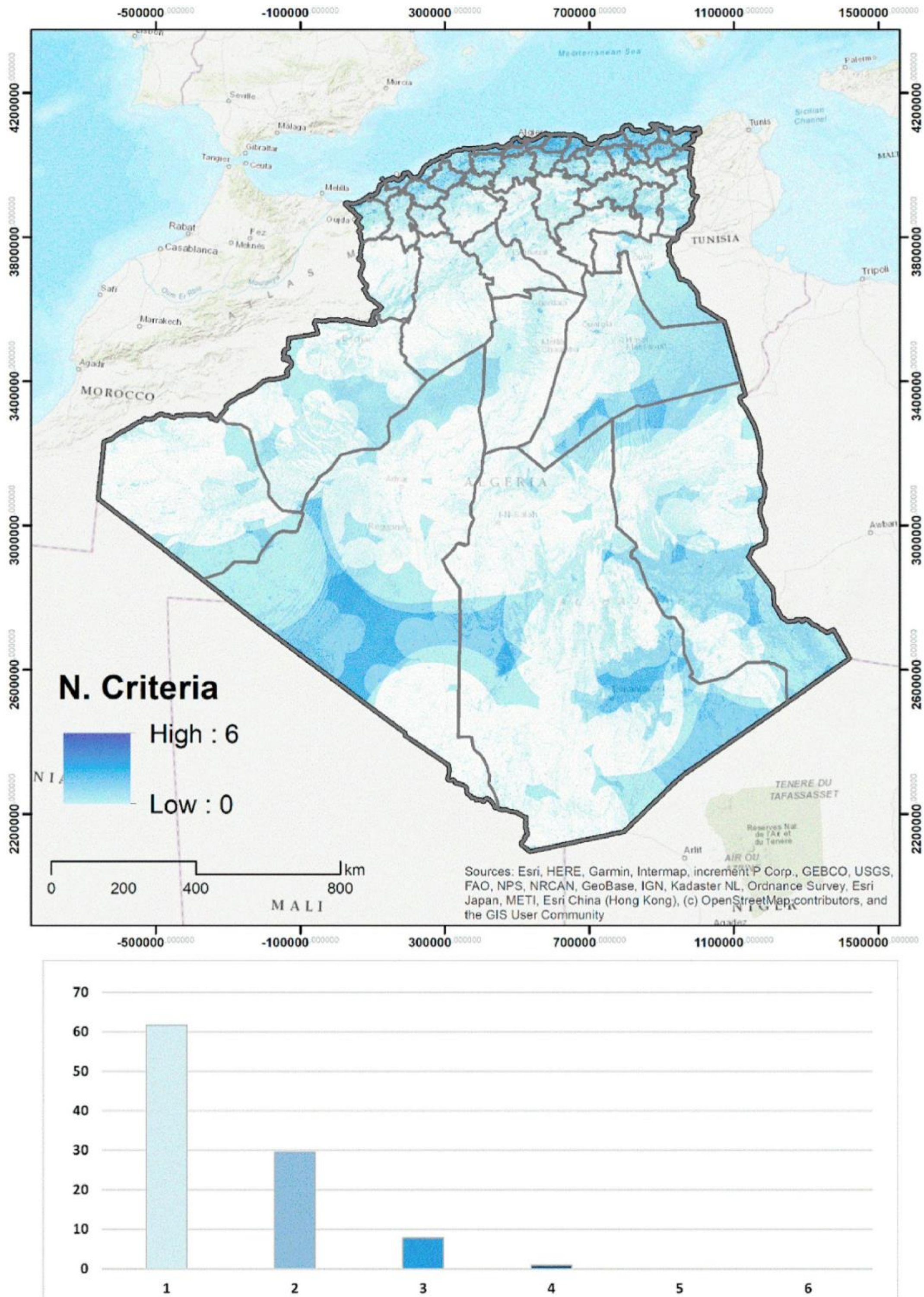

Fig. 7. Unsuitable areas according to the number of unmet criteria.

North of the country which is a region with a dense population and high energy demand.

6. Discussion

In recent years, the commitment to renewable energy has led the definition of objectives to be achieved by several countries. These, in some cases, have been proposed without a real assessment of the territories that could be identified as suitable areas or areas where the activity is unfeasible or highly inadvisable with others [12]. Identifying and mapping these areas is an essential element for the planning of these infrastructures on the territory.

