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A GIS-AHP combination for the sites assessment of large-scale CSP plants with dry and wet cooling systems. Case study: Eastern Morocco

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ABSTRACT

In this paper, we assessed the suitability of the Eastern region of Morocco to host large-scale Concentrating Solar Power (CSP) plants by combining Geographic Information System (GIS) and the Analytic Hierarchy Process (AHP). For this reason, a high spatial resolution GIS database is built using layers provided from different governmental organizations. Additionally, since the potential of the Direct Normal Irradiation (DNI) is the most important criterion for CSP site selection; a high-quality satellite solar map with a spatial resolution of 1 km^2/pixel and twenty years of time coverage was used.

Since CSP power plants need cooling systems for their power block cycle; the suitability of two cooling techniques (dry and wet) were evaluated for this region.

Results show that Eastern Morocco can be considered as a very good location for hosting CSP power plants. For the wet cooling systems, the highly suitable sites to host CSP plants represent 11.7% from the total area, while 5.5% is the proportion of the highly suitable sites for CSP plants with dry cooling systems.

1. Introduction

The development of CSP is promising because they can keep producing electricity after the sun sets or during cloudy periods of the day, thanks to the thermal energy storage. According to the IEA's road map (IEA, 2014), the electricity produced from CSP has strongly increased since 2010, and currently the global operational capacity is around 4728 MW (https://www.nrel.gov/csp/solarpaces/projects_by_status.cfm?status=Operational). The road map envisions that the installed capacity of CSP will reach 1000 GW by 2050, which will avoid 2.1 Gt of CO_2 emissions each year and contribute to 11% of the global electricity production.

Morocco is a deficient country regarding fossil fuels, but it has the potential to be a source of renewable energy, particularly solar and wind (Ouammi et al., 2012; Kousksou et al., 2015). This can cover a part of the country's energy needs and export to Europe as well (Boie et al., 2016). For this reason, the country launched an ambitious project to produce 42% of the electricity from renewable energy sources (14% from wind, 14% hydraulic and 14% solar) by 2020 (http://www.one.org.ma/).

Regarding solar energy, the Moroccan Solar Plan (MSP) was launched in 2009, and the Moroccan Agency for Solar Energy (MASEN) was created for the realization of this project. The objective of the MSP is to produce 2000 MW from solar energy, and five sites were selected to host the future solar plants (Tsikalakis et al., 2011). This plan started with the inauguration of the first part of the NOOR complex in Ouarzazate, with an electrical production of 160 MW and 3.5 h of storage (http://www.masen.org.ma).

The second phase of the MSP will be the construction of a 400 MW plant in Eastern Morocco. For this reason, we got the motivation to conduct this study with the objective to highlight the suitability of this region for hosting CSP power plants with different cooling techniques. To do so, maps with high spatial resolution, and a combination between Geographic Information System (GIS) tools and a Multi-Criteria Decision Making (MCDM) approach has been used.

The combination of GIS tools and MCDM techniques became a successful approach to solve the complex problem of site selection for solar plants. Many researchers use this technique to evaluate the capacity of their regions or countries to host green power plants. For instance, Tahri et al. (2015) assessed the suitability of southern Morocco to host large photovoltaic (PV) farms by using GIS tools and Analytical Hierarchy Process (AHP) – one of the MCDM techniques that will be discussed in detail in the next sections- and they found that 23% of the

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study area is highly suitable to host those kinds of plants. Uyan (2013) used the same technique to evaluate the capacity of Karapinar region in Turkey to host PV plants, and 13.92% of the areas were highly suitable. Some other studies were conducted for southern Spain as well, and the rates of areas with high suitability were 3% for Murcia and 5% for Granada (Sánchez-Lozano et al., 2013; Carrión et al., 2008).

In the literature, the assessment of the suitable sites to host solar plants is mainly dedicated for photovoltaic technology, and only a few studies deal with CSP. Besides, most of the papers dealing with CSP, either investigate the integration on a specific site (Gastli et al., 2010), or do not specify the cooling technic to be used. Furthermore, water availability is rarely considered as a criterion during the site assessment analysis.

Knowing the fact that the DNI is the main criterion for the CSP sites assessment; the use of high quality DNI solar map is crucial. In the literature, most of the authors use low quality solar maps; for instance (Fluri, 2009) used a low-resolution satellite database (40 × 40 km/pixel), and (Ziuku et al., 2014) who created a DNI map by interpolating the ground measurement data.

In this paper, we used a combination of the AHP and GIS tools to find out the most suitable sites to host CSP plants in the Eastern region of Morocco. The used DNI solar map has a high spatial and temporal resolution (1 × 1 km/pixel and an average over 20 years). Additionally, the assessment of the suitability of our study area to host CSP power plants has been done for both cooling techniques dry and the wet.

In the first part of this paper we present and describe the GIS database used in this study. After that, the AHP method, the criteria definition and their weights are described. Finally, two maps showing the suitable sites to host CSP power plants with wet and dry cooling systems are presented and discussed.

