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PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation

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ABSTRACT

This paper presents some preliminary results from a research study conducted on solar energy resource assessment in Oman. GIS-based spatial multi-criteria evaluation approach, in terms of the FLOWA module was used to assess the land suitability for large PV farms implementation in Oman. The tool used applies fuzzy quantifiers within ArcGIS environment allowing the integration of a multi-criteria decision analysis. Land suitability analysis for large PV farms implementation was carried out for the case study of Oman. The overlay results obtained from the analysis of the resultant maps showed that 0.5% of the total land area demonstrate a high suitability level. Different PV technologies were considered for implementation. It was found that the CPV technology provides very high technical potential for implementing large solar plants. In fact, if all highly suitable land is completely exploited for CPV implementation, it can produce almost 45.5 times the present total power demand in Oman.

1. Introduction

Despite the cascade effects of the financial crisis that have affected every sector, in varying degree and geography, the investment in renewable energy continues growing with a sustainable trend. According to the new report of the UNEP (United Nation Environment Programme) [1], the investment in renewable energy rose 5% in 2008 proving definitely the establishment of new methods of electric power generation and confirms that this sector represents now a mainstream energy investment [2]. The climate of the good health of renewable energy is the fruit of the interactions of the governmental and societal engagement towards tangible actions to mitigate climate change by reducing Green House Gases (GHG), reducing their dependency on fossil fuel supply and making energy security a strategic priority. Certainly, the current financial and economical crisis may have slowed down the demand on the fossil fuel energy and driven down prices. But, the world opinion is still convinced, that is only a temporary pause. It seems that there is a latent threat form energy crisis, and will constitute a good stimulus for the emergence of the renewable energy era.

To face this threat from resources depletion, solar energy is recognized as a robust alternative to unsustainable energy use in developed and developing countries. During the last two decades, the rhythm of the implementation of solar farm using Photovoltaic (PV) panels or Concentrated Solar Power (CSP) technologies has accelerated in the countries situated in the solar energy belt, despite their prohibitive costs.

According to the International Energy Agency (IEA) solar electricity will grow up to 20–25% by 2050 [1]. The IEA has also foreseen that, by 2050, the PV and CSP systems will be able to generate 9000 TWh of electricity and reduce the yearly CO_2 emissions by almost 6 billion tones [3].

Comparing the CSP and PV technologies, the CSP necessitate larger amounts of water for cooling and mirror washing than the PV. Therefore, for arid countries with scarce fresh water resources, the PV technology is more suitable, environment friendly, and economical. Besides, the implementation of PV plants is much faster than the CSP ones, which gives it more flexibility to cope easily with the development of the grid system. To enable the development of the PV solar technologies long-term oriented strategies with predictable incentives are needed to ensure the successful deployment of PV systems to competitiveness in the most suitable locations and times.

The Geographical Information System (GIS) reached a high level of maturity and emerged as a powerful tool to build solar energy strategies and to integrate large amounts of PV into flexible, efficient and smart grid. GIS is able to handle, processing, analyzing a large quantities of spatial data and underpinning decision-making for the spatial deployment of PV. Using GIS and Multi-Criteria Analysis (MCA) together provide a fine lens for the optimal site selection for plants. GIS-based MCA is commonly used to solve the conflicts of location suitability and harmonizing the tradeoffs

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and risks related to various experts' judgment engaged in the implementation of different applications [4–6]. However, very little was published on solar applications.

This paper presents a study that aimed at developing the first geographical mapping models to locate the most appropriate sites for different PV technologies in Oman using MCA.

2. Overview of multi-criteria analysis

The principal of the MCA is to condense complex problems with multiple criteria into finest ranking of the best scenarios from which an option is selected [7–10]. In GIS-based MCA and for solar energy purpose, this might include a set of geographically defined criteria, such as solar radiation, Digital Elevation Model (DEM), residential area, sensitive area, transmission lines, load demand, road accessibility etc. Weights can be attributed to the criteria according to the importance of each variable in deriving the optimal alternative and each of the variable and their weights may have a more or less favorable in the final decision than another [11].

The GIS-based multi-criteria analysis relies basically on two main approaches: Boolean overlay operators and weighted summations procedures. Both approaches are considered as decision algorithms based on the Ordered Weighted Averaging (OWA) methodology [12–17] which is an ensemble of multi-criteria aggregation procedures using fuzzy set theory. The OWA incorporate both the criterion importance and order weights. It has enough flexibility to generate a large variety of decision strategies.