In the case of Algeria, the commitment to renewable energies is well evident in the government plans, with solar energy being one

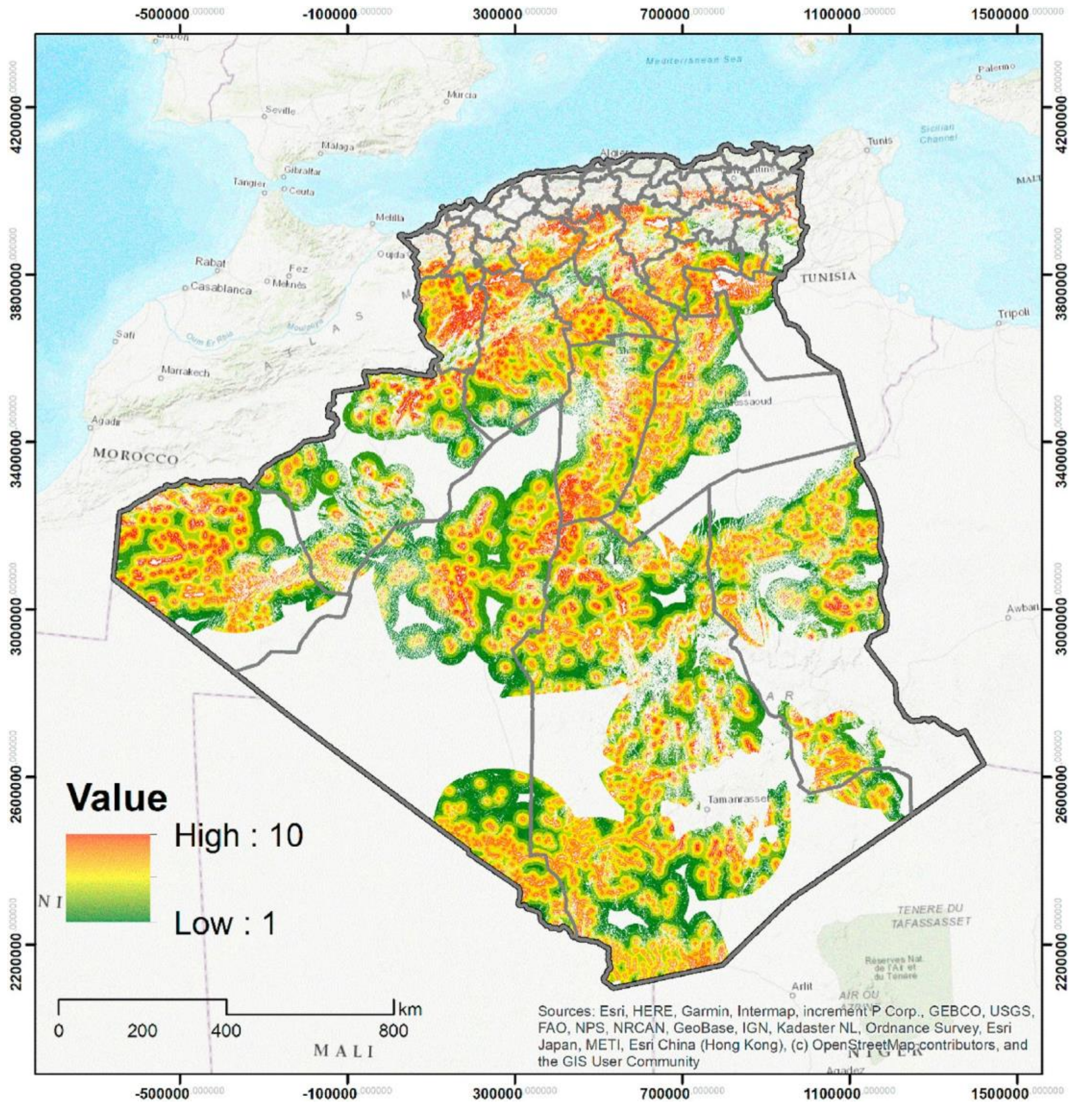

Fig. 8. Potentiality values.

of the most promising options for the country [10]. However, this interest in solar power technologies is mostly justified by the high values of solar radiation available in the country and other considerations that go beyond the radiation criterion must be taken into account to define the potential for the effective exploitation of solar power technologies. The present work aimed then to contribute to this debate by proposing a locational geospatial model for the concentrated solar power installation using a combined MCDM-GIS in Algeria.

This paper adds to the literature reviewed mainly in two ways:

1. Algeria has not been the subject of this research topic previously. Accordingly, this paper will be a reference for future RES mapping examinations in the country.
2. The resulting locational model establishes a dynamic instrument that might be useful to open and private decision makers planning.

Regarding the first point, although several studies addressing the installation of CSP facilities in Algeria are available [70e72], they do not map or select areas according to their potential. To the best of the authors' knowledge, this is the first study on the zoning of the Algerian potential for the implementation of solar facilities that goes beyond the radiation factor. There are many reasons for this but two of them seem to explain most of the difficulties, namely (1) the difficulty of finding appropriate sources of information with quality spatial data that can be used for the spatial display of the criteria and (2) the large size of Algeria's territory, which prevents work with adequate spatial resolutions.