Results show that 5.5% and 11.7% of the region's area, are highly suitable to host CSP plants with dry and the wet cooling systems respectively. While, the non-suitable sites represent 76.3% of the total areas. Those results can be of high interest, not only for MASEN or the Moroccan policy makers, but also for the international investors as well, since Morocco has recently adopted a new regulation allowing private companies to build large renewable energy power plants and inject the electricity produced into the national grid (www.mem.gov.ma). This will undoubtedly contribute to the creation of new jobs and sustainable development, not only for the region, but for the country as well (Sooriyaarachchi et al., 2015).

2. Methodology

2.1. Geographical location

The Eastern region of Morocco is located at the northeast of the country (Fig. 1), bordering Algeria for 500 km in the east and the Mediterranean Sea for 200 km in the north. The surface area of the region is 82800 km2, which represents 11.7% of the country's area. The region has a very young population, and 61% are considered as power-labor. The region has an urbanization rate of 67%, and more than 80% of the population is concentrated in the northern part (www.hcp.ma). This region is well known with its high capacity to produce electricity from both CSP and PV power plants (Alami Merrouni et al., 2016a, 2016b; Ait Lahoussine et al., 2015; Alami Merrouni et al., 2017a, 2017b, 2017c).

2.2. The GIS database

The selection of the most suitable sites for the installation of large-scale CSP plants is very complex, and different parameters have to be taken into consideration during the analysis. Indeed, the solar potential alone is not sufficient; the land suitability and availability have to be taken into consideration as well. A CSP plant cannot be installed in a city, a forest, or a mountainous region (Schlecht and Meyer, 2012), and for economic reasons, it must be as close as possible to the infrastructure for the material transportation during the construction, as well as to the electrical grid to inject the produced electricity (http://www.endorsefp7.eu).

In this study, we primarily collected and built a GIS data set of the solar irradiation, accessibility, hydrology, and land availability of Eastern Morocco. Afterward, a constraints layer was created assembling all the unsuitable areas. Then, the criteria for two cooling scenarios (dry and wet) were defined, and the weight of each criterion was calculated using the AHP method for both scenarios. Finally, the sites suitability for the CSP plants installation was calculated by combining the GIS and the MCDM for the dry and wet cooling scenarios.

2.2.1. Solar irradiation map

In order to assess the solar potential for a region or a country, it is crucial to develop a solar map with high accuracy. Several methods are available for the solar maps development. In the literature, some authors interpolate the solar irradiation data measured at ground level to create a solar map (Bachour and Perez-Astudillo, 2014; Alsamamra et al., 2009). Another technique is the use of the area solar radiation within the ArcGIS software's tools (Clifton and Boruff, 2010). Nevertheless, the most used technique is the analysis of satellite images (Janjai et al., 2013; Martins et al., 2007; Viana et al., 2011; Mahtta et al., 2014). This method provides solar irradiation data for long periods of time (10–20 years), and it covers a large area. Numerous databases provide solar data from the analysis of satellite images (NASA's SSE Release 6.0 (https://eosweb.larc.nasa.gov/sse/), PVGiS (http://solargis.info), and the clean power research SolarAnywhere's database (Perez et al., 2002). For more details about the satellite datasets refer to (Vernay et al., 2014).

In this study, we extracted the DNI solar map of Eastern Morocco from the IRESEN's server map portal (http://www.iresen.org/mapserver/). This map was developed by the MINES ParisTech, the German Aerospace center (DLR), ARMINES, and TRASVALOR in the framework of Solar-Med Atlas project. The map has a high spatial resolution of 1 km and a long-term coverage of 20 years (1991–2010) (http://www.solar-med-atlas.org/solarmed-atlas/map.htm#t=dni).

The DNI map (Fig. 2) resource database was provided by Helioclim-3 within the SODA service. This source of data is considered as very acceptable for resource assessment. It has been reported in the literature, that under the Moroccan climate the DNI Bias is around 7.9% for the hourly DNI records for an average of two years (2012–2013) (Alami Merrouni et al., 2017a, 2017b, 2017c). Additionally, knowing the fact that the error decrease significantly while using long term measurements, we can say that the solar map used in this study is very accurate.

2.2.2. Infrastructure

Generally, a solar plant has to be accessible; it must be as close as possible to cities, roads, railways and electricity grid. Fig. 3 shows the complete road network, the railway network, the cities, and the power grid network of Eastern Morocco. Because of the fast-economic growth and the creation of new projects in the region (www.oriental.ma), the cities have a tendency to sprawl. For this reason, we decided to present the big cities by a buffer of 5 km and the small ones by a buffer of 2 km.

The road network was built based on topographic maps of the region and the transmission lines data were provided by the National Office of Electricity and Water (ONEE).

2.2.3. Vegetation

Fig. 4, shows the vegetation and the protected areas of Eastern Morocco. A protected area is defined by the International Union for the Conservation of Nature (IUCN) as "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (Günther and Joemann, 2018). The vegetation data were provided by the Regional Directorates of Water and Forests (DREF) of the Eastern region of Morocco.