Optimal Site Selection for Solar Farms Using GIS and AHP: A Literature Review

Nabila Tabassum Suprova, MD. Abidur Rahman Zidan, and A.R.M. Harunur Rashid
Department of Mechanical & Production Engineering (MPE)
Islamic University of Technology (IUT)
Board Bazar, Gazipur 1704, Dhaka, Bangladesh.
nabilatabassum@iut-dhaka.edu, abidurrahman@iut-dhaka.edu,a_rashid@iut-dhaka.edu

Abstract

The world is shifting towards renewable energy resources to mitigate environmental problems and,solar energy is one of the most widely used energy sourcesin supplying electricity in many countries. Selecting the appropriate land for solar farm is of crucial importance because of its direct implications onpower output, economic, environmental, and social factors, as well as current and future resources and infrastructure. This paper gives a literature review on the evaluation criteria of selecting these farms using Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) by taking into account factors such as, the solar radiation potential, site location, transportation and techno-economic aspects. The literature is structured and analyzed based on the hierarchy model development, criteria description, objectives, optimal site selection, and constraints. The studies show that the most popular approach is AHP and its extensions with subsequent overlay tool analysis in a GIS environmentin addition to solar irradiation being the key factor in selecting suitable land area. Lastly, through the content analysis framework, the relevant findings in decision-making criteria and gaps are identified that will contribute to promising research directions in the solar energy field in the future.

Keywords
Geographical Information Systems (GIS), Analytical Hierarchy Process (AHP), Multiple criteria analysis, Solar farms, Location planning

1. Introduction
In today's world, energy is fairly considered as a primary measuring criterion of modernization. Electricity demand, one of the country's most important infrastructures, is steadily increasing, resulting in increased industrial and economic activity as well as population growth. Because of these realities, electricity generation plays a significant role in energy policies, and its mismanagement has implications on the environment. Furthermore, deciding on the best method for generating energy has a huge impact on the standard of human lives. Until recently, maximum energy was acquired from fossil fuel sources, such as coal, natural gas, etc. As most of the non-renewable energy resources have limited lifetimes, they are facing a high rate of degradation even though the global energy consumption is skyrocketing day by day.The reason behind this is the contribution to global warming by the release of greenhouse gases due to the consumption of fossil fuel resources in addition to their continuous depletion without being concurrently replaced. In an attempt of protecting the climate, countries have been trying to adopt clean energy sources as their primary source of energy. Renewable energy is the energy that attained from resources which can be naturally replaced within a small timeframe. Many types of renewable energy have become commercially viable in recent years as a result of rapid technological advancement, such as solar, wind, hydro, geothermal, etc. When compared to other sources, solar energy is among the most inexpensive, reliable, safe, and available energies, and is particularly recommended in semi-arid and arid regions. [1]

The deployment of renewable energy such as solar energy has a much greater potential as all resources enforced are ubiquitous and provided for free. There are bountiful prominent sites throughout many countries that could quite conveniently be used as a solar PV power plant. Solar power is the power extracted from sunlight that is further converted into electricity which at times could be done using photovoltaics (PV) or by using concentrated solar power or a blend of both. Solar power is a clean, self-sufficient source of energy which also reduces carbon footprint since it does not omit any greenhouse gas. The implementation of solar power has evolved as one of the world's

© IEOM Society International

fastest surging renewable sources. A while back, many more have recognized that solar energy could become the next new transition in the succeeding days for energy generation.

The amount of solar energy, as expressed by the solar constant, is 1367 W/m^2 as stated by the World Energy Council.By considering both absorption and scattering,the total solar flux reaching the earth's surface is calculated to be 1.08108 GW, and the total amount of energy reaching the earth's surface is 3,400,000 EJ per year. This is about 7000 to 8000 times the global primary energy consumption per year.[2]An equivalent of around 10,000 GW of electricity can be generated by converting only 0.1% of this energy with efficiency as minimal as 10%, rounding the global total to around 6000 GW. The IEA has declared that thirty years from now, solar energy would provide 11% of the world's energy needs.However, by 2030, it is estimated that renewable energy sources will have increased significantly, with an annual growth of 7.6 percent.(IEA2).

The identification of an ideal location for a PV solar power plant is vital to ensure that adequate amount of the solar energy is incorporated to electricity.There are a number of benefits of power generation using solar energy which include environmental advantages, government incentives, versatile locations as well asaccessibility.[3]The challenge of site selection for solar power systems has perplexed electricity generation firms, grid companies, and government agencies. To comprehend the importance of this identification, a number of consequences can be looked at. To begin with, it optimizes transmission planning and also delivers opportune land access. This optimization also leads to developing appropriate scheme and planning for solar energy production. Besides, it helps to protect the ecology by eliminating environmentally sensitive sites and hence, provides reliability for solar power market as a whole.

The amount of solar irradiation varies throughout the year and is more intense in some regions than other. For the installation of utility-scale solar PV plants, vast areas with promising amount of solar irradiation per year are available eventhough, one of the barriers in solar power development is the inconsistency and variability of solar irradiation owing to the geographically dissimilarityof one site to another. There are certain aspects that are essential for the proper utilization of a solar PV plant. This comprises of the strength and weakness of the location of the powerplant, reduction in cost of the project by installing it in an existing framework of infrastructures while maximizing the output power from the solar panels.[4]Furthermore, the factors that affect the performance output of a solar powerplant can be categorized into technical, economic and environmental factors. [5]Conducting research prior to installation of a solar farm is therefore a key step in securing a cost-effective and high-performing solar project.

To achieve these objectives, Geographic information system (GIS)-based approaches for sustainable solar power system planning and design have been used successfully. To supplement GISs' inherent capabilities in determining the spatial patterns or characteristics of events and their attributes, computational models and methods (e.g., probability/statistical, machine learning, and data mining methods) have frequently been combined with GISs.According to the National Center for Geographic Informationand Analysis of the USA (NCGIA),the GIS is described as a system of both hardware and software that is created for the capture, storage, evaluation, modelling and finally representation of the data that is spatially referenced in aid of the solution to complex issues in management and planning sectors. [6]As such, for the analysis of solar farm site selection, GIS have been widely used in this kind of studies for the selection and compilation of essential data.

