


Geographical Information System (GIS)-Based Solar Photovoltaic Farm Site Suitability Using Multi-criteria Approach (MCA) in Southern Tamilnadu, India

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Abstract Tamil Nadu is the eleventh largest state by area and it constitutes 9% of the total installed electricity generation capacity of India which is largely from fossil fuels such as coal and natural gas. Due to the present industrial growth scenario, this amount of electricity generation is not enough so the Government of Tamilnadu has agreed to the Tamil Nadu solar energy strategy in 2012 to meet the electricity needs. The objective of this research study is to categorize the best suitable sites for a solar photovoltaic farm with the aim of minimum cost and maximum output. In this paper, Remote sensing, GIS technologies, and multi-criteria decision analysis (MCDA) are implemented in the energy sector for solar PV siting suitability. Site selection is based on various environmental, technical, and topographical criteria by using weighted overlay multi-criteria analysis. The investigations done in this research are peculiar as the weighted values of the criteria include geopolitical and financial incentives appropriate to the state's social dynamics. The high potential solar irradiation, distance from a road, hill shade and slope, and land use and land cover are considered as the significant factors in identifying the high suitable location for the photovoltaic power plants. The research region covers 55,160 km² and is centered on sixteen districts in southern Tamil Nadu. The annual Global Horizontal Irradiation (GHI) interpolated map derived from NREL data, as

well as other thematic maps acquired from Indian government agency websites, are crucial in this study. Among the 16 districts, 12.096 km² (0.024%) of fully exploited highly suitable area can meet the power demand of Tamil Nadu. Also, considering the moderately suitable area the state is still be potential to generate around 50 GW of electricity as an average. Investigations also suggest that the concentrator technology has tremendous potential of 16.442 GWh/day to meet the electricity power demands as the state is industrialized day by day.

Keywords Weighted overlay · Solar PV Farm · Multi-criteria analysis · Geographical information system · Topography and irradiance

Abbreviations

GHI	Global horizontal irradiation
GUI	Graphical user interface
NREL	National research energy laboratory
PV	Photo voltaic
AHP	Analytical hierarchy process
DS	Dempster-shafer methods
LCOE	Levelized cost of economics
OSM	Open street map
LAR	Land aspect ratio
NASA	National aeronautics and space administration
GIS	Geographical information system
DNI	Direct normal irradiation
NRSC	National remote sensing center
DEM	Digital elevation model
GDEM	Global digital elevation model
MCE	Multi-criteria Evaluation
MCA	Multi-criteria Analysis
MCDM	Multi-criteria Decision Making
MCDA	Multi-decision analysis model

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SF	Shading factor
TP	Total potential

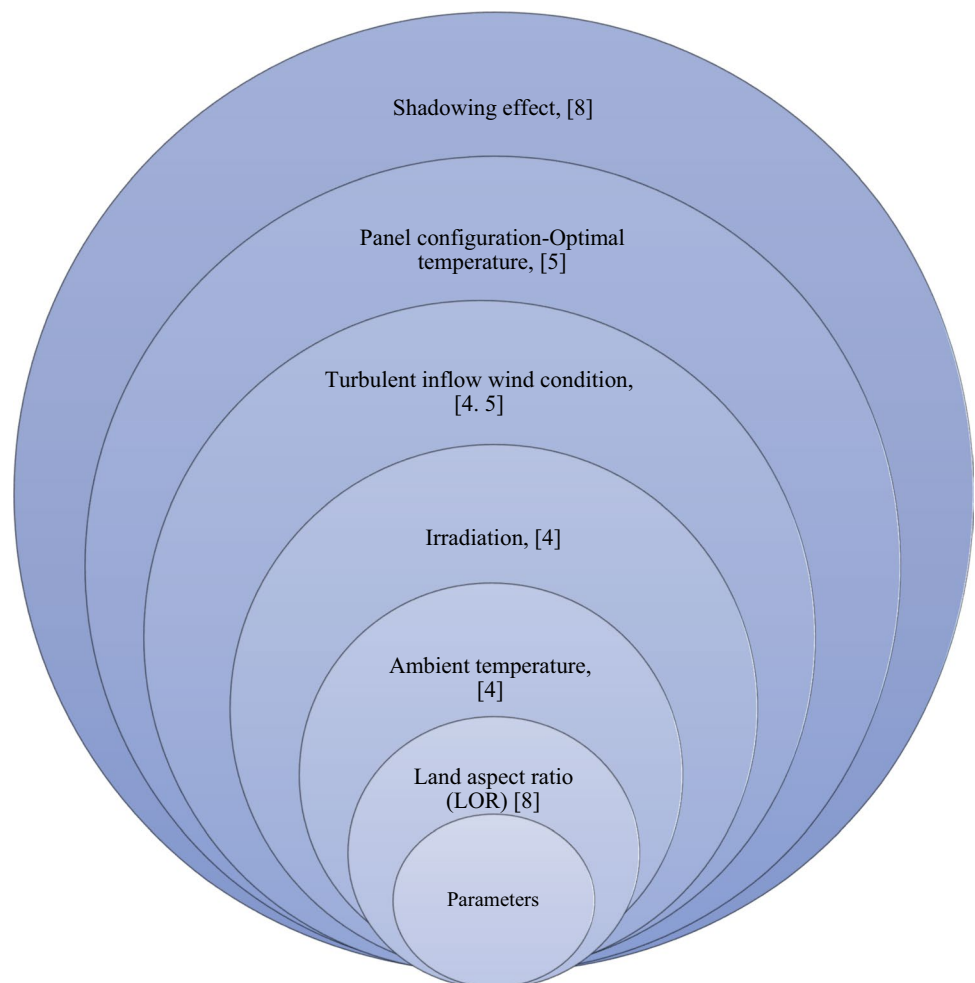
Introduction

Electricity is necessary for social and economic development. As a developing country, India is the world's sixth major energy consumer and in India, a person emits 247 kg of carbon per year [1]. Energy systems can be classified as Fossil fuel and nuclear power based on the present Tamil Nadu situation but still, Tamil Nadu facing substantial electricity generating issues due to fossil fuel environmental impacts and depletion of resources. Renewable energy is the world's main alternative energy resource, and compared to other sources, renewable energy is only easily accessible to mankind. Renewable energy has undeniable advantages like reducing greenhouse gas emissions and air pollutions, and most of this, it is safe while converting to other forms of energy without emitting carbon dioxide. The government of Tamil Nadu has accepted the Tamil Nadu solar energy policy

in 2012 to meet the electricity needs with aim of reducing carbon emission and achieving 3000 MW by 2015 [2].

Solar PV farm location influences the temperature-dependent efficiency and the Levelized cost of economics (LCOE) significantly [3]. Maximizing the solar PV farm power output, Fig. 1, is largely dependent upon the location of the PV farm because ambient temperature, irradiance, and wind speed are purely site-specific parameters [4]. Turbulent inflow wind form and panel formation are examined for their influence on the inclusive efficacy of a solar PV farm. Wind direction and operation temperature in photovoltaic (PV) are dependent on the above two key parameters. Hence, solar farm location is a critical parameter in enhancing the efficiency of the PV farm [5]. Optimal location for the solar PV farm had been investigated using fuzzy logic, analytical hierarchy process (AHP), and Dempster-Shafer (DS) methods independently. Fuzzy –DS methods are handy in identifying the hidden risks in specific site locations for the solar PV farm. Geographical information system (GIS) techniques are proposed to identify the most suitable place for the solar PV farm [6]. Open Street Map (OSM) data are used to obtain geospatial information of the solar PV farm

Fig. 1 Parameters maximizing solar PV Farm power output



and its suitability considering technical and socio-economic constraints [7].

