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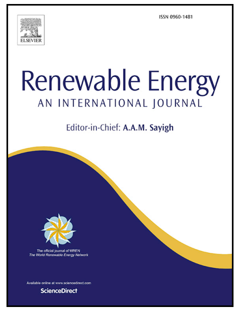

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Theoretical and Technical Potential Evaluation of Solar Power Generation in Iran

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Abstract

Nowadays, utilizing solar energy for power production at high efficiency and in a cost-effective status is a challenging issue for power plant engineers. This challenge would be answered by considering several affecting parameters such as technical, economic, and environmental criteria. In this investigation, in order to provide an assessment for implementing solar power plants in the southeast of Iran, Sistan and Baluchistan province, a multi-criteria decision making (MCDM) approach is linked to a geographic information system (GIS). The MCDM approach is used to appraise the effective criteria for implementing solar power plants. The environment, orography, economic and climate are selected as the important criteria. Each criterion is assessed for the defined location of the investigation (Sistan and Baluchistan province) and in addition, GIS is employed to provide a geographical-graphical valuation to determine the most appropriate place for installing a large-scale solar power production plant. The solar systems considered in this study are photovoltaic (PV) collectors and concentrated solar power (CSP) generation plants (e.g. solar trough collectors). Technical and theoretical valuations are made to specify the amount of solar power which can be harnessed in Sistan and Baluchis-

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tan. In overall, it is demonstrated that this specific location in the southeast of Iran has the technical potential to provide 7,419 TWh/y and 8,758 TWh/y of solar electricity by installing CSP and PV technologies, respectively.

Keywords: Multi-criteria decision making; Potential study; Solar power generation; Geographic information system.

1. Introduction

Recently, due to the advantage of renewable energy technologies, increasing the cost of fossil fuels and its global warming effect, the use of distributed energy sources has been growing[1–4]. Moreover, accessibility to electric power results in social, economic, and technological advances. In the recent decade, the thermal energy demand has increased considerably because of the urbanization, changes in lifestyles and consumption patterns[5]. On the other hand, due to environmental concerns, the use of renewable energies has received more attention. Many potential siting studies about renewable energy have been done previously such as, wind energy [6], geothermal energy [7–9], biomass [10] and solar energy [11] that were conducted using GIS. Amongst different sources of renewable energies, solar energy is widely available throughout the world. Therefore, it can contribute significantly to reducing the dependence on imported energy sources for energy importing countries [12].

In order to utilize the solar energy, sunlight is converted into the usable energy forms (heat or electricity). Generally, there are two different technologies namely photovoltaic panel (PV) and concentrated solar power (CSP) for electricity generation[13]. The CSP technology uses concentrated solar radiation as a high-temperature thermal energy source to drive steam turbines and converts it to the electricity[14][15]. These systems are appropriated for the areas where the direct solar radiation is available and also a number of clear sunny days in the year are high [16, 17]. As well, PV technology is a power system based on the PV cells which converts solar energy into the electricity. Annually, considering the PV market growing by 30-40%, the PV system is turned into one of the most energy carriers by appropriated technologies[15].

Geographical information system (GIS) is a powerful tool to visualize and analyze the energy resource potentials. Several investigations have been performed to assess the solar power plant implementing process and also its feasibility by using remote sensing and GIS. Various interacting criteria are effective for evaluation of the solar power plant. Thus, selecting the most appropriate location and also the better technology for implementing the power plant is a crucial decision. Classic single criterion decision-making methods are not able to address this complicated issue [18].