Multi-Criteria Decision-Making (MCDM) methods have also been used extensively, and these have been integrated frequently with GIS in order to evaluate qualitative and quantitative spatial criteria simultaneously. Given that certain criteria can affect site selection, the use of multiple criteria decision-making (MCDM) approaches can help promote site selection by including key considerations in the decision process for utility-scale grid-connected PV solar energy systems.[7]The Analytic Hierarchy Process—AHP is one of the most common MCDMs. Its key characteristic is that the decision problem is modeled using a hierarchy, with the main goal of the problem at the top and the potential alternatives to be evaluated at the bottom and can be used to visualize and endorse decisions that have several and sometimes overlapping targets. the incorporation of GIS and AHP is a potent procedure for addressing the question of site selection for solar power plants.

© IEOM Society International

1.1 Objectives

In this paper, some of the mostvaluable studies in this field in the last 10 years (2010-2020) are reviewed and presented to achieve all required criteria. The associated studies with solar site selection in different countries using various methodologies are summarized in Table 1.The scope of this review was limited to published literature on GIS-based AHP decision analysis methods and applications in solar radiation mapping, site evaluation, and potential evaluation of setting up solar power plants.There have been a large number of research work on solar potential. The complexity of applying this technology into real-world applications differs significantly between the studies that are earlier mentioned and this paper. This study comprises of the analysis and summary of the overall roles and applications of GIS to research associatedwith solar farm site selection that is not confined to only solar plants. Table 1 summarizes the associated studieswith solar PV site selection. This paper is organized into four sections, starting with a review of the literature using GIS, MCDM and AHP, followed bycomparison and description of the criteria and restriction factors acquired from the data and a comprehensive analysis of the implications of these factors on the final results. Lastly, the conclusion was summarized.

Table 1. Summary of previous research studies on solar site selection

Country	Area-case study	method	References
Oman	Oman	GIS-Fuzzy AHP-OWA	[8]
Spain	Cartagena (Region of Murcia), in south east Spain	GIS-AHP-Topsis	[9]
	Valencian Community, a Spanish region in the east of Spain	GIS-DEM	[10]
Turkey	Western Turkey	GIS-Fuzzy OWA	[11]
	Karapinar region of Konya Province in the Central Anatolia region of Turkey.	GIS-AHP	[12]
	Karaman, Turkey	GIS-MCE-AHP	[13]
	Turkey	MCDM-AHP	[14]
	Igdir, Turkey	GIS-AHP	[15]
	Antalya, turkey	AHP) and FVIKOR	[16]
	Istanbul, Turkey	GIS-AHP	[17]
	Malatya, Turkey	GIS-AHP	[18]
	Igdir,Turkey	GIS-AHP	[1]
England	South Central England	GIS-AHP	[19]
Serbia	Serbia-geographically positioned in southeastern Europe	GIS_MCDM-AHP	[20]
Iran	Isfahan province, Iran	GIS-AHP	[21]
	Iran	GIS-AHP	[22]
	Iran	GIS-fuzzy AHP	[23]
	Tehran, Iran	GIS-AHP	[24]
	Iran	GIS-Boolean Fuzzy	[25]
	Iran	OWA-based approach and GIS	[26]
	Yazd, Zarabad, Chaldoran and Baneh (Iran)	MADM method-TOPSIS	[27]
	IRAN: provinces of Mazandaran, Kermanshah, Razavi Khorasan, and Yazd	GIS-OWA model +MCDA	[28]
	Fars province, Iran	GIS-MCDA-FUZZY AHP-FUZZY ANP	[29]
	Shodirwan region in Khuzestan province, Iran	GIS-Fuzzy AHP	[30]
	Khuzestan province, Iran	GIS-Fuzzy AHP	[31]
Saudi Arabia	Saudi Arabia	GIS, MCDM, AHP	[32]

© IEOM Society International

Morocco	Eastern Morocco	GIS-AHP	[33]
	southeast of the Atlas Mountains, Morocco	GIS-AHP	[34]
	Eastern Morocco	GIS-AHP	[35]
Korea	Ulleung Island, Korea	GIS-AHP	[36]
Thailand	Songkhla, Thailand	GIS-AHP	[37]
Mauritius	Mauritius	Multi-criteria GIS	[38]
China	China's capital, Beijing	GIS-MCDM-Best Worst Method	[39]
	China	AHP	[40]
Pakistan	14 cities in Pakistan	AHP-F-VIKOR approach	[41]
India	Seven districts of Rajasthan in India	GIS-Fuzzy AHP	[42]
	India	AHP-Fuzzy TOPSIS	[43]
Indonesia	Indonesia	GIS-AHP	[44]
	West Kalimantan Province (WKP). INDONESIA	GIS-AHP-MCDA	[45]
	Bali	GIS- Fuzzy AHP - PROMETHEE	[7]
Mediterranean	Regional Unit of Rethymno, Mediterranean	GIS-AHP (spatial MCDM)	[46]
Iraq	Erbil Governorate—Iraq	GIS and Boolean-AHP	[47]
Bhutan	Bumthang valley in central Bhutan	GIS-AHP	[48]
Kuwait	Kuwait	GIS	[49]
Egypt	Northwest Coast of Egypt	GIS-AHP	[50]
	Ismailia Governorate, Egypt	AHP	[51]

2. Literature Review

Ahmet, Seda and Gokhan[1] mentioned about applying analytical hierarchy process (AHP), one of the MCDM in addition to geographical information systems (GIS) to locate the most suitable areas for solar-wind energy with case studies in four counties of Igdir: Tuzluca, Igdir Central, Karakoyunlu and Aralik.In this studyboth qualitative and quantitative factors were analysedand problems were solved by using mapping technique and AHP method. The GIS-based model suggested by Mahmoud, Ahmed and Hassan[52]demonstrates the application of GIS as a Decision Support System (DSS) in developing national strategies with regards to the siting of best solar PV systems farms as well asin evaluating the potential electric power generation.