Although there are territories that have a large free official geospatial database available, in this case, obtaining information of this type for Algeria is not an easy task. It is for this reason that, in this work, an extensive effort has been made in searching and compiling geospatial information that is provided mainly from world web portals that distribute them free of charge. Several sources have been consulted, analyzed and compiled. Among those already, the following can be highlighted: Global Solar Atlas, or the SRTM Digital Elevation Database v4, for the orography and topography criteria. Both sources have been used by some authors for close purposes. For example, Dupont et al. [73] used Global Solar Atlas to obtain world solar irradiation values. Also, SRTM 30m Digital elevation was used for Croatia [27], Morocco [32] and Egypt [74] case studies. The large size of Algeria, and the fine spatial resolution (100 m × 100 m), has complicated the necessary analyses, and a server, capable of performing studies at a fine scale has been used. Multiple spatial and thematic indexing tasks have been carried out to speed up the analyses.

Regarding the second point, the model constitutes a useful tool both for public planning agencies and for private investors, which may a priori dismiss areas where this activity is unfeasible or highly inadvisable with some of the values or characteristics of the territory. Identifying areas suitable at this scale would be highly inconsistent. This is because other criteria must be taken into account which, by definition, cannot be assessed at this scale (visual impact, impact on birds, landscape, social acceptance, among others) and even less so for territory as large as Algeria. Besides, the opinion of local decision-makers, industry and sector experts should be sought to select the criteria factors and weights, that should be chosen adapted to the study area, where regulations must be taken into account. The usefulness of this tool is then deemed to be on helping planners and private investors to identify areas to focus and allocate resources. In these areas, further analysis where other variables, that are costly and difficult to obtain for large areas, should be further investigated. The indicator and the associated methodology provide first-hand information to other researchers and policymakers as a first step towards more comprehensive assessments.

The model developed easily allows for re-assessment, in case any of the criteria is updated (for example, the construction of a new road) or the weightings of the criteria changed. Also, the model could point out where the improvement of one of the criteria could increase the area with the highest potential values.

Models and results are generally verified by comparison with other studies in the study area. In this sense, Oakleaf et al. [75]; used GIS and MCDM to generate worldwide zoning at 1 km resolution, to identify incompatible or optimal zones for the implementation of power plants including CSP. The need to analyze the global level forced the use of fewer exclusion criteria. Also comparing with the proposed model in this work, different factors, data sources and resolutions were used.

For example, the average annual direct normal irradiation (DNI) data used in Oakleaf et al. [75]; was obtained from the Global Solar Dataset 3 km, available from 2016, while in our case it has been obtained from the Global Solar Atlas, available from 2017, with a resolution of 250 m. Suitability factors, weightings, and constraints used were also different. Nevertheless, there are several points of concurrence between the two models in the unfeasible areas, both in the number (that is similar, almost 51%) and location (see Fig. 9).

The areas with the greatest potential vary in number. Despite these differences, our results show that approximately 70% of the territory with the highest values match in both models. However, 80% of the values cataloged as very high by Oakleaf et al. [75]; coincides with unfeasible, very low and low areas. This is due, as previously mentioned, to the lower number of unfeasibility criteria used. Consequently, the developed model in this work is more complete, as it uses a greater number of criteria and different sources, some of them, at finer spatial resolutions.

The Algerian government included in the National Program for Renewable Energy, the gradual application of renewable energy in the next years. The government selected Béni Abbès (Béchar province), Naâma, Béchar, M'Ghaïer (El Oued province), El Goléa (Ghardaïa province), Laghouat, Ouargla, El Oued and Adrar as the best areas for installing CSP [11,76]. All of these areas have great solar potential in our model, however, the model also identifies other areas for solar development, such as the provinces of Tindouf, El Bayadh and Tamanrasset.

7. Conclusions

The paper aimed to design a methodology for RES mapping with a particular focus on CSP. This methodology recognizes that the privileged solar irradiation is the main decision factor for the integration of this technology on energy policy goals of the North African regions but explicitly acknowledges and accounts for other factors that cannot only limit the potential of certain locations but can even exclude regions classified as unsuitable areas.

The best areas for CSP installation in Algeria were analyzed using the MCDM approach and GIS software. Results showed that about 51.6% of the total surface of the country was found incompatible for installing CSP. The excluded area was mostly due to the factors related to the proximity to the electricity grid, slope of the site and access to water. Regarding the ranking of the compatibility areas, provinces of Naâma, Laghouat and Ghardaïa were resulted as the best sites, followed by Ouargla and El Oued. The results of the appropriate sites confirm a previous governmental assessment but highlight also some other regions with high potential for CSP projects.