In this regard, Trieb et al. [19] analyzed the technical and economic potential of the CSP using annual direct normal irradiance (DNI) data by excluding sites where geographically unsuitable for solar plants in the world. In a similar study, Tahri et al. [20] applied integration of GIS and multi-criteria decision making (MCDM) methods to assess the suitability land for large scale solar electric generation farms. The criteria which were used are location, orography, land use and climate. Based on the location criterion, the ground which was flat and oriented toward the source was selected as the best suitable area. Within another study, Janke [21] identified suitable areas for wind and solar farm using MCDM and GIS modeling techniques. In this investigation, land-cover, population density, federal owned lands, and distance to roads, transmission lines, and cities were considered according to their suitability. Finally, they concluded that the solar energy in small scale is more suitable in comparison to the large scale power plant. Based on a combination of GIS capability and an MCDM technique, the evaluation of the optimal placement of photovoltaic solar power plants in southeast Spain was studied by Lozano et al. [22]. In the study, environmental and economic factors were used in site selection process.

Currently, Iran's total power generation capacity is approximately 75GW. Over the past 10 years, demand for power in its domestic market has grown by 6.5% annually, and the country has also started to export significant amounts of power to its neighboring countries [23]. Iran is a large country with a diverse climate and topography in which the solar resources are also abundant with more than 300 days of sunshine annually [24]. Renewable energies implementation such as grid-connected PV and CSP power plants are prompted by the Iranian Government. In this regard, several studies were conducted to estimate the solar energy potential in Iran. Moini et al. [25] provided the monthly and annual maps of Iran's solar radiation on the horizontal surface using angstrom approximated model. Besarati [26] computed a map of the value of the solar energy reaching to the earth surface in 50 Iranian main cities based on solar radiation value. Alamdari et al. [27] estimated the global horizontal irradiance (GHI) map for Iran. In the study, they suggested some cities with average horizontal solar radiation above of the 500 Wh/m^2 for more investigations in the photovoltaic application.

In this study, the methodology based on the literature is developed by considering various criteria and alternatives to find the most appropriate solar farms for PV and CSP sites in Sistan and Baluchistan province located in the southeast of Iran. Despite the previous studies, a novel methodology is conducted in the current research regarding theoretical and technical methods of the solar power generation for both PV and CSP technologies in a non-build-up area which can also be used in another location in the world. Defined alternatives which were used in some literature reviews and this study are shown in Table 1. The aim of this study is to present the technical and theoretical potential of the best suitable area for solar power generation with regard to the appropriate technology in each city of the selected province.

2. Methodology

2.1. Defining criteria for site selection

To achieve the best area for installing a solar power plant, the defined criteria in the literature are identified and categorized. It makes possible to characterize and quantify alternatives in a decision- making process [31]. The proposed goal, which is divided into two levels of criteria and related alternatives are shown in Figure 1. Climate, orography, environmental, and economic criteria are considered in the first level. These can be subdivided into seven alternatives at the second level

Table 1: Defined alternatives of literature review and proposed study

Parameters	Merrouni et al. [28]	Tahri et al. [20]	Yushchenko et al. [15]	Watson et al. [29]	Gastli et al. [30]	This study
Type of technology	PV	PV	PV-CSP	PV-wind	CSP	PV-CSP
slops	*	*	*	*	*	*
GHI	*	*	*	*	*	*
DNI			*			*
Average temperature		*				*
Roads	*	*	*	*		*
Power line	*		*	*		*
Build-up area	*	*	*	*		*
Land use	*	*	*	*		*
River						*
Airport						*

including land use, slope, aspect, distance to the urban area, distance to roads and highways, potential solar radiation, and land surface temperature.