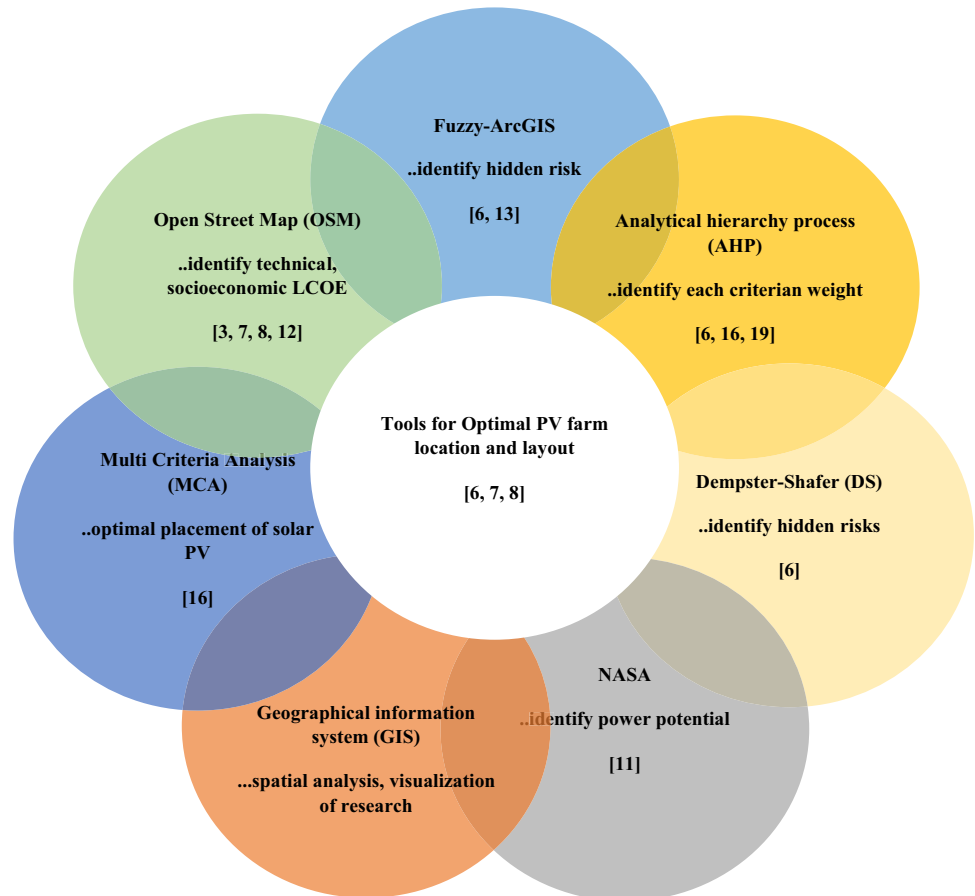
An innovative computational algorithm was introduced to optimize the layout design of the PV farm, Fig. 2, and the Levelized cost of electricity (LCOE) using the local meteorological data in Kota Kinabalu, Malaysia. Land aspect ratio (LAR), shadowing effect are the key parameters in optimizing the solar PV farm layout [8]. The three exceedingly appropriate provinces within the inhibited area of Ulleung Island were identified employing a weighted fuzzy summation technique within a GIS setting. By considering criterion parameters that give the uppermost values for solar power adaptation such as greater solar irradiation, extended daylight hours, low ambient air temperature, nearness to prevailing transmission lines and roads for PV installations, the findings of this study could theoretically lead to bargains in Levelized costs of electricity (LCOE) for provincial placement of solar PV farms [9, 10].

Solar PV farm power potential in Libya had been assessed using meteorological information available with the NASA database. Solar energy potential sites in Libya were identified based on the available solar radiation as it is a location-specific parameter. Investigations were useful in designing and developing both the technically viable and economically

feasible solar PV farm in Al Kufrah which is a suitable location due to the available high annual solar radiation [11]. The effects of fluctuating wind/solar ratios on energy system stability in China are investigated and maps (OSM) are generated indicating the optimum values. Using these values, the most stable and suitable locations for the PV farms are identified. Investigations lead to eastern Inner Mongolia, north-eastern China, and northern China as a potential site for solar PV farms. Optimum values of wind/solar ratios are essential in enhancing the stability of power [12].

A research study on the assessment of solar energy resources in Oman was carried out and some initial results were reported. The method used uses fuzzy quantifiers within the ArcGIS setting to enable multi-criteria decision analysis to be implemented. For the Oman case study, a land suitability investigation was conducted out for the development of quality PV farms. The outline results of the research of the resultant mapping showed that 0.5% of the land area showed a high degree of suitability [13]. Renewable energy is sustainable energy that has a far smaller impact than other sources of energy on the ecosystem. In Turkey, investment in solar energy has grown dramatically over the last few years. Due to the quality of the land, local weather conditions, nearness to high transmission capacity lines, agronomic

Fig. 2 Tools to identify PV Farm optimal location and layout\



amenities, and ecological protection problems, site choice for solar farms is a perilous issue for major project implementations. For various site selection studies, multi-criteria assessment approaches are also used [14].

The selection of appropriate solar power plant sites requires spatial assessment, taking into account technological, environmental, and socio-economic requirements. This research employs a fuzzy logic model for the selection of spatial sites for solar power generation in Iran. The technologies of the GIS are used for geographic investigation and interpretation of relevant studies. The findings listed some regions in the neighborhood of the settlements of Mahalat and Zarandineh as beneficial for the production of solar energy [15]. A hybrid MCA and GIS approach has been recorded for the optimum allocation of large solar PV farms in the Makkah area in western Saudi Arabia. To evaluate the associated decision criteria, the Analytic Hierarchy Process (AHP) approach was taken. Appropriate land is then classified using a GIS solution via a static overlay of spatially scattered graded criteria [16]. Using the GIS and MCDA, appropriate probable locations for solar PV farms are identified in the case of Antalya, Turkey, which comprises Turkey's fifth-highest populated city. The combination of GIS-MCDM is handy in assessing the above locations based on numerous logistical, geographical, and irradiance conditions. The map statistics employed in the investigation were open access, and other statistics were attained from local governments [17].

Research had been carried out to expedite the consequence of joining both the GIS tools and MCDM scheme to evaluate the appropriateness of certain sites to implement a renewable energy development scheme in the southern region of Morocco. GIS-based MCDM was adopted to solve the multifaceted conclusion complications of apportioning land appropriateness and producing the maps [18]. Rigorous implementation of the system shows 3.0% of the study area scoring the safest-suitability index for utilization of solar re-source, thus mitigating the risk of future capital expenditure. The proposed methodological system used can be conveniently used by prospective investors and analysts of renewable energy via a web-based front-end application with proper GUI for personalized weighting schemes [19]. Another research was explored by recommending AHP with the ArcGIS method for solar PV farm location appropriateness investigation. The weights of the parameters were determined using the AHP scheme, and the optimal location for solar power plants was mapped using ArcGIS. ArcGIS is a decision-making mechanism for recommending appropriate places to the government. Finding ideal places for a solar PV installation allows a solar PV power system's performance to be increased [20].

Researchers explored the assessment model to estimate the optimal location for a PV farm developmental scheme in

Beijing, based on GIS with an MCDM approach. A weighted criterion was used to produce the necessary maps by GIS. Land appropriateness catalog was used to categorize lands into five diverse clusters using the available data. Solar GIS maps as well as several ArcGIS tools were used in establishing the northern and north-eastern parts of Beijing are suitable for the implementation of the Solar PV projects [21]. The research was carried out by combining GIS and MCE techniques to weigh the land appropriateness for the setting up of solar PV farms in the municipality of Ourique in the South of Portugal [22]. Another GIS-based MCDM approach was adopted to recognize the apt solar PV farm locations in East Shewa Zone, Ethiopia. Global solar radiation, aspect, slope, distance to the power grid, and roads were recognized as the aptness aspects is usually [23].

MCE methods and GIS have gained prominence as a technique for various site selection investigations. In the 1960s, MCE techniques were developed to aid decision-making. According to the literature, MCE is a term that is often used in a variety of fields. The use of a synthesis of GIS and MCE techniques as a spatial decision support system for determining appropriate locations is becoming more popular. A validated study on solar farm site selection using a hybrid of GIS and MCE technologies is extremely unusual. The investigation was carried out with the help of GIS and AHP to assess the best locations for solar PV farms [14] [24]. The GIS and MCDM methods were coupled to assess ideal locations and technological potentials for large-scale solar PV farms. Potential sites are defined with the help of spatial techniques by extracting restrictive parameters such as protected areas, ground cover, and transportation networks. MCDM is such a useful tool in identifying the land appropriateness for solar PV farms in Ningxia, China. This scheme was gaged with the inclusive contemplation of diverse aspects, such as climate, location, and the availability of water, which are designed by the AHP scheme [25].

