Renewable and Sustainable Energy Reviews 51 (2015) 1354–1362

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The evaluation of solar farm locations applying Geographic Information System and Multi-Criteria Decision-Making methods: Case study in southern Morocco

Meryem Tahri [a,*], Mustapha Hakdaoui [a], Mohamed Maanan [b]

[a] Laboratory of Applied Geology, Geomatic and Environnement, Faculty of Science – Ben M'sik, University Hassan II – Casablanca, Morocco
[b] Laboratory of Littoral, Environnement, Remote Sensing and Geomatic – Institute of Geography and Planning – University Nantes, France

ARTICLE INFO

Article history:
Received 14 January 2015
Received in revised form
15 May 2015
Accepted 9 July 2015

Keywords:
Analytical hierarchy process
Geographic information system
Multi-criteria decision-making
Optimization of locations
Renewable energy
Southern Morocco

ABSTRACT

Environmental policies are currently largely devoted to fostering the development and implementation of renewable energy technologies in Morocco.

This work studies the outcome of combining both Geographic Information System (GIS) tools and the Multi-Criteria Decision-Making (MCDM) method to assess the suitability of a certain set of locations to carry out a renewable energy project. For the sake of concreteness, we consider the case of the Ouarzazate photovoltaic solar energy project, which is located in the southern region of Morocco and aims to be connected to the national power grid of the country. Four criteria were used: location, orography, land use and climate, and the Analytical Hierarchy Process (AHP) was used to calculate the corresponding criteria weights. Climate turns out to be the most important criterion since it defines the potential electricity production of a certain photovoltaic field. Next comes orography, which reveals the steepness or gentleness of the slopes in a particular area. Finally, regarding the location criterion, the most suitable sites are those where the ground is flat and oriented towards the south.

Contents

1. Introduction

With increasing awareness of the risks of climate change, many countries have endorsed strategies for a transition to low carbon economies. A major decarbonization strategy is to substitute fossil power generation with renewable energy sources [1–3].

The 1992 United Nations (UN) Conference on Environment and Development along with the resulting UN Framework on Climate Change breathed new political life into donor assistance for renewable energy. The Kyoto Protocol of the United Nations Framework Convention on Climate Change, which was adopted

* Corresponding author. Tel.: +212 5 22 70 46 72; fax: +212 5 22 70 46 75.
E-mail address: t.meryem4@gmail.com (M. Tahri).

http://dx.doi.org/10.1016/j.rser.2015.07.054
1364-0321/

in December 1997, marked a crucial turning point in the effort to promote the use of renewable energy [4–7].

Global renewable energy capacity has grown rapidly in recent years and is expected to continue to do so [8]. This explains the increase in the global energy demand in the last decade, which can be seen as the direct consequence of significant technology advances [9]. Indeed, cumulative global renewable electricity installed capacity grew by 108% from 2000 to 2013 (from 748 gigawatts (GW) to 1560 GW). Worldwide solar generation grew by a factor of 68 between 2000 and 2013. Germany led the world in cumulative photovoltaic installed capacity [10].

The capacity worldwide of newly-installed solar photovoltaic energy (PV) was 38.4 GW in 2013, with growth coming mainly from Asian countries, especially China and Japan, which now rank as the first and second global markets, respectively. The European Photovoltaic Industry Association scenarios show that solar energy could provide between 10% and 15% of Europe's electricity demand in 2030 [11]. As expected, the Middle East and North Africa (MENA) region has vast resources of solar energy due to its Density of Normal Irradiation (DNI) [12].

The Moroccan authorities launched a National Renewable Energy and Efficiency Strategy in 2008 in order to promote energy efficiency and to meet a 42% (14% solar, 14% wind, 14% hydraulic) target of green energy production by 2020 [13]. By adopting such an ambitious strategy, the government has confirmed its interest in being a serious partner in the Mediterranean Solar Plan (MSP), which would enable the country to take advantage of its significant solar and wind resources, secure its energy supply, reduce its energy dependency and diversify its energy mix. The MSP is expected to enable the country to benefit from solar energy electricity and eventually to export the surplus to Europe, according to the new green energy trade scheme provided by the 2009/28 Directive article 9 [14–16]. Moreover, the installation and operation of renewable energy source plants could have significant economic implications in terms of increased production and employment [17].