To achieve the result, Shaimaa, Ahmed, Alaa and Eid (2020) used the Analytic Hierarchy Process (AHP) method to determine the weights of the multi-criteria (techno-economic and environmental), concluding it to be a more suitable tool to solve site selection problems.[5]H.S., A. Sunarso, K. Ibrahim, S.A. Murti, I. Budiarto (2020) applied reliable site-suitability assessment toolsof solar power plants to account for the protection of cultural, natural, and ecological conservation areas.[53]A work done by Ugyen and Jai Govind (2020)[48] evaluated the Solar Energy Potential for Bumthang valley in central Bhutan using geographic information system (GIS) and Analytic Hierarchy Process (AHP). Similarly, sustainable siting areas for solar power generation farms siting were identified by Marina and Theocharis(2019)[46], allowing the application of a spatial multi-criteria decision-making approach.A study done by A. Tunc, G. Tuncay, Z. Alacakanat and F.S. Sevimli(2019) showed that in terms of managing multi-layered geographic data, regulating benchmark weight, and presenting the result product in an appropriate format, the combined use of GIS and MCDM techniques has provided significant benefits.[17]

Another study done by Shahid, Juntakan, Kuaanan, Jompob and Saroj [37]presents a GIS-based method for locating suitable sites for utility-scale wind and solar farms in Thailand's Songkhla Province. In a GIS setting, the MCDM approach allows for the solution of complex problems and the facilitation of decision-making and the use of AHP was used to establish the importance and weight of the criteria selected. Twelve maps were created using GIS based on the AHP-calculated weights for both the wind and solar cases, and then overlaid to obtain the final suitability maps.

To determine the best suitable areas for solar power plants Mevlut(2017) [13]combined the AHP with a GIS tool in the Ayranci region in Karaman, Turkey. By using a GIS tool to perform spatial MCE for decision makers,both time and money are saved in the decision-making processes in addition to providing clearer results.

The Analytic Hierarchy Process (AHP) approach was also used in a study to prioritize the land of Khuzestan province, Iran to weigh the techno-economic and environmental criteria and to draw the final map of the suitability of lands as solar farms where fuzzy logic and fuzzy membership functions were used to create criteria layers in the environment of GIS to draw the map of the suitability of lands.[54]Kadek, Riyanarto and Nurul(2016)[7]focused on how integrated Fuzzy AHP-PROMETHEE method directly in ArcGIS can make the process of determining the location of the solar farm will be more simple and effective. Amulti-criteria decision making framework incorporating an analytical hierarchy process involving expert stakeholders was applied by Joss and Malcolm(2015)[55] in a study, which is a novel approach for this type of study, implying reliability in the concluding results. Based on the literature and study done by Rajiv and Harish[42], Fuzzy Analytical Hierarchy Process (Fuzzy AHP), which is advanced and a simple method,can be used for allocation of solar plant in an ideal location.

3. Methodology

3.1 GIS

The ultimate potential of GIS for utilizing geographical knowledge to build a spatial decision support system has been demonstrated. By combining GIS with other approaches, policymakers may gain a greater understanding of their choices and enhance their selection by taking into account a variety of subjective and contradictory parameters. The GIS-based MCDM method is widely used in spatial analysis to find the best sites for a variety of applications, including landfill site selection, urban planning, and renewable energy site selection. Integrating the two fields brings their strengths together and can provide a finer lens and more accurate decision for choosing the best solar site location. The Geographic Information System (GIS) is a computer medium (hardware and software) used to analyze, edit, consult, store, and dispose of spatial data in order to solve complex planning problems. Choosing a site for a utility-scale solar farm based on extensive data, especially from GIS, has a number of advantages. It ensures a high degree of solar irradiation and a moderate air temperature to improve the solar project's efficiency. When the project is built on flat terrain, facing south, and without significant shadow, the site's orientation can be optimized. Taking into account the locations near these utilities and surrounding urban areas, which are the key consumption points, minimizes losses from transportation, power transmission, and development. Moreover, the negative effects on the environment, community, and infrastructure reduces and excludes protected areas and unsuitable sites from the study region. GIS-based technologies are detail-oriented, repeatable across many areas, and can be streamlined to increase automation. They do, though, take time and use a lot of computing resources.

GIS-based solar radiation measurement techniques may be categorized based on the form of data used. If solar radiation data are collected at specific stations, interpolation may be used to approximate solar radiation in regions where it is not measured. Without the use of measuring instruments, GIS maps make it easier to determine radiation levels at different sites and times. There have been several attempts to approximate the spatial distributions of solar radiation or other parameters since solar data are not available for all potential locations. GIS-based approaches for determining ideal sites for solar power plants can be divided into two categories based on whether they are used on a federal or local scale. On a regional scale, site selection experiments using GISs have been extensively undertaken, and the findings have been usefully extended for policy. and the design of the installation. Boolean overlay operators and weighted summation procedures are the two primary methods used in GIS-based multi-criteria analysis. In particular, site assessment using a GIS is useful for promoting regional decision making, and environmental, technological, socioeconomic, and risk factors must be considered in addition to solar radiation. These factors may be used to rule out areas that aren't feasible by means of a Boolean overlay. GISs are useful for determining physical potential (total solar radiation on the surface/rooftop) and geographic potential (available surface/rooftop area when the shadow is taken into account), as well as for DB and simulation, rooftop extraction, radiation, modelling,

© IEOM Society International

shading analysis, and spatial analysis.Furthermore, in the background of technological potential evaluation, GISs can be used to envision and perceive solar energy-based power production or economic values in a geospatial context.

3.2 MCDM

Multiple-criteria decision-making (MCDM) or multiple-criteria decision analysis (MCDA) is an operations analysis sub-discipline that examines multiple competing criteria in decision-making.People have been interested in making decisions that affect their daily lives since the dawn of time. For several years, scientists have been fascinated by the study of how humans do this role. In this sense, we'll need to model the environment in which we'll be moving, i.e., in such a way that it simplifies (represents) the actual structure while still being simple to understand and execute. As a result, we study the various options available to us, as well as the parameters that would be used to test those options. The Multi-Criteria Decision Making (MCDM) appears to be straightforward at first glance, but it is an integral part of the entire discipline.[12] For a long time, decision-makers have been interested in using multi-criteria analysis to consider contradictory and subjective criteria [27]. Decision-making entails identifying and weighing alternatives in order to find the best solution that takes into account a variety of factors as well as the expectations of the decision-makers. Every single decision is made in the context of a specific environment which is a collection of a set of information, alternatives, values and preferences that are available at the time the decision must be made [56].