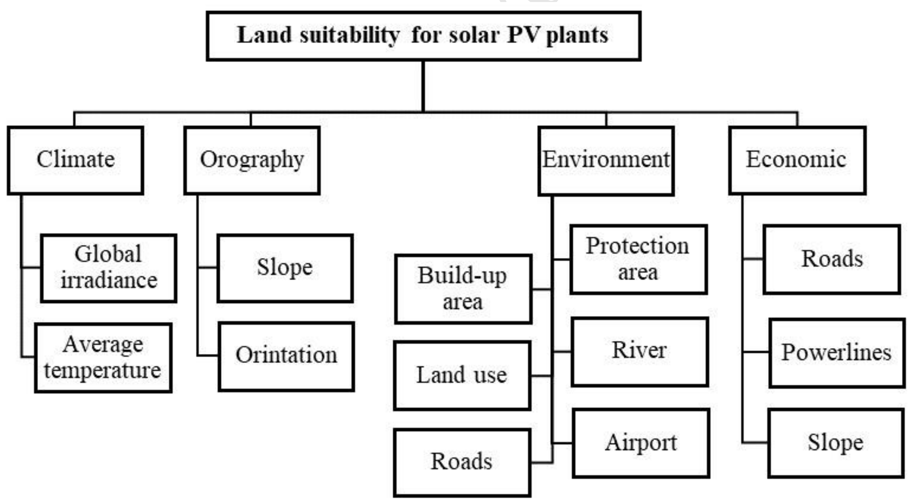


Figure 1: A flow diagram of decision making for selecting the best solar potential area

A group of experts in solar and power plant engineering fields was asked to do a survey and their comments were used and presented in Table 2. Furthermore, due to the fact that in some areas like the environmentally protected areas, roads,

Table 2: Input data of criteria, alternatives and indicators

Criteria	classifying layers	Indicators
Orography layers	slops (%)	<3
		3-8
		8-15
		15-20
		>20
	Orientation	South
		Southeast
		Southwest
		East
		West
		Northeast
		Northwest
		North
Climate layers	Global Horizontal Irradiance ($KWh/m^2/year$)	< 1100
		1100-1200
		1200-1300
		1300-1400
		1400-1500
		1500-1600
		1600-1700
		1700-1800
		1800-2000
		2000-2191
	Direct Normal Irradiance ($KWh/m^2/year$)	<757
		757-800
		800-900
		900-1000
		1000-1100
		1100-1200
		1200-1300
		1300-1500
		>1500
	Average temperature ($^\circ C$)	<15
		15-18
		18-23
		23-26
		26-29
		29-31
		31-34
		24-37
		>37
Economic layers	Roads (km)	0-1
		1-2
		2-3
		>3
	Power line (km)	<1
		1-5
		5-30
		>30
	Build-up area (km)	0-1.5
		1.5-3
		3-5
		5-7
		>7
Environmental layers	Land use	Forest
		Bareland
		Jungle/agriculture
		Masil
		Range
		Rock

rivers, airports, and transmission lines, there is no possibility of solar power plant installation, these areas are eliminated from the solar potential map (Table 3).

Table 3: Restrictive area

Discarding Layers	Buffer Distance
Protection area	500 m
River	1000 m
Build-up area	2 km
Roads	1.5 km
Power lines	1 km
Airport	3 km

For identification of the solar power plant potential on a regional scale in Iran, Sistan and Baluchistan province is selected as a case study. Sistan and Baluchistan province is one of the 31 provinces of Iran with the highest potential of solar irradiance [31] in the country. It is located in the southeast of the country (27.5300N, 60.5821E) as shown in Figure 2. As well, the geographic coordinates of Sistan and Baluchistan's cities are shown in Table 4. The province area is 181,779km^2, which represents about 4.11% of the total national land of Iran, with 2.5 million inhabitants. in 2016 in 19 districts. Based on solar statistics reports, the number of sunny days is more than 300 days in this region. Sistan and Baluchistan province has a warm climate and its average mean temperature is 43C. On the other hand, the minimum temperature which is -11.4°C can be experienced in the province in January.

2.2. Multi-criteria decision making and analytical hierarchy process

The analytical hierarchy process (AHP) is based on mathematics and psychology. It was originally introduced by Saaty in 1980 [32]. The AHP covers multiple aspects process to help decision makers to make comparisons and solve complex decision problems [32].