The evaluation of site suitability for the PV solar farm was expedited in the Desert of Chihuahua, Mexico using two multi-criteria decision-making methodologies integrated with GIS [26]. In the municipality of Ourique, Portugal, research was conducted to create an MCE modeling method with GIS that integrates yielding parameters with territorial constraints to aid in the decision-making process regarding the location of solar PV farms [27]. Integrating MCDM and GIS methods, the most appropriate locations to host solar PV power plants in Eastern Morocco were investigated. As a result, four conditions and eight sub-criteria were preferred. Their weights were measured, and solar PV power plant viability maps were developed [28]. GIS analysis combined with the MCDM methodology is typically used to assess suitability for ground-mounted solar PV farm installations from legal, social, technological, fiscal, and environmental perspectives [29]. Solar, land use, and population progress

requirements were paired with closeness to power lines and roads to determine viable areas using GIS tools. Since a GIS-based evaluation of the fields, each state's technical capacity was estimated. The MCDA scheme was used to simulate the decision-making process for the construction of a strategic solar PV plant. The model took into consideration all of the factors that must be included in the construction of a solar PV farm, as well as economic and policy factors that are thought to have a significant impact on the PV market value [30]. Hence, various criteria for both site and technology selections and the importance of each criterion are closely dependent on regional, economical, energy policy [31]

Multi-Criteria Analysis (MCA) is an open and explicit technique in the decision-making process. MCA determines the preferences for any structure among different alternatives. It is a technique that provides a ranking and compares it with a variety of criteria. It also analyzes and integrates among different objectives and interests of many factors with qualitative and quantitative information [32–34]. In this case, Geographical Information System (GIS) is widely used for spatial problems for decision-makers. Decision-makers define their choices between different locations, objects, alternatives, and actions [32]. Recently in development of multi-criteria analysis in GIS has solved many complex problems for people in many diverse sectors such as environment, energy, crime, urban development, and so on [35]. Researchers in India recently investigated the feasibility of solar and wind farm places in the country. The report goes on to say that the state of Rajasthan in India has the best land for solar plant installation (20,881 km²) [36]. Nevertheless, a consolidated list of researches in identifying the suitability of land using the GIS-based MCDA approach is given, Table 1.

In this paper, Remote sensing, GIS technology, and multi-criteria methodologies are used in the energy sector to determine the viability of solar PV site. To yet, no data on the suitability of the solar PV farm in the Southern Tamilnadu site is available. As a result, an analysis of this province was conducted to determine the most appropriate site location for the implementation of renewable energy, such as grid-connected Photovoltaic solar energy.

PV site suitability

PV grid-connected centralized system is a very effective way to meet the demands of power shortage as installation takes much less period than other power sources. However, the siting for installation of this type of technology has a lot of constraints as this needs a large amount of area when compared to a conventional source of energy. To develop a large PV farm some factors are to be considered to reduce

the cost and maximize the output. Most of the factors are the same for all over the globe, but few factors are regional, Table 2 [46].

In this study, we applied gridded maps of annual GHI, land-use and land-cover, hill shading, terrain slope, and distance from the road network. Grid connectivity was omitted as a criterion because spatial grid data are proprietary and not completely available. The study area is not located in seismic risk zone [47] which also includes floods and sand storms. Spatially generated layers according to criteria were weighted using weighted overlay multi-criteria analysis in the ArcGIS environment. Solar PV land aptness model using the AHP and sensitivity investigation approach in a GIS setting using remote sensing data in the southern Moroccan region. The most important environmental considerations to consider when determining the suitability of a location for solar PV installations are insolation, slope, aspect, and temperature [48, 49].

Considered Materials and Methods

Present Study Area

Tamil Nadu is a state of India, where almost 50% of energy is produced using a non-conventional source of energy [50]. The state is keen to develop more non-conventional sources of power plants mainly solar power plants due to power shortage and environmental factors. The study area is the southern part of the state which is near to the equator. The study area covered 16 districts (Cuddalore, Ariyalur, Thiruchirappalli, Madurai, Theni, Pudukottai, Thanjavur, Nagapattinam, Thiruvarur, Sivaganga, Virudhunagar, Tirunelveli, Kanyakumari, Thoothukudi, Ramanathapuram, and Perambalur) and an area of 55,160 km², Fig. 3.

Data collected from Government Research centers

Solar irradiation map obtained from NREL

The Global Horizontal Irradiation (GHI) map is generated using India Solar Resource data (NREL). The hourly data of the typical metrological year are derived for every 10 km (0.1° X 0.1° latitude and longitude) [51]. The NREL uses the SUNY model developed by Perez et al. [52] where geostationary satellite data used for cloud index for obtaining GHI and Direct Normal Irradiation (DNI). Points created for every 0.1° X 0.1° latitude and longitude with z- value as Annual GHI (kWh/m²/day) [53].

The 10 km resolution data are rescaled to 30 m resolution using powerful statistical interpolation called Kriging in ArcGIS environment. The kriging model uses different weight functions of points within the radius for distance &

Table 1 GIS-based MCDA for the Solar PV power plant

Author	Considered criterion	Area of implementation
Piotr Jankowski 1995, [24]	Service amenities, recreational events, retail channels, hazardous waste dumping locations, and perilous zones	To develop a model for global application
Eastman, [32]	Proximity to roads, Proximity to the labor force, Slope, gradient, Distance from wildlife reserves	Land suitability for a precise objective based on a diversity of features
Hong Jiang et.al 2000, [35, 37]	Proximity to the road, proximity to the town, slope gradients, and distance from Lake Nakuru Park	Industrial land allocation in Nakuru, Kenya
Janke et.al 2010, [38]	Landcover, federal lands, population density and transmission lines, distance to roads and cities	Modeling of wind and solar farms in Colorado
Yassine et.al 2011, [13]	Solar Radiation, Sensitive areas, Grid proximity, Land Accessibility, Hydrographic line, Land slope, Land use, Sand/dust risk, Load poles	PV site suitability analysis in Oman
Greene, Randal et.al 2011, [39]	Geology criterion, Road distance, Slope criterion, water distance	To develop a model for global application
Kata Tisza 2014, [30]	Solar resource, Available area, Land use, Topography, Accessibility, Grid connection, Financial incentives	Utility-scale solar plants in four states in the south-east US
Meryem Tahri et.al 2015, [18]	Solar radiation, slope, and slope orientation, land surface temperatures, road, hydrology, protected area, elevation, Distance to an urban area, and distance to road	Evaluation of solar farm locations in Ouarzazate, Ghassate, and Ait Zineb, Morocco
Alexander Devine 2015, [34]	Distance from established extents, slope, aspect, and Land Use	Site suitability analyses for Solar Photovoltaic Farms
Jangwon Suh et.al 2016, [9]	Residential areas, land use plan, tourist sites, landscape designations, wildlife designations, hydrographic areas, hydrographic area, slope failure zone, elevation	Solar PV farm in Ulleung Island, Korea
Andreas Georgiou et.al 2016, [19]	Electricity grid, road network, land price, elevation, slope, solar energy, and distance from main roads	Location assortment in identifying a solar park for the Limas-sol district in Cyprus
Sara Rodrigues et.al 2017, [27]	Topography, solar radiation, temperature, proximity to power lines, proximity to system roads	Solar PV farms in Ourique municipality, Portugal
Al Garni et.al 2018, [40]	Solar irradiation, protected areas, land slope, land use, closeness to water bodies and the roads	Solar Power Site Suitability
Alqaderi, et.al 2018, [41]	Solar irradiation, power grid and the roads, land slope, and use, protected areas, proximity to water bodies	Solar Power Site Suitability in UAE
Hasan Zabihi et al. 2019, [42]	Elevation, maximum temperature, minimum temperature, slope angle, and rainfall	To develop a model for citrus cropland near the Caspian Sea
Jay R.S.Doorga et.al 2019, [29]	Elevation, global solar radiation, slope and aspect, sunshine duration, air temperature, and relative humidity	To identify probable solar PV farm sites in Mauritius
Ingrid Piirisaar 2019, [43]	Solar radiation, aspect, and slope, distance from urban areas and roads network	Arrangement of utility-scale PV solar farms in Kilkenny, Ireland
Wigati et.al 2019, [10]	City, land use, slope, and road, land use, distance to the city, and the road network	Site selection with desired conditions
Ghasempour, et.al 2019, [31]	Slope, aspect, road adjacency, and grid accessibility	Selecting solar plants sites and solar plants technologies
Mokarram et.al 2020, [6]	Solar radiation concentration, distance to a power transmission line, air temperature, distance to major roads, distance to inhabited areas, land use, slope and elevation, number of cloudy days and dusty days, relative humidity	The best setting for erecting solar PV farms
Hashemizadeh et.al 2020, [21]	Solar potential, slope and aspect, urban area, transportation network, and power transmission lines, railways and waterways,	Location assortment for PV power plant projects in Beijing