The analytical hierarch process (AHP) [18] is another approach used in decision-making strategies. It is a robust structured approach dealing with complex decisions. The AHP is based on the additive weighting model and has been used within GIS in two different modes [19]. The first technique can be used to derive the importance weights coupled with criterion map layers. In second step, the weights are aggregated with the criterion map layers in a manner identical to weighted combinations approach [19]. This Method offers an important advantage for a spatial decision problem with a wide range of alternatives making it impossible to complete pair-wise comparisons of the alternatives. The second technique of AHP can be used to combine the priority for all levels of the hierarchical structure, including the level representing alternatives. According to this approach a small number of alternatives can be evaluated [19,20].

OWA and AHP algorithms were incorporated in the GIS platforms since 1995. They were refined afterward with the integration of the AHP_OWA procedures using fuzzy quantifiers in GIS solutions [21]. AHP_OWA have been used around the world in a wide variety of decision situations [22–25]. However, few applications were conducted on renewable energies. In this paper we propose to use the AHP_OWA using fuzzy quantifiers in GIS environments to develop an index for land suitability for PV and CSP farms implementations.

3. Application methodology to PV farms siting

3.1. PV site suitability

Solar energy resource assessment and site suitability for large PV farms implementations is affected by different factors which can be classified in three main categories: Technical, Economical and Environmental. These factors depend on the geographical location, biophysical attributes and socio-economical infrastructure of the country under study.

For a country like Oman, which is situated astride the tropic of cancer and characterized by an arid and very hot climate, the typical parameters that affect most the optimum location of large PV farms are shown in Table 1. Notice that the dust and sand risk factors are only specific to the region and may not apply for other countries with temperate climate.

The suitability of the location of a PV farm is determined based on the combination with different weights of all the factors listed above. The most insolated areas are predisposed to high suitability.

Proximity to roads avoids additional cost of infrastructure construction and consequential damage to the environments. Lands that have minimal value due to past use and present conditions should be evaluated for potential PV farms deployment. PV farms are particularly suitable where the connection to the existing electric grid is effortless. The arrangement to implement PV farms in close proximity to the existing grid and loads pole reduce significantly transmission losses.

Large-scale PV farms require flat terrain or fairly steep slope that is facing south with less than a 5% graded slope. The deployments of the PV at large scale were adopted in the perspective of sustainable development and mitigation of climate change, because it operates for long periods with low maintenance. PV systems were recognized as technologies that have virtually no environmental impact, because, they are clean and silent. From this standpoint, the implementation of PV farms, should respect the sensitive areas under landscape and monument protection due to esthetic requirements. Zone of influences identified as critical risk zone for PV farms such as floods and windy area, should be avoided. Also, area with abundance of dust, combined with the occurrence of fog and mist, will affect the efficiency (revenue) of PV farms. For instance, if a solar collector surface is maintained at a cleanliness level of 90%, the estimated annual loss in revenue reach up to 10% [26]. Furthermore, washing with water (conventional cleaning method) may well involve prohibitive costs especially in an arid country like Oman.

3.2. Selection criteria

In this study, the evaluation criteria were selected based on study goals, spatial scale, and accessibility to the geo-referencing data base. For instance, the resolution of the digital elevation model is selected based on the capacity of the computer machine which is used. Besides, the complete transmission lines spatial dataset were not available and thus were not used. This omission will also allow identifying potential pathways for future transmission lines development to make them pass nearby most suitable locations for large PV farms implementations.

3.3. Analysis tool

The tool used in this analysis is the Fuzzy Logic Ordered Weight Averaging (FLOWA) module developed by Boroushaki and Malczewski [19] that was integrated within ESRI ArcMap 9.3. It incorporates the concept of fuzzy (linguistic) quantifiers into the GIS-based land suitability analysis via ordered weighted averaging (OWA). OWA is defined as a multi-criteria evaluation procedure (or combination operator). The nature of the OWA evaluation procedure

Table 1
Classification of factors affecting optimum locations for large PV farms.

Technical	Economical	Environmental
Solar Radiation	Grid proximity	Sensitive areas
Land Accessibility	Land slope	Hydrographic line
Land use	Load poles	Sand/dust risk