3.3 AHP

The Analytic Hierarchy Process (AHP) is a math and psychology-based approach for arranging and evaluating complex decisions. It was created in the 1970s by Thomas L. Saaty and has since been refined. It consists of three parts: the end objective or dilemma you're attempting to solve, all potential solutions (referred to as alternatives), and the parameters you'll use to evaluate the alternatives.The aim of a MCDM method is to investigate a number of alternatives in the light of a number of criteria and conflicting objectives [6]. The AHP methodology [57] has been accepted by the international scientific community as a robust and flexible multi-criteria decision-making tool for reviewing complex decision problems. According to Malczewski[58], it's the third most popular approach in GIS multi-criteria decision analysis articles from 1990 to 2004.Fields of application are various: environment and transportation, urban and regional planning, agriculture, tourism and recreation etc. The basic principles of AHP are: structuring the complex decision problem as a hierarchy of objective, criteria, and alternatives, pair-wise comparison of elements at each level of the hierarchy with respect to each criterion on the previous level, and ultimately vertically synthesizing the judgement across the various levels of the hierarchy. The AHP has also been used to select locations for wind farms, hydropower projects,and concentrated solar power plants.

Georgiou and Skarlatos [35] developed AHP-based methodology to calculate and assess land suitability for optimum PVPP site selection. The same authors excluded heavily vegetated areas, open water, and build-up land from the assessment in order to strengthen and restrict it only to PVPP-acceptable areas. Nine constraint factors were also used to generate a binary mask that decreased the evaluated area. Xiao et al. [59]showed that in desert conditions, AHP model can successfully exhibit the best locations for PVPP. Sanchez-Lozano et al.[6] AHP is therefore the best choice because it is widely accepted by the international scientific community as a powerful and scalable tool for solving difficult problems in the decision-making process.[20]

4. Criteria and Restriction Factors

Several criteria and restriction factors should be considered when installing a solar project on a utility-scale with the purpose of optimizing the site, which will result in a more effective system. Table 2 and Table 3 are summaries of the criteria and restrictions factors recurring in the studies reviewed in this paper. It can be seen that solar irradiation is the key factor for commercial-scale solar plants. The top five criteria considered in the criteria for selected solar PV site suitability studies are shown in figure 1.Furthermore, proximity to power lines and substations ensures sufficient grid connectivity and helps to avoid the high cost of constructing new lines while also reducing power loss in the transmission system.

Table 2. Criteria for Solar Farm Suitability Studies

Criteria	Sub Criteria	References
Climate	Solar irradiation	[1][2][23][32][33][16][19][14][27][6][39][16][29][26][28][46][47][8][43][10], [19], [21], [22], [32], [34], [38], [42], [44], [48]–[50]
	Average temperature	[2][9], [11], [12], [23], [27], [33]
	Annual Sunshine hours	[4], [14], [16], [33]
	Number of rainy days	[35]
	Number of cloudy days	[19][16]
	Rainy and snowy days	[19][14]
	Number of dusty days	[19][16]
	Humidity	[19][16] [33][14]
Environmental	Land Accessibility	[1][35]
	Load poles	[1]
	Agrological capacity	[2][29]
	Land use	[1][5][23][14][27][6][15][6][4]
	Pollutant Emission	[33]
Orography	Land slope	[1], [2], [36], [37]-[45], [4], [12], [14], [16], [27], [29], [33], [35][19], [20], [42], [43], [49]
	Elevation	[9], [12], [14], [26], [36], [39], [43]
	Plot areas	[2], [13], [25], [36], [48]
	Land orientation	[2], [16], [23]
Location	Distance to urban areas	[1]-[4], [13], [27], [28]
	Distance from residential areas.	[3], [13], [15], [18], [27], [28], [39], [40][8], [30], [34], [38]
	Distance to transmission lines	[1], [13], [29], [31], [42], [43], [45], [49][5], [12], [20]
	Distance to main roads	[1], [2], [5], [6], [8], [12], [18], [23], [29], [34], [40], [42], [48]
	Distance to substations	[2], [35]
	Distance to powerlines	[24][44]
	Distance to the airports	[3], [9]-[20], [42], [44]
	Distance to the river	[8]-[19], [48], [49]
	Distance to lake and wetlands	[21], [22], [32], [40], [48]
Economic	Payback period (year)	[1], [2], [5], [6], [40], [42], [48]
	Return on investment (%)	[6],[40], [42], [48]
	Net profit on capital (%)	[8], [9], [38], [49]
	Land cost	[18], [31], [32], [34], [38]
Social	Agricultural effect	[19], [44], [48]
	Public interest	[9],[16],[20],[28]
	Public security	[3], [30]
	Policy support	[20],[28],[30]
Risk	Environmental Risk	[1][35]
	Time delay Risk	[48]
	Economical Risk	[42], [48]

The most common restriction used in solar PV site suitability studies is shown in Figure 2. Secure land, agricultural areas as well as watercourses and streams, are obviously the most excluded areas. The securedlands comprise of wildlife sanctuaries, nationalparks, industrial areas, and sacred places.Furthermore, due to the low economicviability of such projects, high slope areas are also not favored.