Table 1 (continued)

Author	Considered criterion	Area of implementation
Lijian Sun et.al 2021, [25]	World heritage sites, national parks, Forest, Agriculture, housing construction, river, airport, roads, railway network, and slope	Probable valuation and appropriate locations assortment of PV farms in Ningxia, China
Şura Kırçalı et.al 2021, [17]	Elevation, solar irradiation, slope, aspect, land, sunshine duration, distance to residential areas, distance to transformers, distance to roads, annual average temperature	Site suitability analysis for solar farms in Antalya, Turkey
Günen et.al 2021, [44]	global horizontal irradiation, aspect, slope, land use/cover, bird migration routes, faults, rivers, water surfaces, power line, road transportation network, railway transportation 11 networks, and transformer centre	The best location for solar PV power plants in Kayseri, Turkey
Sofia Spyridonidou et.al 2021, [45]	Land use, geographic boundaries, and shape of the site, distance from residential areas, land occupation, proximity to the road network, the slope of the terrain, environmental protected areas, important bird areas, touristic zones, historical and archeological areas,	Identification of large-scale onshore wind farms and solar PV farms in Israel
Saraswat et.al 2021, [36]	Solar Irradiance, Available area, Land use, Topography, Accessibility, Grid connection, Slope	Suitability of the solar PV and wind farms locations in India
Prieto-Amparán, et.al 2021, [26]	Land use/land cover, distance from main roads, solar radiation, annual mean temperature, vapor pressure, slope, aspect, wind speed, soil texture, and landforms	Solar PV farm suitability in the Desert of Chihuahua, Mexico

Table 2 Factors affecting PV Farm

FACTORS	
Solar resource	Global Horizontal Irradiation (GHI) and shading affect the performance of Photovoltaic panels
Land-use & Land-cover	Land cost and for some environmental issues, habitat issues forest, water bodies and Built-up areas are restricted or neglected for suitability
Topography	A flat surface or slope at south-facing is preferable for study areas that are in the northern hemisphere. Shadows of hills and mountains affect the performance of the panel at various sun orientations
Local Climate & Geotechnical	snow, floods, sand storms, earthquakes, and extreme temperature
Accessibility	Road, grid accessibility, and cost of laying new roads
Geopolitical	Reserved or sensitive areas are neglected
Financial Incentives	Capital support from government and tariff which differ from countries and state to state

orientation of known points which might be scattered to the unknown points, whereas other methods treat the points within the radius as the same [54]. Figure 4 shows interpolated Annual Global Horizontal Irradiation.

Data on the land and land cover obtained from NRSC

Land use and land cover are obtained from Bhuvan Thematic Service which was done by NRSC (National Remote sensing center) on a 1:50,000 scale using progressive Resources at-2 terrain amended LISS-III data of 2011–12. This is shown in Fig. 4. Inclusive precision of diverse land use and land cover classes are 79% where for water bodies it is 97%, as per the real-time data available from the trusted resources [55]. The

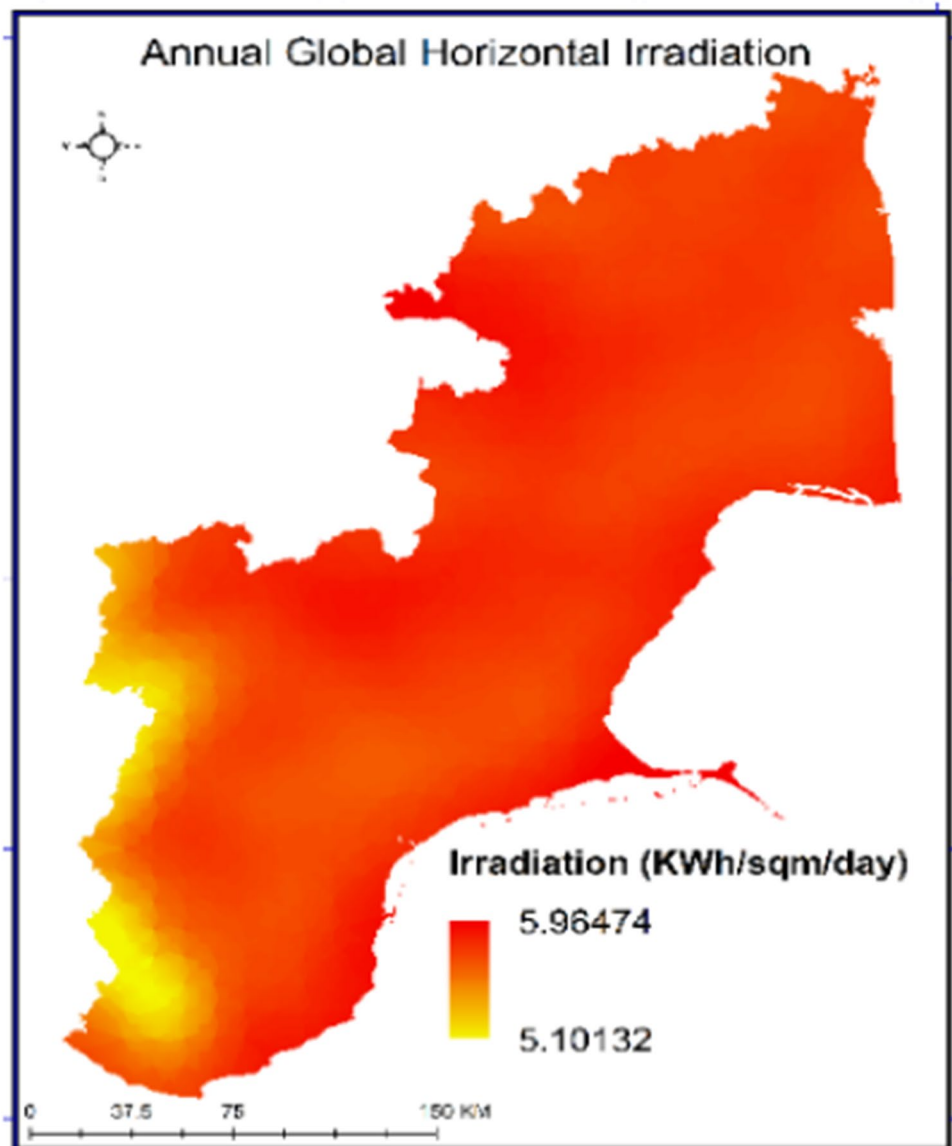
map is again reclassified into 5 classes Built-up, Cropland, forest, water bodies, and Wasteland, Fig. 5.

Areas nearby forest and Built-up areas are not considered. 500 m from the forest are neglected due to some roughness of forest affects the solar radiation and 1000 m from built-up areas are neglected due to development of urban and rural areas. A buffer is created of 500 m from the forest, 1000 m from the built-up area, and 1000 m from coastal areas are created in the ArcGIS environment.

Hill shade and slope Data obtained from NASA, USA

Digital Elevation Model (DEM) data are needed to Generate Hill shade and Slope. These data are obtained from

Fig. 4 Annual Global Horizontal Irradiation



Distances from Road obtained from Google maps

Major road networks like state and national are considered and distance from these are generated, Fig. 7, using a simple method of finding distance between two points called Euclidean distance in ArcGIS environment.