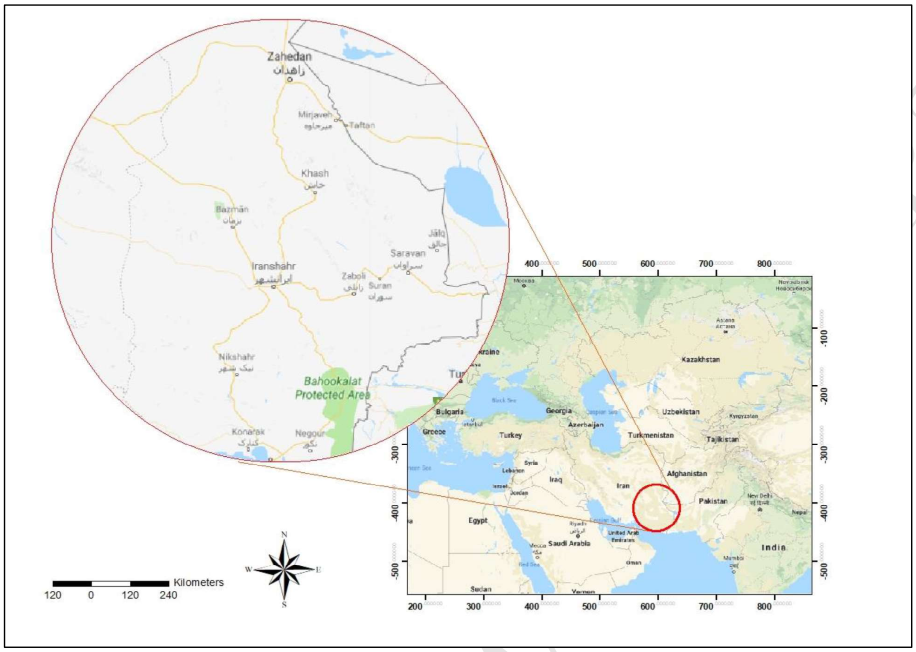


Figure 2: Geographic location of Sistan and Baluchistan Province

The first step in the AHP method is to assess the criteria that enable us to make an accurate comparison and right decisions to provide subjective judgments. In the AHP process the decision making procedure is breaking down into a hierarchy of the goals, criteria, and alternatives, respectively. The framework of this approach is illustrated in Figure 3. It should be noted that the AHP method is based on applying pairwise comparison in order to drive weight for alternatives [15].

Typically, to show the importance of factors, 9 points with values ranging from 1 to 9 are used as shown in Table 5 [32, 33]. For instance, A1 is more important than A2 equals to a_{12} (as an example a_{12}=3) and the relative of A2 to A1 is its reciprocal (a_{21}=1/3). The higher weight, the higher importance of the corresponding criterion. Also, a decision by sensitivity analysis and synthesis results can be made. To visualize the suitable area, the AHP method is mostly used in combination with GIS [29, 34]. The weight of criteria and alternatives can be defined as matrix A (Eq. 1)

Table 4: Geographic coordinates of the case study

City	Latitude	Longitude
Iranshahr	27°15'N	60°40'E
khash	28°15'N	61°15'E
Dargan	27°60'N	59°68'E
Zabol	31°0'N	61°32'E
Mehrestan	27°13'N	61°68'E
Zahedan	29°30'N	60°50'E
Zehak	30°89'N	61°67'E
Saravan	27°34'N	62°35'E
Sarbaz	26°63'N	61°26'E
Sib and suran	27°25'N	61°96'E
Konarak	25°41'N	60°36'E
Nikshahr	26°15'N	60°10'E
Hirmand	29°50'N	60°85'E
Chabahar	25°29'N	60°64'E

121 which is normalized as a new matrix [32],

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & a_{n3} & \dots & a_{nn} \end{bmatrix} \tag{1}$$

Table 5: AHP weighting scales

Definition	Scale values	
	a_{ij}	a_{ij}
Equal importance	1	1
Intermediate	2	0.5
Moderate importance	3	0.33
Intermediate	4	0.25
Strong importance	5	0.2
Intermediate	6	0.17
Very strong importance	7	0.14
Intermediate	8	0.13
Extreme importance	9	0.11