Table 3. Restriction factors used in solar energy studies

No.	**Restrictions**	**References**
1	Protected Areas	[6][55][7][60][24][4][25][15][39][41][17][46][47][48]
2	Dams	[60][3][61]
3	Flood area	[60][39]

© IEOM Society International

4	Land use	[60][62][45]
5	Rivers/Lakes	[60][3][63][7][61][25][47]
6	Sand dunes	[60][62]
7	Roads and Railways	[60][3][56][7][61][64][13][24][4][15][41][62][45]
8	Slope	[60][3][55][56][13][4][25][17][47]
9	Sensitive areas	[60][7][15]
10	Communication/Transmission line	[6][7][13][15][37][38][47][45]
11	Coastline	[65][7]
12	Wildlife areas	[65][3][55][64][46]
13	Residential areas	[3][63][55][56][7][61][24][39][41]
14	Airport and Military areas	[3][37][38][39][47]
15	Archeological sites	[3][46]
16	Agricultural land	[55][61][64][24][41][48]
17	Wetlands and Forests	[24][7][61][41][46]
18	Urban Areas	[60][55][56][24][4][25][39][41][47]
19	Biologically Significant Areas	[47]
20	Elevation	[3][55][13][17][47]

5. Discussion and Conclusion

In this paper, several published articles on the use of GIS and MCDM-based methods in planning and design of solar power systems along with selecting the best technologies were reviewed. The results of different scenarios show sensitivity to the criteria weights and provide a wide range of land suitability distributions, showing that both economic and technical factors influence the assessment of the study field. The key criteria in site selection, according to the reviewed literature, are economy, environment, risk, geography, vision, ecology, community, and climate. Many factors influence decision-making when it comes to solar energy, including technological aspects, economic aspects, viability, performance, land use, versatility, CO emission, performance, and efficiency. Since solar radiation is listed in all studies for site location, it can be concluded that it is one of the most significant factors for such farms, followed by land slope and distance to main roads, whereas the protected lands and agricultural regions were considered the highest restriction factors in the literature.

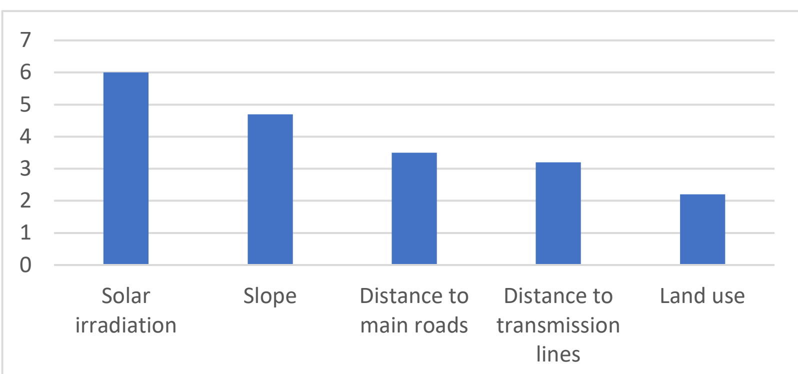

Figure 1: Top 5 criteria in large-scale solar PV studies

© IEOM Society International

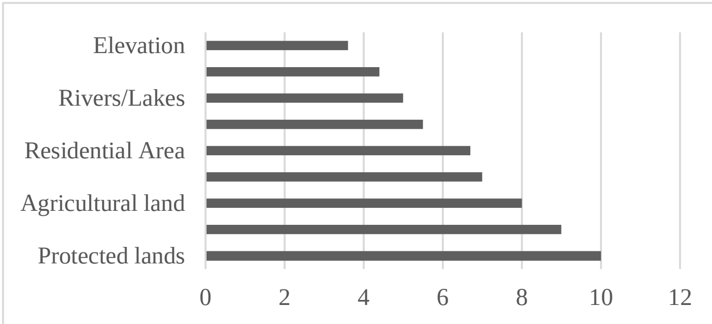

Figure 2: Top 5 restriction factors in solar site selection

The review indicates AHP to be the most common and effective MCDM techniques used in the case study due to its versatility and potential application in a number of critical evaluation problems. All of the potential, economic, and environmental aspects of solar energy are linked to a geospatial framework, so GIS can be used as a baseline. The proposed review will assist solar energy DMs and developers in locating solar project sites that provide significant technological efficiency at a low cost and low environmental impact by conduction more efficient research in the relative fields. In order to maximize the benefits of renewable energy, GIS should be used more efficiently, and the study field should be extended in future work. When several criteria are used to choose a solar farm site, this study will provide a methodology and decision support to the decision maker. Using more inputs increases the likelihood of making better choices. Furthermore, different decision-making processes will lead to different outcomes.

References

[1] A. Koc, S. Turk, and G. Şahin, "Multi-criteria of wind-solar site selection problem using a GIS-AHP-based approach with an application in Igdir Province/Turkey," *Environ. Sci. Pollut. Res.*, vol. 26, no. 31, pp. 32298–32310, 2019, doi: 10.1007/s11356-019-06260-1.

[2] World Energy Council, "Energy Resources: Solar," *World Energy Counc. 2013 World Energy Resour. Sol.*, pp. 1–28, 2013, [Online]. Available: http://www.worldenergy.org/wp-content/uploads/2013/10/WER_2013_8_Solar_revised.pdf.

[3] M. Uyan, "GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region Konya/Turkey," *Renew. Sustain. Energy Rev.*, vol. 28, pp. 11–17, 2013, doi: 10.1016/j.rser.2013.07.042.

[4] H. Z. Al Garni and A. Awasthi, "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia," *Appl. Energy*, vol. 206, no. July, pp. 1225–1240, 2017, doi: 10.1016/j.apenergy.2017.10.024.

[5] S. M. Habib, A. El-Raie Emam Suliman, A. H. Al Nahry, and E. N. Abd El Rahman, "Spatial modeling for the optimum site selection of solar photovoltaics power plant in the northwest coast of Egypt," *Remote Sens. Appl. Soc. Environ.*, vol. 18, p. 100313, 2020, doi: 10.1016/j.rsase.2020.100313.

[6] J. M. Sánchez-Lozano, J. Teruel-Solano, P. L. Soto-Elvira, and M. Socorro García-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.*, vol. 24, pp. 544–556, 2013, doi: 10.1016/j.rser.2013.03.019.

[7] K. A. Wiguna, R. Sarno, and N. F. Ariyani, "10.1109@ICTS.2016.7910305.pdf," pp. 237–243, 2016.

[8] Y. Charabi and A. Gastli, "PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation," *Renew. Energy*, vol. 36, no. 9, pp. 2554–2561, 2011, doi: 10.1016/j.renene.2010.10.037.