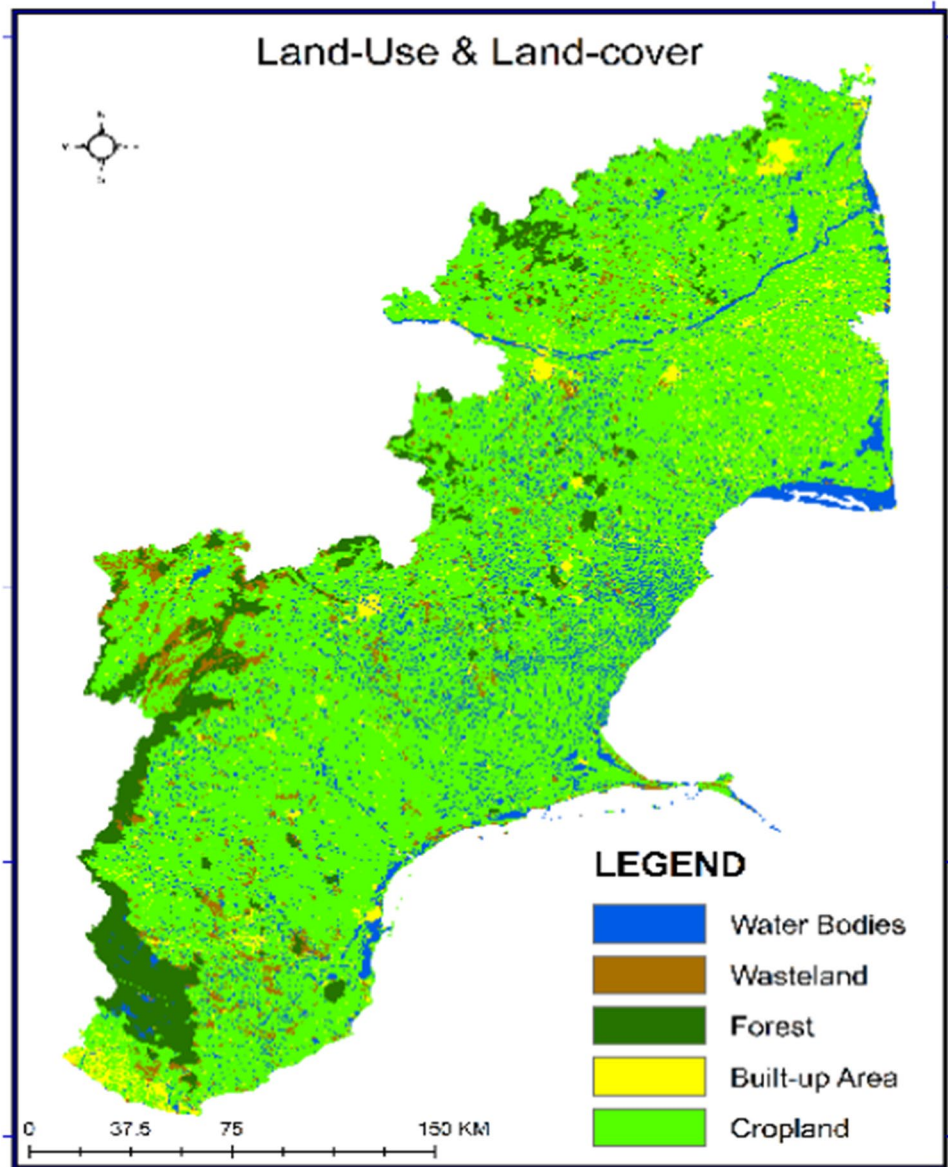
Multi-Criteria Analysis (MCA)

Stanley Zionts popularized the MCDM or MCDA methods (1979). When assessing choices, conflicting parameters are common: expense or price is typically one of the key measures, and some indicator of efficiency is usually an additional condition, sometimes at odds with the price. MCDM is related to structuring and addressing multi-criteria choice

and scheduling issues. The goal is to help others [41]. Multi-Criteria Analysis (MCA) is an open and explicit technique in the decision-making process. MCA determines the preferences for any structure among different alternatives [29]. It is a technique that provides a ranking and compares it with a variety of criteria. It also analyzes and integrates among different objectives and interests of many factors with qualitative and quantitative information [16].

MCDM is a set of techniques for formulating decision challenges, as well as designing, analyzing, and favoring different options. MCDM splits the issue down into smaller chunks, ensures that all available parameters are considered, and assures that the decision-making process is of high quality. Overall, MCDM aids the decision-maker in the quest for the finest presented choices by structuring the decision process and limiting and evaluating the potential alternatives.

Fig. 5 Usage of the land and Land-cover



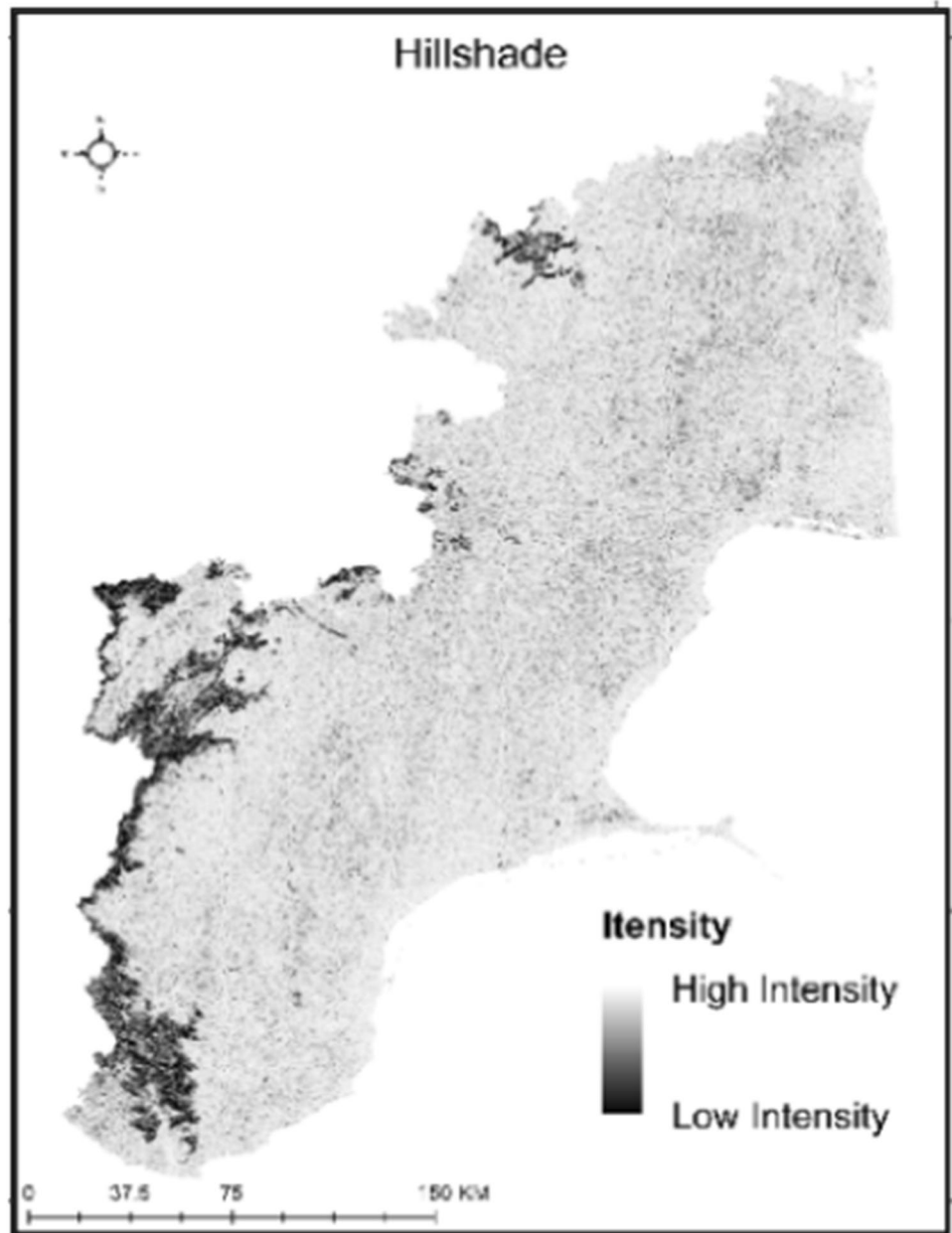
Even though site selection is a complicated issue with several stages and parameters to consider, both GIS and MCDM would be used to decide the most advantageous positions. The use of GIS techniques and MCDM approaches allows spatial databases to be integrated with a wide variety of assumptions [43].

Table 3 Hill shade Azimuth and Altitude angle

Altitude	Azimuth
15 ⁰	60 ⁰
15 ⁰	120 ⁰
85 ⁰	180 ⁰
15 ⁰	240 ⁰
15 ⁰	300 ⁰
75 ⁰	360 ⁰

The suggested integrated structure is made up of distinct phases that are divided into two modules: preparation and field investigation. This includes all applicable social, fiscal, and environmental elements of a sustainable siting study. A collective and participatory planning methodology is currently being used to bridge the current testing disparities in site selection processes devised by combining spatial planning tools, GIS, and MCDM schemes [45].

Combining GIS and MCDM methods is often employed to deliver detailed planning and precise evidence for most suitable site selection for solar PV power plants, GIS provides the collection, analysis, and evaluation of data affecting the solar PV power plants installed in the spatial database. 4 MCDM provides a comprehensive analysis of spatial databases that can be used by multi-criteria methodologies for a fast and agile solution of the problem [44].