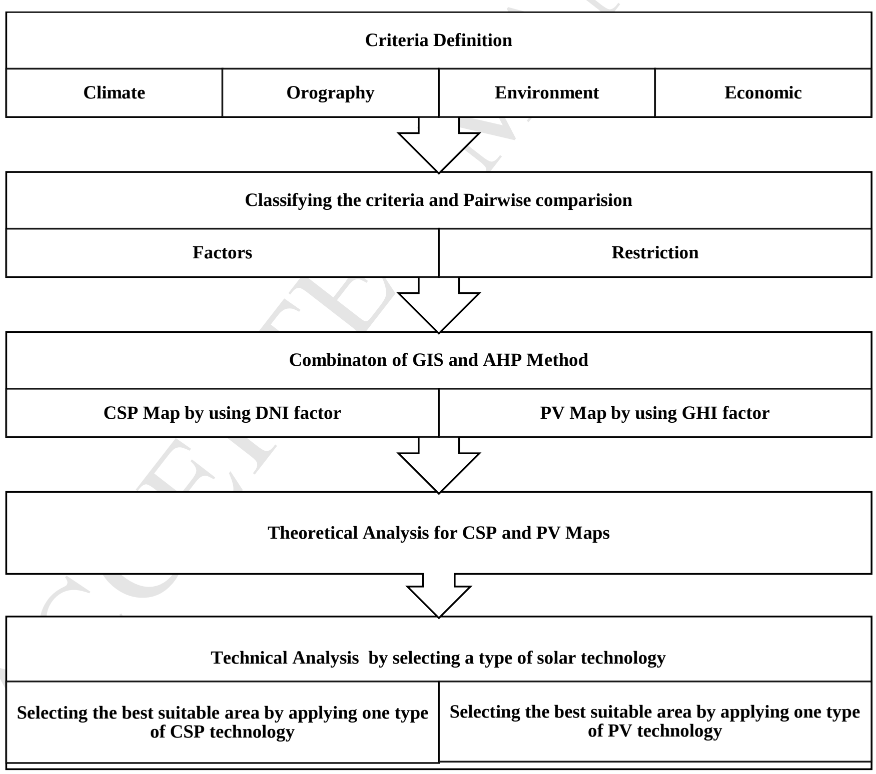


Figure 3: The steps of methodology for selecting the best suitable area of solar power plants

The weights of criteria and alternatives are calculated by expert choice which is a user-friendly and practical tool for analytical thinkers. The decision-making problem is modeled in the expert choice software to arrange a goal or decision down to fewer parts. So, by dividing goals into sub-criterion, decision-makers would be able to apply judgment to achieve their goals. Finally, the result of the computation can provide beneficial information about the defined criteria and alternatives.

For evaluating the inconsistency measuring of the experts' judgments, the pair-wise comparison is verified by the consistency ratio (CR) which is calculated by Eq. 2:

$$CR = CI/RI \tag{2}$$

Where the value of CR demonstrates the correctness of the procedure should be below 10%. On the other hand, if the value is more than 10%, a major revision is required in the weighting process [32, 35]. RI refers to Random Index. The RI value indicates the average deviation from randomly generated matrices of different sizes as given in Table 6. CI refers to the consistency index obtained by RI value by using,

$$CI = (\lambda_{max} - n)/(n - 1) \tag{3}$$

where λ_{max} displays the maximum eigenvalue of comparison matrix A. After computing the eigenvalue and the priority vector, λ_{max} is obtained from the summation of products of multiplying the sum of each column of the matrix by the corresponding value of the priority vector. λ_{max} can be calculated by,

$$(A\lambda_{max} - I) \cdot W_j = 0 \tag{4}$$

Table 6: Random consistency indexes

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54

Where I is defined as an identity matrix and A is a comparative matrix. W_j is the weight of the criteria matrix. Table 7 indicates the criteria matrix (matrix A) used for obtaining normalized criteria weights (Table 8) based on AHP method which says that the climate criterion has the weight of 58% in comparison to the orography (25%), economic (5%) and environment (12%). In this study, the pairwise comparison is verified by the consistency analysis where the value of λ_{max}, CI, and n are, 4.056, 0.01867 and 4, respectively. When the criteria were organized by the AHP method, the same procedure is repeated with nine alternatives. As shown in Table 9, the alternatives final weights using in each criterion is obtained by the AHP method.