[9] J. M. Sánchez-Lozano, J. Teruel-Solano, P. L. Soto-Elvira, and M. Socorro García-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.*, vol. 24, pp. 544–556, 2013, doi: 10.1016/j.rser.2013.03.019.

[10] I. Guaita-Pradas, I. Marques-Perez, A. Gallego, and B. Segura, "Analyzing territory for the sustainable development of solar photovoltaic power using GIS databases," *Environ. Monit. Assess.*, vol. 191, no. 12, 2019, doi: 10.1007/s10661-019-7871-8.

[11] N. Y. Aydin, E. Kentel, and H. Sebnem Duzgun, "GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey," *Energy Convers. Manag.*, vol. 70, pp. 90–106, 2013, doi: 10.1016/j.enconman.2013.02.004.

[12] M. Uyan, "GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region Konya/Turkey," *Renew. Sustain. Energy Rev.*, vol. 28, pp. 11–17, 2013, doi: 10.1016/j.rser.2013.07.042.

[13] M. Uyan, "Optimal site selection for solar power plants using multi-criteria evaluation: A case study from the Ayranci region in Karaman, Turkey," *Clean Technol. Environ. Policy*, vol. 19, no. 9, pp. 2231–2244, 2017, doi: 10.1007/s10098-017-1405-2.

[14] S. Ozdemir and G. Sahin, "Multi-criteria decision-making in the location selection for a solar PV power plant using AHP," *Meas. J. Int. Meas. Confed.*, vol. 129, no. July, pp. 218–226, 2018, doi: 10.1016/j.measurement.2018.07.020.

[15] S. Ozdemir and G. Sahin, "Multi-criteria decision-making in the location selection for a solar PV power plant using AHP," *Meas. J. Int. Meas. Confed.*, vol. 129, no. July, pp. 218–226, 2018, doi: 10.1016/j.measurement.2018.07.020.

[16] M. K. Anser, M. Mohsin, Q. Abbas, and I. S. Chaudhry, "Assessing the integration of solar power projects: SWOT-based AHP–F-TOPSIS case study of Turkey," *Environ. Sci. Pollut. Res.*, vol. 27, no. 25, pp. 31737–31749, 2020, doi: 10.1007/s11356-020-09092-6.

[17] A. Tunc, G. Tuncay, Z. Alacakanat, and F. S. Sevimli, "Gis based solar power plants site selection using analytic hierarchy process (ahp) in istanbul, Turkey," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch.*, vol. 42, no. 2/W13, pp. 1353–1360, 2019, doi: 10.5194/isprs-archives-XLII-2-W13-1353-2019.

[18] H. E. Colak, T. Memisoglu, and Y. Gercek, "Optimal site selection for solar photovoltaic (PV) power plants using GIS and AHP: A case study of Malatya Province, Turkey," *Renew. Energy*, vol. 149, pp. 565–576, 2020, doi: 10.1016/j.renene.2019.12.078.

[19] J. J. W. Watson and M. D. Hudson, "Regional Scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation," *Landsc. Urban Plan.*, vol. 138, pp. 20–31, 2015, doi: 10.1016/j.landurbplan.2015.02.001.

[20] D. Doljak and G. Stanojević, "Evaluation of natural conditions for site selection of ground-mounted photovoltaic power plants in Serbia," *Energy*, vol. 127, pp. 291–300, 2017, doi: 10.1016/j.energy.2017.03.140.

[21] M. Zoghi, A. Houshang Ehsani, M. Sadat, M. javad Amiri, and S. Karimi, "Optimization solar site selection by fuzzy logic model and weighted linear combination method in arid and semi-arid region: A case study Isfahan-IRAN," *Renew. Sustain. Energy Rev.*, vol. 68, pp. 986–996, 2017, doi: 10.1016/j.rser.2015.07.014.

[22] M. Azizkhani, A. Vakili, Y. Noorollahi, and F. Naseri, "Potential survey of photovoltaic power plants using Analytical Hierarchy Process (AHP) method in Iran," *Renew. Sustain. Energy Rev.*, vol. 75, no. October, pp. 1198–1206, 2017, doi: 10.1016/j.rser.2016.11.103.

[23] E. Noorollahi, D. Fadai, M. A. Shirazi, and S. H. Ghodsipour, "Land suitability analysis for solar farms exploitation using GIS and fuzzy analytic hierarchy process (FAHP) - A case study of Iran," *Energies*, vol. 9, no. 8, pp. 1–24, 2016, doi: 10.3390/en9080643.

[24] M. Sadeghi, M. Karimi, and G. Engineering, "Gis Based Solar and Wind Using Mcda," vol. XLII, no. October, pp. 7–10, 2017.

[25] H. Yousefi, H. Hafeznia, and A. Yousefi-Sahzabi, "Spatial site selection for solar power plants using a gis-based boolean-fuzzy logic model: A case study of Markazi Province, Iran," *Energies*, vol. 11, no. 7, 2018, doi: 10.3390/en11071648.

[26] M. K. Firozjaei, O. Nematollahi, N. Mijani, S. N. Shorabeh, H. K. Firozjaei, and A. Toomanian, "An integrated GIS-based Ordered Weighted Averaging analysis for solar energy evaluation in Iran: Current conditions and future planning," *Renew. Energy*, vol. 136, pp. 1130–1146, 2019, doi: 10.1016/j.renene.2018.09.090.

[27] M. A. Nazari, A. Aslani, and R. Ghasempour, "Analysis of solar farm site selection based on TOPSIS approach," *Int. J. Soc. Ecol. Sustain. Dev.*, vol. 9, no. 1, pp. 12–25, 2018, doi: 10.4018/IJSESD.2018010102.

[28] S. N. Shorabeh, M. K. Firozjaei, O. Nematollahi, H. K. Firozjaei, and M. Jelokhani-Niaraki, "A risk-based multi-criteria spatial decision analysis for solar power plant site selection in different climates: A case study in Iran," *Renew. Energy*, vol. 143, pp. 958–973, 2019, doi: 10.1016/j.renene.2019.05.063.