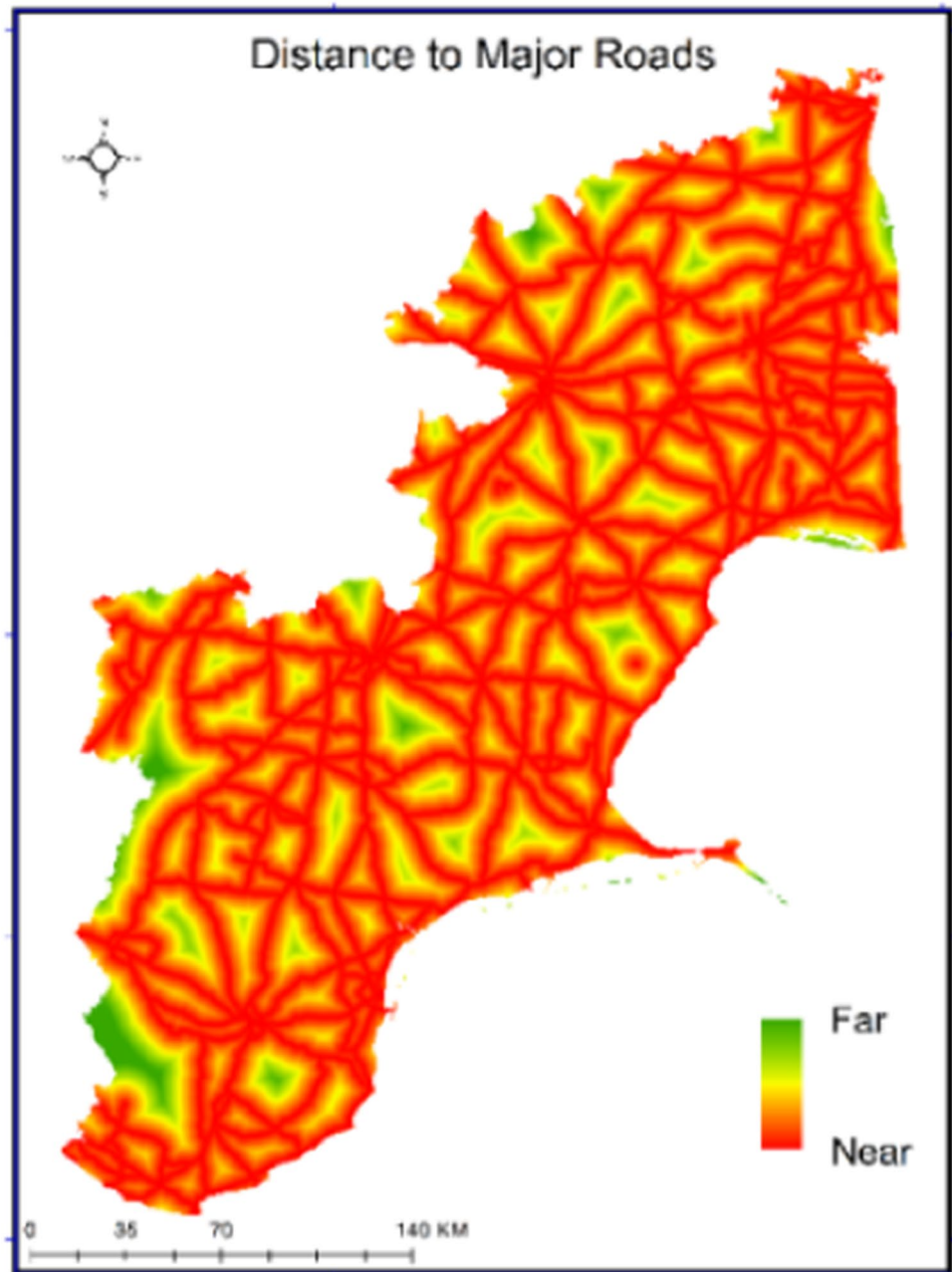
Fig. 6 Hill shade

MCDM methods are well-suited to solve strategic decision-making challenges, according to the majority of scholars. Many competing priorities may be encircled using MCDM approaches systemically and visibly. MCDM, which is focused on multi-attribute value features, is used to aid energy forecasting as well as to identify and prioritize appropriate locations for renewable energy sources [20, 59]. MCDA is a collection of strategies that assist decision-makers in properly configuring multi-faceted decisions and weighing the pros and cons of various options [39]. In site selection tasks, MCE methods have been commonly used in conjunction with GIS, offering a basis for analyzing environmental, economic, and cultural factors that influence land

suitability [22]. Many possible techniques in MCA are used according to the nature of the problem. Properly defining the criteria process is key to provide enough information for decision-makers.

Land-use suitability analysis is a good match for MCDM approaches since it is multi-criteria by default. These methods can help with energy and environmental modeling in particular [34]. Ranking different criteria were difficult for decision-makers until they started using MCA. The weighted overlay technique is simple and mostly used the MCA technique for site suitability [60]. This technique applies a common scale of values for dissimilar and discrete layers [61]. All the criteria may not be equally important so different

Fig. 7 Distance from Major roads



influence percentages are given by the user and give the result by summation of layers.

Flowchart of Weighted Overlay MCA Technique examines defined objectives that are taken into account as major issues, alternatives, and ambiguity. To improve clarity and convenience of use, a sub-model is created. Input Layers influencing the output of appropriate sites are being identified. One of the most significant processes is the selection of criteria, which is dependent on the accessibility of data and the broader context of the investigation region from geological, and environmental viewpoints. Research gathered for this investigation was obtained from India's

Solar Resource Data (NREL), the National Remote Sensing Centre (NRSC), Hill shadow /slope obtained from NASA, and the distances from the road were estimated using Google Maps. The weighted overlay MCA Technique tool in the ArcGIS environment is used to identify and specify the % of impact of defined input layers. The weighted linear combination in MCA could be graphically displayed using GIS, for assessing the range and extent of feasible and excluded segments. A weight can be established in a GIS context for each layer as various weights are assigned to an assessment criterion that reflects its relevance compared to other criteria under investigation. When allocating weights, four methods

are available: pairwise comparison, trading of analysis method, ranking, and rating. The entire weightage distribution was determined using an analytical hierarchy process-based MCA. The layers of the multiple maps acquired by GIS and weighted by weighted overlay MCA analysis are then merged to provide a single map displaying the optimum and most appropriate sites for solar PV farm site suitability, Fig. 8.

Results and discussion

The well-defined objectives are considered while taking the key issues, alternatives, and uncertainty. The components and how it works is also defined clearly initially. When the input layers are very complex to use, it is recommended to form a sub-model for better clarity and ease of the process. Layers that affect the output of suitable sites are being identified. To break down the complexity of the problem some constraint layers are generated, Fig. 9. The defined input layers are reclassified to a common scale of values. Influence percentages are identified and defined in the weighted overlay model in the ArcGIS environment. The output is analyzed for alternatives and reported.

Visualizing different decision-making scenarios was made incredibly easy with the Weighted Overlay MCA

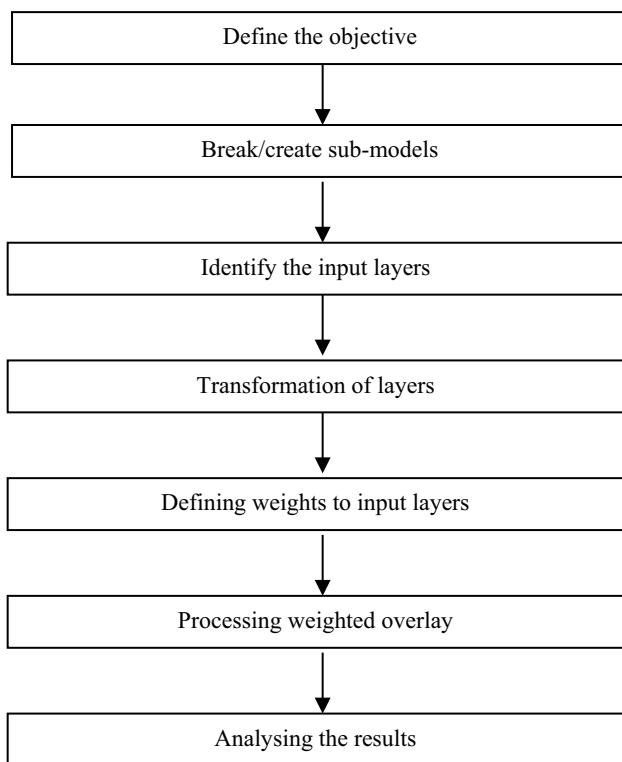


Fig. 8 Flowchart of weighted overlay MCA technique

Technique tool. GIS was utilized for spatial analysis and data visualization. The GIS tool was initially used to screen the distribution and extent of viable and exclusion zones, and it is now used to graphically display the weighted linear combination in MCDA. In a GIS setting, the overall weightage distribution for each layer for the weighted overlay was completed. Analytical hierarchy process-based MCDA was used to determine the overall weightage distribution. Through the use of a weighted overlay analysis, the ideal and most suitable locations for the solar PV farm site suitability were found.