Morocco is a country with a high potential for both wind and solar energy [18,19]. In fact, the potential solar radiation is 4.7 kW h/m^2/day in the north and 5.6 kW h/m^2/day in the south. As of 2012, the total installed capacity was 6620 MW. Furthermore, the national electricity demand has significantly increased with a growth rate of 8% [13]. This being said, the Ministry of Energy, Mines, Water and Environment [20] will invest $13.5 billion over the next four years to strengthen its power generation capabilities by building an additional 4585 MW capacity, 40% of which should consist of renewable energy projects [21].

Morocco's goal is to build a total capacity of 2000 MW of electrical production from solar energy at five sites: Ouarzazate (500 MW), Ain Bni Mathar (400 MW), Foum Al Oued (500 MW), Boujdour (100 MW) and SebkhatTah (500 MW) [22].

In 2009, the Moroccan Agency for Solar Energy (MASEN) launched the development of the 500 MW Ouarzazate plant. This ambitious project is being developed in three phases based on two technological variants: Photovoltaic (PV) and Concentrated Solar Power (CSP). Phase one (NOOR I) was achieved in 2015 [23,24]. The MASEN plans to install the second and third phases for grid-connected photovoltaic solar energy near Ouarzazate, with a total capacity of 300 MW of solar thermal energy (200 MW with parabolic-trough mirrors and 100 MW with solar tower technology) [24].

However, no data have been published on the suitability of the location of the Ouarzazate PV farms. For this reason, we chose the case study of this region to assess the most appropriate optimal site selection for the implementation of renewable energy, such as grid-connected photovoltaic solar energy. The aim of this research is to present the basic principles, methods, and some applications of GIS-based Multi-Criteria Decision-Making for solving the complex decision problems of allocating land suitability and producing the maps. The Analytical Hierarchy Process (AHP) is used to calculate criteria weights in order to evaluate existing (NOOR I) and potential sites (NOOR II, III). In addition, this work is designed to compare other case studies. This approach could be applied to other similar areas in the world.

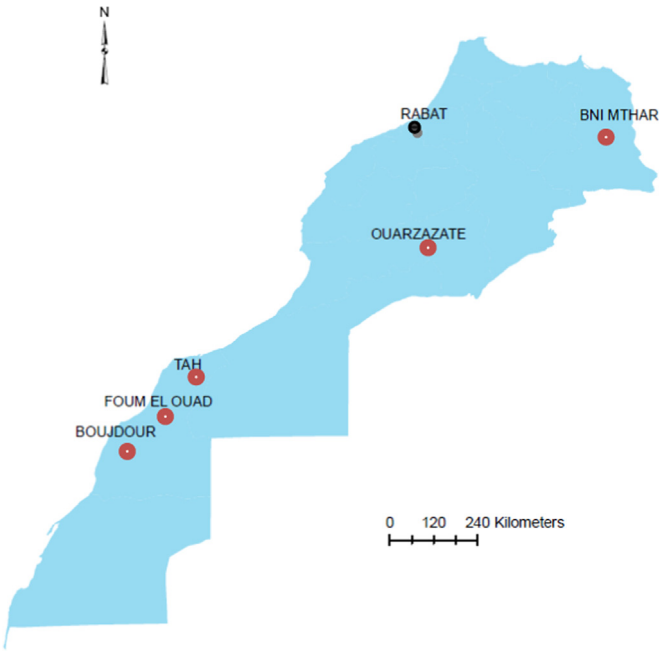

Fig. 1. The five sites identified for Moroccan solar projects.

2. Materials and methods

2.1. Study area

The study area is located southeast of the Atlas mountains (Fig. 1) and includes the region of Ouarzazate, Ghassate and Ait Zineb. It occupies an area of approximately 167,595 km^2 and has a population of around 81,240 [25], with the majority of the land outside the urban area being semi-arid. The phase one solar farm (NOOR I) installed there has a surface area of about 33 square kilometers.

2.2. Application of Multi-Criteria Decision-Making methods (MCDM) in renewable energy

Planning using multi-criteria analysis has attracted the attention of decision-makers for a long time to consider conflicting and subjective criteria [26].

Decision-making is about identifying and choosing alternatives to find the best solution that takes into account different factors and also considers the decision-makers' expectations. Every single decision is made with regard to a certain environment. This environment is the collection of a set of information, alternatives, values and preferences available at the time when the decision must be made [27].

One of the most popular MCDM is the Analytical Hierarchy Process (AHP) [28]. This is a theory of measurement for dealing with quantifiable and/or intangible criteria that has found rich applications in decision theory, conflict resolution and models of the brain. It is based on the principle that, to make decisions, the