[29] M. Mokarram, M. J. Mokarram, M. Gitizadeh, T. Niknam, and J. Aghaei, "A novel optimal placing of solar farms utilizing multi-criteria decision-making (MCDA) and feature selection," *J. Clean. Prod.*, vol. 261, p. 121098, 2020, doi: 10.1016/j.jclepro.2020.121098.

[30] A. Asakereh, M. Omid, R. Alimardani, and F. Sarmadian, "Developing a GIS-based Fuzzy AHP Model for Selecting Solar Energy Sites in Shodirwan Region in Iran," *Int. J. Adv. Sci. Technol.*, vol. 68, pp. 37–48, 2014, doi: 10.14257/ijast.2014.68.04.

© IEOM Society International

[31] A. Asakereh, M. Soleymani, and M. J. Sheikhdavoodi, “A GIS-based Fuzzy-AHP method for the evaluation of solar farms locations: Case study in Khuzestan province, Iran,” *Sol. Energy*, vol. 155, pp. 342–353, 2017, doi: 10.1016/j.solener.2017.05.075.

[32] H. Z. Al Garni and A. Awasthi, “Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia,” *Appl. Energy*, vol. 206, no. September, pp. 1225–1240, 2017, doi: 10.1016/j.apenergy.2017.10.024.

[33] A. Alami Merrouni, F. Elwali Elalaoui, A. Ghennioui, A. Mezrhab, and 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*, vol. 166, no. March, pp. 2–12, 2018, doi: 10.1016/j.solener.2018.03.038.

[34] M. Tahri, M. Hakdaoui, and M. Maanan, “The evaluation of solar farm locations applying Geographic Information System and Multi-Criteria Decision-Making methods: Case study in southern Morocco,” *Renew. Sustain. Energy Rev.*, vol. 51, pp. 1354–1362, 2015, doi: 10.1016/j.rser.2015.07.054.

[35] A. Alami Merrouni, F. Elwali Elalaoui, A. Mezrhab, A. Mezrhab, and A. Ghennioui, “Large scale PV sites selection by combining GIS and Analytical Hierarchy Process. Case study: Eastern Morocco,” *Renew. Energy*, vol. 119, pp. 863–873, 2018, doi: 10.1016/j.renene.2017.10.044.

[36] J. Suh and J. R. S. Brownson, “Solar farm suitability using geographic information system fuzzy sets and analytic hierarchy processes: Case study of Ulleung Island, Korea,” *Energies*, vol. 9, no. 8, 2016, doi: 10.3390/en9080648.

[37] S. Ali, J. Taweekun, K. Techato, J. Waewsak, and S. Gyawali, “GIS based site suitability assessment for wind and solar farms in Songkhla, Thailand,” *Renew. Energy*, vol. 132, pp. 1360–1372, 2019, doi: 10.1016/j.renene.2018.09.035.

[38] J. R. S. Doorga, S. D. D. V. Rughooputh, and R. Boojhawon, “Multi-criteria GIS-based modelling technique for identifying potential solar farm sites: A case study in Mauritius,” *Renew. Energy*, pp. 1201–1219, 2019, doi: 10.1016/j.renene.2018.08.105.

[39] A. Hashemizadeh, Y. Ju, and P. Dong, “A combined geographical information system and Best–Worst Method approach for site selection for photovoltaic power plant projects,” *Int. J. Environ. Sci. Technol.*, vol. 17, no. 4, pp. 2027–2042, 2020, doi: 10.1007/s13762-019-02598-8.

[40] W. Yunna and S. Geng, “Multi-criteria decision making on selection of solar-wind hybrid power station location: A case of China,” *Energy Convers. Manag.*, vol. 81, pp. 527–533, 2014, doi: 10.1016/j.enconman.2014.02.056.

[41] Y. A. Solangi, S. A. A. Shah, H. Zameer, M. Ikram, and B. O. Saracoglu, “Assessing the solar PV power project site selection in Pakistan: based on AHP-fuzzy VIKOR approach,” *Environ. Sci. Pollut. Res.*, vol. 26, no. 29, pp. 30286–30302, 2019, doi: 10.1007/s11356-019-06172-0.

[42] R. Guptha, H. Puppala, and S. Kanuganti, “Integrating fuzzy AHP and GIS to prioritize sites for the solar plant installation,” *2015 12th Int. Conf. Fuzzy Syst. Knowl. Discov. FSKD 2015*, pp. 465–470, 2016, doi: 10.1109/FSKD.2015.7381987.

[43] S. Sindhu, V. Nehra, and S. Luthra, “Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis: Case study of India,” *Renew. Sustain. Energy Rev.*, vol. 73, no. October 2016, pp. 496–511, 2017, doi: 10.1016/j.rser.2017.01.135.

[44] K. Nagasaka and M. Rumbayan, “Development of priority decision for renewable energy potential using analytical hierarchy process and geographical information system method,” *Int. J. Adv. Mechatron. Syst.*, vol. 5, no. 4, pp. 270–278, 2013, doi: 10.1504/IJAMECHS.2013.057666.

[45] H. S. Ruiz, A. Sunarso, K. Ibrahim-Bathis, S. A. Murti, and I. Budiarto, “GIS-AHP Multi Criteria Decision Analysis for the optimal location of solar energy plants at Indonesia,” *Energy Reports*, vol. 6, no. xxxx, pp. 3249–3263, 2020, doi: 10.1016/j.egyr.2020.11.198.

[46] M. Giamalaki and T. Tsoutsos, “Sustainable siting of solar power installations in Mediterranean using a GIS/AHP approach,” *Renew. Energy*, vol. 141, pp. 64–75, 2019, doi: 10.1016/j.renene.2019.03.100.

[47] “2020_A GIS-based Boolean logic-analytical hierarchy process for solar power plant (case study Erbil Governorate—Iraq).pdf.” .

[48] U. Tempa, J. G. Singh, C. Change, and P. Thani, “and AHP approach : A Case Study of Bumthang,” pp. 705–710, 2020.

[49] M. A. Hassaan, A. Hassan, and H. Al-Dashti, “GIS-based suitability analysis for siting solar power plants in Kuwait,” *Egypt. J. Remote Sens. Sp. Sci.*, no. xxxx, 2020, doi: 10.1016/j.ejrs.2020.11.004.