The mains research implications and conclusions can be highlighted from this study:

(1) GIS software is a valuable tool to illustrate data, carry out the necessary analyses and present results in the geographic maps to support the resolution of complex problems as is the case of the selection of renewable energies power plants location.
(2) The combination of MCDM and GIS results in an effective decision support model as it allows for the inclusion of technical and non-technical criteria and integrates value judgment in this model. The results show that although Algeria presents high DNI values, other criteria should be considered for an effective decision making process.
(3) The results are sensitive to two main factors: data availability for GIS mapping and the experts' feedback. This last aspect in particular calls for further research. The extension of the number of the stakeholders involved would be of great benefit, to ensure that a consensual mapping would be achieved in the end avoiding social conflicts, feelings of unfairness and even compensation costs.
(4) The proposed methodology can be applied to other RES technologies in the country provided that the criteria are adapted to the specific requirements of each technology. The possibility of applying it to wind and biomass is particularly appealing given the expected growth of these technologies in Algeria.

Although an exertion has been made to utilize the best accessible free geospatial information for our assessments, there are inherent uncertainties due to the nature of global spatial data. Also, there are uncertainties linked to any MCDM process (e.g., setting limitations, calculating spatial criteria values, and selecting criteria weights), and only the uncertainty and sensitivity of a primary source (criteria weights) were evaluated. However, the model presented a necessary approximation to the potential of Algerian territory for the installation of CSP facilities. Areas where more detailed studies should be carried out and higher quality information should be gathered were identified. The analysis is deemed to be useful to support decision making in the energy policy of the country and bringing confidence to investors to install solar power plants.