Based on the region under research, the maps of the specified criteria were sorted and prepared for analysis. The gathered criterion maps were classed using the aforementioned criteria and grading methodology. To calculate the weighting of each criterion that will have an influence on the analysis following the reclassification operation, an overlapping technique was used. The overlay analysis results map indicates that the ideal area for solar PV farm site suitability has been identified.

The methodology presented in section-4 was applied and data generated from different processes of criteria are processed with weighted overlay MCA technique in ArcGIS by following steps below [62] and finally, the output of the site suitable for solar PV farm was generated for further analysis.

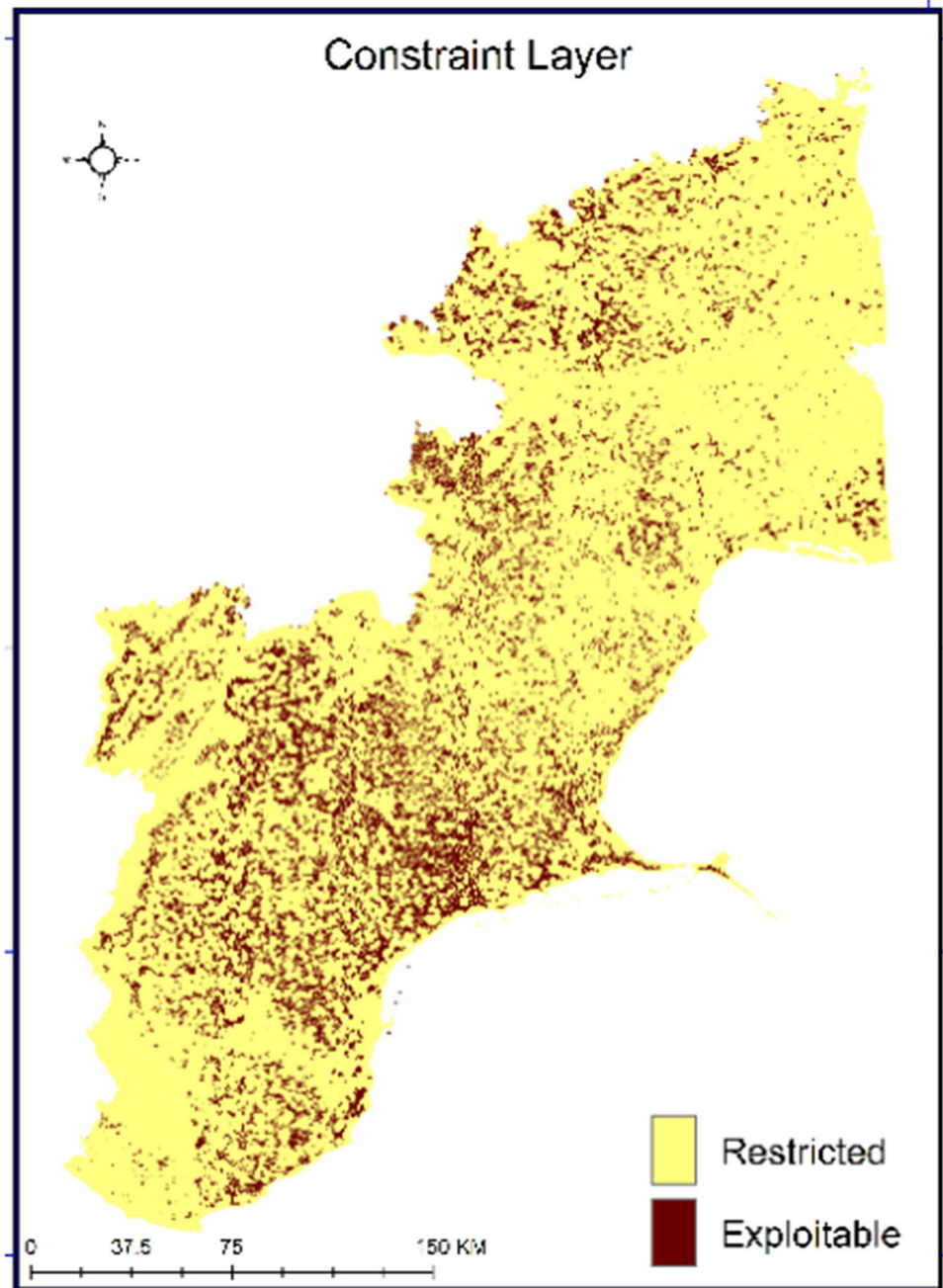
Step 1: All identified layers for MCA were converted to 30 m resolution according to DEM datasets for uniformity. The Data originality or accuracy of the dataset loses in the conversion of DEM datasets.

Step 2: The solar GHI layer was reclassified with a 1–10 scale of values. Hill shade layers with various azimuth and altitude angles were added in ArcGIS with raster calculator and reclassified with the same scales of values, similarly, the distance from the road network is reclassified to a common scale of values 1–10.

Step 3: In this study, the consideration of site appropriateness for places including water bodies, forests, built-up areas, coastal areas, and buffer areas was strictly limited. These parameters serve as assessment criteria. Buffering and weighted overlay analysis are used in GIS as multi-criteria methods for spatial information analysis. The state of Tamilnadu is used as the test region for the study of the best facility placement for solar photovoltaic farm site suitability, Fig. 10. The slopes of greater than 15° south facing and 5° for aspect are completely restricted. These two layers weights same are combined to generate a constraint layer and it is been reclassified to a common scale with other layers.

Step 4: Using the Weighted Overlay technique in the ArcGIS environment influence percentage for four different layers are given as in Table 4. And results are generated and presented in Fig. 10.

Table 5 indicates the potential of solar PV forms that could generated the electric power. Excluding the unsuitable

Fig. 9 Constraint layer

and low suitable areas the 16 districts of Tamilnadu, the state is still be potential to generate 50 GW of electricity as an average. The low value for the highly suitability for the PV forms is expected as these investigations considered many more weighted values of the criteria. For example, geopolitical and financial incentives are rarely considered as weighed values of the criteria in any of the investigations in the recent past. The chosen weighted values of criteria are because of the social dynamics of the state Tamilnadu which is a way different from any other state in other parts of the world. For clarity and user-friendliness, the weighted overlay

results are assessed and classed using an appropriateness scale. There are three appropriateness categories for areas: high, medium, and low. For cutting-edge PV technology, the potential power generation in a highly favorable location is assessed.

According to research, there are 10 places with the greatest potential for solar photovoltaic farms. These were identified based on the final findings of the weighted overlay, and they are marked in red on the map in Fig. 10. After taking into account the current land cover in Ramanathapuram, Krishnagiri, and Thuthukudi districts, seven of the ten