[50] S. M. Habib, A. El-Raie Emam Suliman, A. H. Al Nahry, and E. N. Abd El Rahman, “Spatial modeling for the optimum site selection of solar photovoltaics power plant in the northwest coast of Egypt,” *Remote Sens.*

Appl. Soc. Environ., vol. 18, p. 100313, 2020, doi: 10.1016/j.rsase.2020.100313.

[51] H. A. Effat, “Selection of Potential Sites for Solar Energy Farms in Ismailia Governorate, Egypt using SRTM and Multicriteria Analysis,” *Cloud Publ. Int. J. Adv. Remote Sens. GIS*, vol. 2, no. 1, pp. 205–220, 2013.

[52] M. A. Hassaan, A. Hassan, and H. Al-Dashti, “GIS-based suitability analysis for siting solar power plants in Kuwait,” *Egypt. J. Remote Sens. Sp. Sci.*, no. xxxx, 2020, doi: 10.1016/j.ejrs.2020.11.004.

[53] H. S. Ruiz, A. Sunarso, K. Ibrahim-Bathis, S. A. Murti, and I. Budiarto, “GIS-AHP Multi Criteria Decision Analysis for the optimal location of solar energy plants at Indonesia,” *Energy Reports*, vol. 6, no. xxxx, pp. 3249–3263, 2020, doi: 10.1016/j.egyr.2020.11.198.

[54] A. Asakereh, M. Soleymani, and M. J. Sheikhdavoodi, “A GIS-based Fuzzy-AHP method for the evaluation of solar farms locations: Case study in Khuzestan province, Iran,” *Sol. Energy*, vol. 155, pp. 342–353, 2017, doi: 10.1016/j.solener.2017.05.075.

[55] J. J. W. Watson and M. D. Hudson, “Regional Scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation,” *Landsc. Urban Plan.*, vol. 138, pp. 20–31, 2015, doi: 10.1016/j.landurbplan.2015.02.001.

[56] M. Tahri, M. Hakdaoui, and M. Maanan, “The evaluation of solar farm locations applying Geographic Information System and Multi-Criteria Decision-Making methods: Case study in southern Morocco,” *Renew. Sustain. Energy Rev.*, vol. 51, pp. 1354–1362, 2015, doi: 10.1016/j.rser.2015.07.054.

[57] I. Basak and T. Saaty, “Group decision making using the analytic hierarchy process,” *Math. Comput. Model.*, vol. 17, no. 4–5, pp. 101–109, 1993, doi: 10.1016/0895-7177(93)90179-3.

[58] J. Malczewski, “GIS-based multicriteria decision analysis: A survey of the literature,” *Int. J. Geogr. Inf. Sci.*, vol. 20, no. 7, pp. 703–726, 2006, doi: 10.1080/13658810600661508.

[59] J. Xiao, Z. Yao, J. Qu, and J. Sun, “Research on an optimal site selection model for desert photovoltaic power plants based on analytic hierarchy process and geographic information system,” *J. Renew. Sustain. Energy*, vol. 5, no. 2, pp. 1–16, 2013, doi: 10.1063/1.4801451.

[60] Y. Charabi and A. Gastli, “PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation,” *Renew. Energy*, vol. 36, no. 9, pp. 2554–2561, 2011, doi: 10.1016/j.renene.2010.10.037.

[61] A. Alami Merrouni, F. Elwali Elalaoui, A. Mezrhab, A. Mezrhab, and A. Ghennioui, “Large scale PV sites selection by combining GIS and Analytical Hierarchy Process. Case study: Eastern Morocco,” *Renew. Energy*, vol. 119, pp. 863–873, 2018, doi: 10.1016/j.renene.2017.10.044.

[62] S. N. Shorabeh, M. K. Firozjaei, O. Nematollahi, H. K. Firozjaei, and M. Jelokhani-Niaraki, “A risk-based multi-criteria spatial decision analysis for solar power plant site selection in different climates: A case study in Iran,” *Renew. Energy*, vol. 143, pp. 958–973, 2019, doi: 10.1016/j.renene.2019.05.063.

[63] W. Yunna and S. Geng, “Multi-criteria decision making on selection of solar-wind hybrid power station location: A case of China,” *Energy Convers. Manag.*, vol. 81, pp. 527–533, 2014, doi: 10.1016/j.enconman.2014.02.056.

[64] S. Sindhu, V. Nehra, and S. Luthra, “Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis: Case study of India,” *Renew. Sustain. Energy Rev.*, vol. 73, no. December 2016, pp. 496–511, 2017, doi: 10.1016/j.rser.2017.01.135.

[65] N. Y. Aydin, E. Kentel, and H. Sebnem Duzgun, “GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey,” *Energy Convers. Manag.*, vol. 70, pp. 90–106, 2013, doi: 10.1016/j.enconman.2013.02.004.

Biography

Nabila Tabassum Suprova is a graduate mechanical engineer. She earned his BSc. in mechanical engineering from Islamic University of Technology (IUT), Bangladesh. Her research interests include Renewable Energy, Computation Fluid Dynamics, Combustion and Operations Research. She is a member of the Institution of Mechanical Engineers (IMechE).

MD. Abidur Rahman Zidan is a graduate mechanical engineer. He earned his BSc. in mechanical engineering from Islamic University of Technology (IUT), Bangladesh. His research interests include Renewable Energy, Computation Fluid Dynamics, Combustion. He is a member of IMechE.

© IEOM Society International

Dr. A R M Harunur Rashid is an Associate professor of Department of Mechanical and Production Engineering (MPE) at the Islamic University of Technology (IUT). He earned his PhD from Dublin City University (DCU) and B.Sc. in Mechanical Engineering from Bangladesh University of Engineering and Technology (BUET). His research activities include the area of Ergonomics, Engineering Design, Industrial Engineering, Safety & Human Factors Engineering, Engineering Economy & Management, Maintenance Engineering, Operations Research and Renewable Energy. He has been serving as Honorary General Secretary of IEOM Society of Bangladesh since 2016.

© IEOM Society International