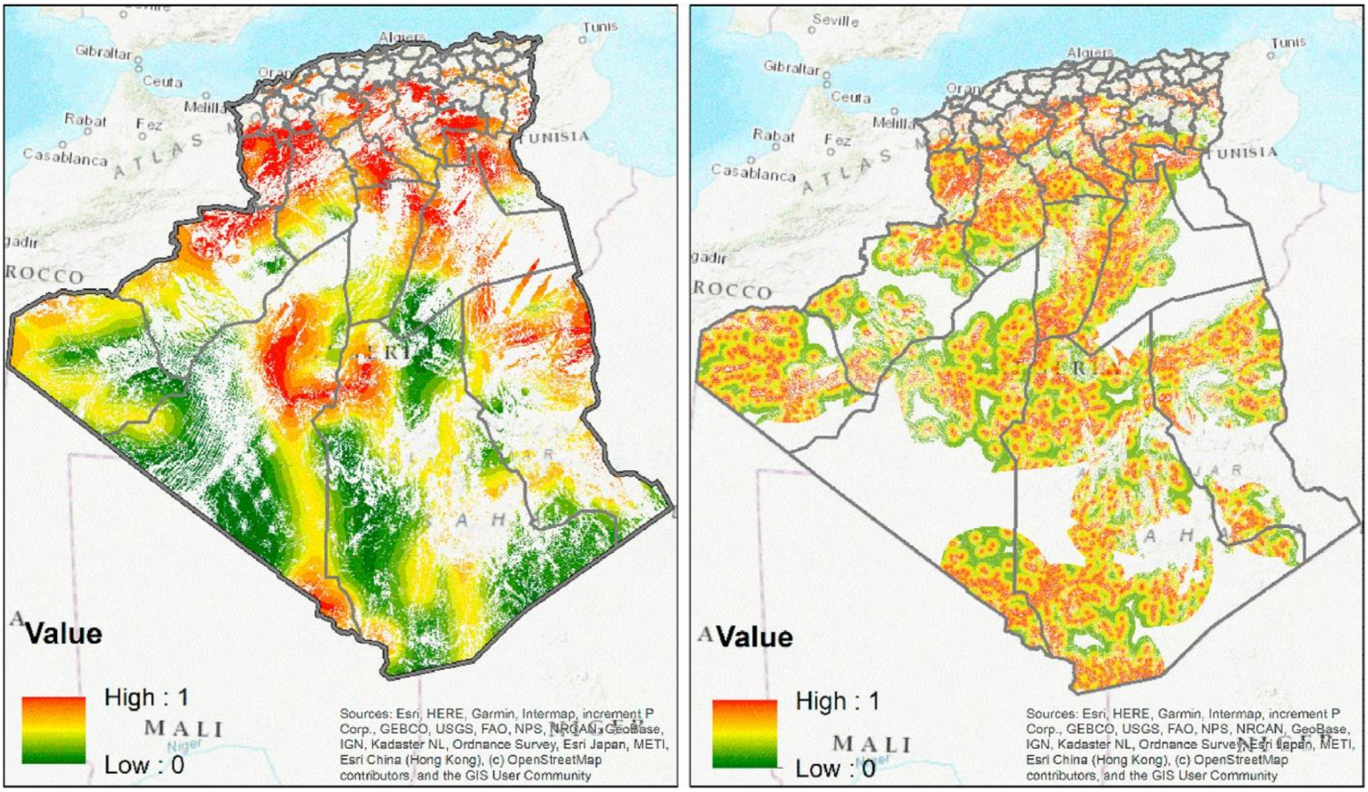

Fig. 9. Suitability values from Oakleaf et al. [75] (a), and from our model (b).

CRediT authorship contribution statement

Brahim Haddad: Conceptualization, Methodology, Formal analysis, Visualization, Writing - original draft. Pilar Díaz-Cuevas: Methodology, Validation, Writing - review & editing, Writing - original draft, Visualization. Paula Ferreira: Writing - review & editing, Writing - original draft, Visualization. Ahmed Djebli: Methodology, Validation, Writing - review & editing, Writing - original draft, Visualization. Juan Pedro Pérez: Methodology, Validation, Writing - review & editing, Writing - original draft, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank all open source data providers and ESRI Maps for provide the background maps. Also authors thank J. R. Oakleaf et al. for make available spatial data linked to global potential for renewable energy. The authors are also thankful to experts of the research center CDER and the engineering experts who participated in the AHP for their assistance.

References

[1] EIA, World energy outlook, Retrieved, 2020 from, https://www.iea.org/reports/world-energy-outlook-2019/renewables#outlook-by-scenario, 2019.

[2] C. Nakhle, Nuclear Energy's Future in the Middle East and North Africa, Carnegie Middle East Center, 2016. Retrieved, 2020 from, http://carnegie-mec.org/2016/01/28/nuclear-energy-s-future-in-middle-east-and-north-africa-pub-62562.

[3] N. Supersberger, F. Laura, Integration of renewable energies and nuclear power into North African Energy Systems: an analysis of energy import and export effects, Energy Pol. 39 (2011) 4458e4465.

[4] B. Brand, K. Blok, Renewable energy perspectives for the North African electricity systems: a comparative analysis of model-based scenario studies, Energy Strategy Reviews 6 (2015) 1e11.

[5] N.S. Ouedraogo, Opportunities, barriers and issues with renewable energy development in Africa: a comprehensible review, Current Sustainable/Renewable Energy Reports 5 (2019) 1e9.

[6] A. Bouraiou, A. Necaibia, N. Boutasseta, S. Mekhilef, R. Dabou, A. Ziane, Status of renewable energy potential and utilization in Algeria, J. Clean. Prod. (2020) 246e119011.

[7] B. Haddad, A. Liazid, P. Ferreira, Electricity planning in Algeria, in: International Conference on Efficiency, Cost, Optimization, Simulation and Environmental, Impact of Energy Systems. Portoroz, Slovenia, 2016.

[8] Algérie Presse Service, Plan d'action du gouvernement pour la mise en œuvre du programme du president de la republique, Retrieved, 2020 from, https://www.algerie-eco.com/wp-content/uploads/2020/02/plan-action-gouvernement-fr-6-fev-2020.pdf, 2020.

[9] IRENA, Estimating the Renewable Energy Potential in Africa, 2014.

[10] H. Haddad, A. Liazid, P. Ferreira, A multi-criteria approach to rank renewables for the Algerian electricity system, Renew. Energy 107 (2017) 462e472.

[11] N. Bailek, K. Bouchouicha, M. EL-Shimy, A. Slimani, Updated status of renewable and sustainable energy projects in Algeria, in: M. EL-Shimy (Ed.), Economics of Variable Renewable Sources for Electric Power Production, Lambert Academic Publishing/Omniscriptum Gmbh & Company Kg, 2017. Publisher.

[12] P. Díaz-Cuevas, J.M. Camarillo-Naranjo, J.P. Pérez-Alcantara, Relational spatial database and multi-criteria decision methods for selecting optimum locations for photovoltaic power plants in the province of Seville (southern Spain), Clean Technol. Environ. Policy 20 (2018) 1889e1902.

[13] A. Kumar, B. Sah, A.R. Singh, Y. Deng, X. He, P. Kumar, R.C. Bansal, A review of multi criteria decision making (MCDM) towards sustainable renewable energy development, Renew. Sustain. Energy Rev. 69C (2) (2016) 596e609.

[14] M. Shao, Z. Han, J. Sun, C. Xiao, S. Zhang, Y. Zhao, A review of multi-criteria decision making applications for renewable energy site selection, Renew. Energy (157) (2020), 977-403.