Fig. 10 PV farm Site suitability level

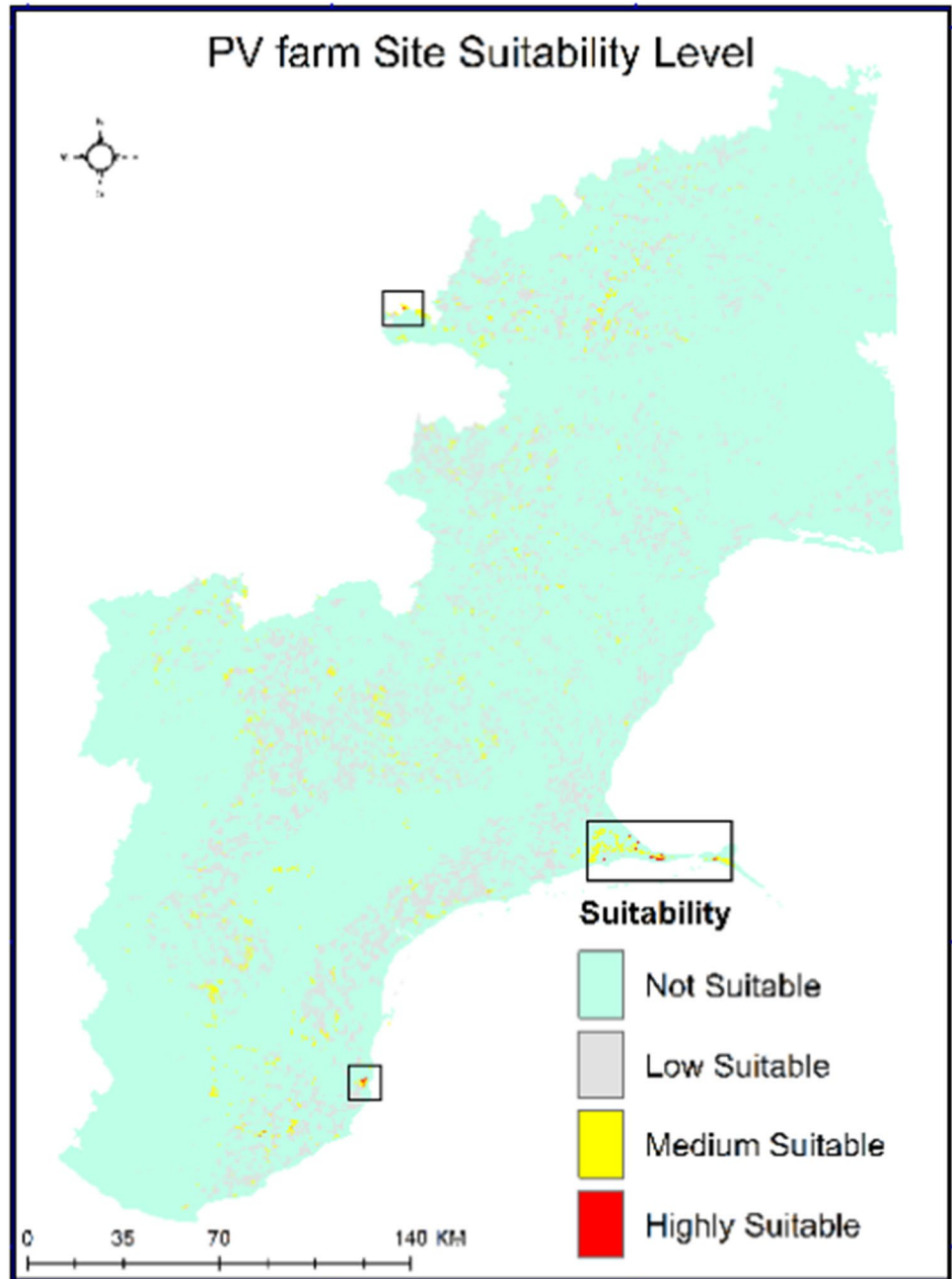


Table 4 Input Influence % for Weighted Overlay

Layers	Influence (%)
Annual GHI	40
Constraint Layer	30
Hill shade	15
Distance from road	15

areas were determined to be the most appropriate. According to the findings, the bulk of Tamilnadu’s districts, with the exception of the state’s northern region, are suitable

(medium) for the development of solar photovoltaic farms. In this research, 10° is used as the PV panel tilting angle. Tilt angle and orientation both play a significant role in optimizing the solar radiation gathered by a PV panel. Since the studies were conducted at noon, the hour angle is taken to be 0°. Only a very tiny section of the land is very appropriate, and the most of the area has poor suitability, as shown in output Fig. 10.

Total Potential from the highly suitable area is calculated by summation of the product of solar radiation per m² and efficiency of the different PV technologies [63]. Table 6, shows that concentrator technology has more potential of

Table 5 The % of site-suitability areas based on investigation results

Suitability cases	Area of suitability for the solar power plant		Proposed capacity of PV farm, MW
	Estimated Area, km ²	Suitable Area, %	
Not suitable	34,585	63	–
Low suitable	21,369	38	–
Medium suitable	585	1.1	91,600
Highly suitable	12,906	0.024	2000
Total	16 districts—55,160 km ²	100	93,600 MW

Table 6 Potential & estimated output from highly suitable areas With Present Technology of Modules

PV Technology	Module Efficiency η %	Total Potential (TP) GWh/day	Estimated Output (TP * SF), GWh/day	Site suitability	Installed Capacity (GWh)
Mono Crystalline	23	16.442	12.332	Medium/ High	0.5
Multi crystalline	20	14.274	10.706	Medium / High	3
Thin film	12	8.564	6.423	Medium / Low	0

16.442 GWh/day. The Estimated output is calculated with the local shading factor (SF). A minimum value of 0.75 is applied to the Shading factor along total potential (TP) to estimate the output power with various PV technologies. There are upcoming Technologies, which increase the efficiency of current modules, which further can increase the energy generation per area such technologies are Perovskite cells, Multijunction cells, and some different materials in thin-film modules too. To assess the robustness of the data, a simulation model of scales or other unpredictable investigation technical approaches along with the MCDM approach should be done and discussed further. Furthermore, certain technological complexities, such as land conversion factor and PV module output ratio, have a bearing on the findings, necessitating further analysis to make a more reliable estimate.

Validation of the present work:

Groundwater management in Egypt, flood vulnerability assessments in Ethiopia, and the identification of groundwater potential zones in South Africa all make extensive use of GIS-based MCA. The GIS-based MCA tool is also useful for determining the potential for groundwater in the Kattankolathur block of Tamil Nadu and evaluating the state of the vegetation in the Sali River basin of West Bengal. Therefore, the GIS-MCA tool had been used for anything from evaluating the condition of agricultural soils in Morocco that were watered with wastewater to finding prospective groundwater recharge zones in Tamil Nadu's Ponnaniyar watershed. These recent studies demonstrate the efficacy of the GIS-MCA tool in locating Tamilnadu's most promising locations for solar photovoltaic farm sites.

Scope of the work

Multi-Criteria Analysis is an explicit technique compares, analyzes and integrates a variety of criteria with many factors considered as layers with weightage. The results will help developers, the government, and other interested parties identify prospective locations for the installation of solar PV farms in Tamilnadu's southern districts. Additionally, they will support decision-making about power grid expansion to support investments in solar PV power plants and foster synergies in energy generation and transmission. When it comes to assumptions, data consistency, decision-makers' preferences, and applicable methodologies, the findings should be carefully considered in practise. In-depth information and study are required for real implementation. For example, even though a location is close to the grid, the congestion issue brought on by the penetration of solar PV power output should be properly examined and appraised. The policy makers' preferences in determining restrictive parameters, estimation measures, and their measurements have a significant effect on the outcomes (power output). To assess the robustness of the data, simulation model of scales or other unpredictable investigation technical approaches along with the MCDM approach should be done and discussed further. Furthermore, certain technological complexities, such as distance from the substation to the end point user, Grid availability for stakeholders, load flow details of each available substation or newly developing substation, land conversion factor and PV module output ratio, would have a bearing on the findings, necessitating further analysis to make a more reliable estimate. Besides this, since the Southern districts of Tamilnadu are also popular for tourism destinations, migratory birds, archeological sites, and river streams, future

studies can look at the economic opportunities for solar PV power production as well as the ecological impacts of land use. Nevertheless, getting appropriate data from various government sources would be challenge.

Conclusion

This paper explained the implementation of multi-criteria analysis for decision-makers by using Geographical information system. The significant aspects of solar PV power location aptness study are solar irradiance, slope, land use, forest land, area, and distances from roads. The results show the suitable areas can meet the demand of the state of Tamil Nadu. Then 12.906 km² of the highly suitable area which is only 0.024% of the study area can establish 2000 MW of Photovoltaic farm. Investigations also conclude that by considering the moderately suitable areas of the state, it is still possible for the state to generate around 50 GW of electricity from the solar PV farms as an average. The present study also suggests that the concentrator technology has more potential of 16.442 GWh/day which is significant to meet the electricity power demands. This capacity makes sense to put the electricity gap between the state's demand and supply. Unlike in other similar research, the estimated possibility of a solar PV farm is due to the unusual weighted values of the factors such as geopolitical and financial incentives. If the state begins to employ this large amount of green solar capacity to meet its energy needs, this document will assist to bridge the electricity gap between rural and urban regions. The biggest of the regions satisfied the suitability evaluation standards. Solar irradiance, slope, land usage, forest land, acreage, and distances from roadways were all important factors in the solar PV power placement aptness research. This geographical data may be used to conduct a more extensive examination of the power plant's construction by public or private investors. Different multi-criteria analyses can be used for even more complicated judgments.

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Declarations

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