[15] B. Resch, G. Sagl, T. T6rnros, et al., GIS-based planning and modeling for renewable energy: challenges and future research avenues, Int J Geo-Inf 3 (2014) 662e692.

[16] R. Avtar, N. Sahu, A.K. Aggarwal, S. Chakraborty, A. Kharrazi, A.P. Yunus, J. Dou, T.A. Kurniawan, Exploring renewable energy resources using remote sensing and GISda review, Resources 8 (2019) 149.

[17] H.Z. Al-Garni, A. Awasthi, Solar PV power plants site selection: a review,

Advances in Renewable Energies and Power Technologies 1 (2018) 57e75. Solar and Wind Energies.
[18] S.M. Habib, A.E.E. Suliman, A.H. Al Nahry, E.N.A. El Rahman, Spatial modeling for the optimum site selection of solar photovoltaics power plant in the northwest coast of Egypt, Remote Sensing Applications: Society and Environment (18) (2020) 100313.
[19] H.E. Çolak, T. Memişoğlu, Y. Gerçek, Optimal site selection for solar photovoltaic (PV) power plants using GIS and AHP: a case study of Malatya Province, Turkey, Renew. Energy (149) (2020) 565e576.
[20] G. Rediske, J. Siluk, M. Cezar, L. Michels, P.D. Rigo, C.B. Rosa, G. Cugler, Multi-criteria decision-making model for assessment of large photovoltaic farms in Brazil, Energy (2020) 117e197.
[21] S. Moradi, H. Yousefi, Y. Noorollahi, D. Rosso, Multi-criteria decision support system for wind farm site selection and ensitivity analysis: case study of Alborz Province, Iran, Energy Strategy Reviews (29) (2020) 100478.
[22] P. Díaz-Cuevas, J. Domínguez-Bravo, A. Prieto-Campos, Integrating MCDM and GIS for renewable energy spatial models: assessing the individual and combined potential for wind, solar and biomass energy in Southern Spain, Clean Technol. Environ. Policy 21 (9) (2019) 1855e1871.
[23] D. Messaoudi, N. Settou, B. Negrou, Site selection methodology for the wind-powered hydrogen refueling station based on AHP-GIS in Adrar, Algeria, EnrgyProced 162 (2019) 67e76.
[24] O.N. Mensour, B. El Ghazzani, B. Hlimi, A. Ihlal, A geographical information system-based multi-criteria method fort heevoluation of solar farms location: acase study in Souss-Massa area, southern Morocco, Energy 182 (2019) 900e919.
[25] A. Tunc, G. Tuncay, Z. Alacakanat, F.S. Sevimli, Gis based solar power plants site selection using analytic hierarchy process (AHP) in Istanbul, Turkey, Int. Arch. Photogramm. Remote Sens. Spatial Inf XLII-2/W13 (2019) 1353e1360. Sci.
[26] M. Giamalaki, T. Tsoutsos, Sustainable siting of solar power installations in Mediterranean using a GIS/AHP approach, Renew. Energy 141 (2019) 64e75.
[27] I. Gašparović, M. Gašparović, Determining optimal solar power plant locations based on remote sensing and GIS methods: a case study from Croatia, Rem. Sens. (2019) 11e1481.
[28] P. Díaz-Cuevas, GIS-based methodology for evaluating the wind-energy potential of territories: a case study from andalusia (Spain), Energies 11 (10) (2018) 1e16.
[29] M.B. Alqaderi, W. Emar, O.A. Saraereh, Concentrated solar power site suitability using GIS-MCDM technique taken UAE as a case study, Int. J. Adv. Comput. Sci. Appl. 9 (4) (2018) (IJACSA).
[30] A. Yushchenko, A. Bono, B. Chatenoux, M.K. Patel, N. Ray, GIS-based assessment of photovoltaic (PV) and concentrated solar power (CSP) generation potential in West Africa, Renew. Sustain. Energy Rev. 81 (P2) (2018) 2088e2103.
[31] H. Yousefi, H. Hafeznia, A. Yousefi-Sahzabi, Spatial Site Selection for Solar Power Plants Using a GIS-Based Boolean-Fuzzy Logic Model: A Case Study of Markazi Province, Energies, Iran, 2018, pp. 11e1648.
[32] A. Alami Merrouni, F. Elwali Elalaoui, A. Ghennioui, A. Mezrhab, A GIS-AHP combination for the sites assessment of large-scale CSP plants with dry and wet cooling systems. Case study: eastern Morocco, Sol. Energy 166 (2018) 2e12.
[33] G. Tazi, O. Jbaihi, A. Ghennioui, A. AlamiMerrouni, M. Bakkali, Estimating the Renewable Energy Potential in Morocco: solar energy as a case study, IOP Conf. Ser. Earth Environ. Sci. 161 (1) (2018), 012015.
[34] W. Khemiri, R. Yaagoubi, Y. Miky, Optimal placement of solar photovoltaic farms using analytical hierarchical process and geographic information system in Mekkah, Saudi Arabia, in: AIP Conference Proceedings, 2056, 2018, 020025.
[35] T.R. Ayodele, A.S.O. Ogunjuyigbe, O. Odigie, A.A. Jimoh, On the most suitable sites for wind farm development in Nigeria, Data in Brief 19 (2018) 29e41.
[36] M. Deswal, J.S. Laura, Selection of collection sites and optimization of waste bins of rohtak city, Haryana (India), Int. J. Eng. Res. Dev. 14 (4) (2018) 29e38.
[37] H.Z. Al-Garni, A. Awasthi, Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia, Appl. Energy 206 (15) (2017) 1225e1240.
[38] M. Sadeghi, M. Karimi, GIS-Based solar and wind turbine site selection using multi-criteria analysis: case study Tehran, Iran, Int. Arch. Photogram. Rem. Sens. Spatial Inf. Sci. XLII-4/W4 (2017). Tehran's Joint ISPRS Conferences of GI Research, SMPR and EOEC 7-10, Tehran, Iran.
[39] B. Rapal, A. Sumabat, N. Lopez, Analytic hierarchy process for multi-criteria site selection of utility-scale solar and wind projects, Chemical Engineering Transactions 61 (2017) 1255e1260.
[40] O.P. Akkas, M.Y. Erten, E. Cam, N. Inanc, Optimal site selection for a solar power plant in the central anatolian region of Turkey, Int. J. Photoenergy (2017) 13. ID 7452715.
[41] A. Aly, S.S. Jensen, A.B. Pedersen, Solar power potential of Tanzania: identifying CSP and PV hot spots through a GIS multicriteria decision making analysis, Renew. Energy 113 (2017) 159e175.
[42] M. Mierzwiak, B. Calka, Multi-criteria analysis for solar farm location suitability, Rep. Geodesy Geoinf. 104 (2017) 20e32.
[43] Y. Noorollahi, H. Yousefi, M. Mohammadi, Multi-criteria decision support system for wind farm site selection using GIS, Sustainable Energy Technologies and Assessments 13 (2016) 38e50.
[44] M. Szurek, J. Blachowski, A. Nowacka, Gis-based method for wind farm location multi-criteria analysis, Min. Sci. 21 (2014) 65e81.
[45] M. Uyan, GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey, Renewable and Sustainable Energy Reviews 28 (2013) 11e17.
[46] A. Tahri, Y. Bounadja, B. Mehtougui, PV system performance evaluation tool based on MATLAB environment, in: The 3rd Asia-Arab Sustainable Energy Forum & the 5th Int. Workshop on SSB Hirosaki, 2013, pp. 6e8. Japan.
[47] J.M.S. Lozano, J.T. Solano, P.L.S. Elvira, M.S.G. Cascales, Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: case study in south-eastern Spain, Renew. Sustain. Energy Rev. 24 (2013) 544e556.
[48] T.L. Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation (Decision Making Series), McGraw-Hill International Book Co, New York, 1980.
[49] F. Amrouche, A. Benzaoui, F. Harouadi, B. Mahmah, M. Belhamel, Compressed Natural Gas: the new alternative fuel for the Algerian transportation sector, Procedia Engineering 33 (2012) 102e110.
[50] ONS, Retrieved from, http://www.ons.dz, 2020.
[51] United Nations, World population prospects, 28pp, Retrieved, 2020 from, https://population.un.org/wpp/Publications/Files/WPP2019_DataBooklet.pdf, 2019.
[52] MEN, Ministry of Energy and Mining of Algeria, Bilan énergétique national, 2019.
[53] S. Shoufila, L'avenir énergétique de l'Algérie : quelles seront les perspectives de consommation, de production et d'exportation du pétrole et du gaz à l'horizon 2020-2030, Les Cahiers du CREAD 96 (2011).
[54] M. Abbas, Z. Belgroun, H. Aburidah, N.K. Merzouk, Assessment of a solar Parabolic Trough power plant for electricity generation under mediterranean and arid climate conditions in Algeria, Energy Procedia 42 (2013) 93e102.
[55] D. Sarpong, P.E. Baffoe, Selecting suitable sites for wind energy development in Ghana, Ghana Mining Journal 16 (1) (2015) 8e20.
[56] A. Thiam, C. Mbow, M. Faye, P. Stouffs, D. Azilinon, Assessment of hybrid concentrated solar power-biomass plant generation potential in sahel: case study of Senegal, Nat. Resour. 8 (2017) 531e547.
[57] World Bank, Middle East and North Africa Region Assessment of the Local Manufacturing Potential for Concentrated Solar Power (CSP) Projects, World Bank, Washington, DC, 2011. Retrieved, 2020 from, http://documents.worldbank.org/curated/en/543071468278941180/Middle-East-and-North-Africa-Region-assessment-of-the-local-manufacturing-potential-for-Concentrated-Solar-Power-CSP-projects.
[58] N. Drouiche, R. Khacheba, R. Soni, Water policy in Algeria, in: S. Zekri (Ed.), Water Policies in MENA Countries. Global Issues in Water Policy, 23, Springer, Cham, 2020.
[59] S. Ziuku, L. Seyitini, B. Mapurisa, D. Chikodzi, van KuijkK, Potentialof concentrated solar power (CSP) in Zimbabwe, Energy Sustain Dev (23) (2014) 220e227.
[60] A. Tatem, WorldPop, open data for spatial demography, Data 4, Sci (2017) 170004, https://doi.org/10.1038/sdata.2017.4. Retrieved, 2020 from.
[61] F.R. Stevens, A.E. Gaughan, C. Linard, A.J. Tatem, Disaggregating census data for population mapping using random forests with remotely-sensed and ancillary data, PloS One 10 (2) (2015), e0107042.
[62] T.G. Farr, M. Kobrick, Shuttle radar topography mission produces a wealth of data, Eos Trans. AGU 81 (48) (2000) 583e585.
[63] T.G. Farr, P.A. Rosen, E. Caro, R. Crippen, R. Duren, S. Hensley, M. Kobrick, M. Paller, E. Rodriguez, L. Roth, The shuttle radar topography mission, Rev. Geophys. 45 (2) (2007).
[64] T.L. Saaty, A scaling method for priorities in hierarchical structures, J. Math. Psychol. 15 (3) (1977) 234e281.
[65] E. Forman, K. Peniwati, Aggregating individual judgments and priorities with the analytic hierarchy process, Eur. J. Oper. Res. 108 (1) (1998) 165e169.
[66] L.M. Abdullah, Analytic Hierarchy Process Based Methods and its Applications, university of terranago, Malaysia, 2015. Edited by.
[67] W. Ossadnik, S. Schinke, R.H. Kaspar, Group Aggregation techniques for analytic hierarchy process and analytic network process: a comparative analysis, Group Decis. Negot. (25) (2016) 421e457.
[68] F. Pauer, K. Schmidt, A. Babac, K. Damm, M. Frank, et al., Comparison of different approaches applied in Analytic Hierarchy Process - an example of information needs of patients with rare diseases, in: BMC Medical Informatics and Decision Making, 16, 2016, p. 117. Nr. 1.
[69] R. Whitaker, Validation examples of the analytic hierarchy process and analytic network process, Math. Comput. Model. 46 (7e8) (2007) 840e859.
[70] A.Rouibah,D.Benazzouz, R.Kouider,A.Al-Kassir, G.J.G.Sanz-Calcedo, K.Maghzili, Solar tower power plants of molten salt external receivers in Algeria: analysis of direct normal irradiation on performance, Appl. Sci. 8 (8) (2018) 1221.
[71] N. Yamani, A. Khellaf, K. Mohammedi, O. Behar, Assessment of solar thermal tower technology under Algerian climate, Energy 126 (2017) 444e460.
[72] S. Boudaoud, A. Khellaf, K. Mohammedi, Solar tower plant implementation in Northern Algeria: technico economic assessment, in: 5th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO), Hammamet, 2013, pp. 1e6.
[73] E. Dupont, R. Koppelar, H. Jeanmart, Global available solar energy under physical and energy return on investment constraints, Appl. Energy 257 (2020) 113968.
[74] Effat, Mapping solar energy potential zones, using SRTM and spatial analysis, application in lake nasser region, Egypt International Journal of Sustainable Land Use and Urban Planning. ISSN: 1927-8845 3 (1) (2016) 1e14 [IJSLUP].

[75] J.R. Oakleaf, C.M. Kennedy, S. Baruch-Mordo, J.S. Gerber, P.C. West, J.A. Johnson, J. Kiesecker, Mapping global development potential for renewable energy, fossil fuels, mining and agriculture sectors, Scientific Data 6 (2019) 101.

[76] Laissaoui M., Bouhalassa A., Hazmoun M., Lechehab S., Simulation d'une tour solaire a concentration par sam. Séminaire International sur le Génie Climatique et énergétique, 9-10 et 11 Novembre 2015 Constantine, Algérie.