Table 7: Pairwise comparison matrix (assigned to criteria)

Criteria	Orography	Environment	Economic	Climate
Orography	1	3	5	0.33
Environment	0.33	1	3	0.2
Economic	0.2	0.33	1	0.11
Climate	3	5	9	1

Table 8: Normalized pairwise comparison matrix

Criteria	Orography	Environment	Economic	Climate	Normalized priority Vector (W_j)	Weights (W_j%)
Orography	0.22	0.32	0.28	0.2	0.25	25
Environment	0.07	0.11	0.17	0.12	0.12	12
Economic	0.04	0.04	0.06	0.07	0.05	5
Climate	0.66	0.54	0.5	0.61	0.58	58

2.3. Criteria classification maps

In order to specify the most suitable area, a combination of defined alternatives in each criterion (Figure 4) is applied to indicate the best suitable area in criteria as shown in Figure 5. Regarding the GIS and spatial analysis tool, all the criteria final maps are classified from 1(low potential) to 10(high potential). For more details, four categorized criteria are subdivided as follows,

Table 9: Final weights of alternatives

Factors	Weights (%)
Land use	7
Average temperature	26
Distance from roads	2
Distance from power lines	4
Distance from build-up area	2
Slope	16
Orientation	12
GHI / DNI	31

2.3.1. Climate

Climate factors (solar irradiance and average earth temperature) are known as the most significant parameters for the decision rule that defines whether the selected location will be appropriate for the estimated electricity production capacity of the PV or CSP power plants [31]. In the presented study, solar irradiance and average temperature values are redefined by distributed classes.

As depicted in Figure 4(a) and Figure 4(b), the most significant area is covered by more than 1600kWh/m^2 and 1400kWh/m^2 for global horizontal irradiance (GHI) and direct normal irradiance (DNI), respectively. These figures represent the theoretical potential of the both types of the solar irradiance which is categorized from the least irradiation to the highest irradiation (Table 2). As seen in Figure 5(a), the climate alternatives are combined based on the weighting method.

2.3.2. Orography

Generally, the most suitable areas for installation solar panels are the ground which is flat and oriented to the south. In this paper, ground's slopes by more than 3% are considered as less valuable due to higher construction cost. Basically, due to the geographic location of the selected area, most areas are highly desirable as shown in Figure 4(c) and Figure 4(d). By combining the slope and orientation classified maps, a map of orography is produced as shown in Figure 5(b).

2.3.3. Environment

In addition to the climate and orography criteria, several influencing variables including roads, rivers, land uses, build-up areas, protected areas and airports are chosen as environmental alternatives. Some studies prefer to install power plants close locations to urban areas because of the high demand for electricity and also reducing the associated transmission cost. However, making solar power plants close to urban areas may impede urban growth [36]. In this case, the environment parameters are shown in Figure 4(e) to Figure 4(h). A view of the classified environmental alternatives is demonstrated in Figure 5(c).

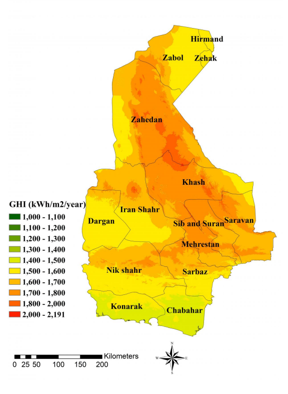
2.3.4. Economic

Economic factors such as the distance from roads and power lines can impact the construction cost of the solar power plant installation. Projects are also more likely to be successful if they are in an accessible distance from the power grid [37]. Likewise, if the ground slope is less than 3% and suitable for solar panel installation, it can be the most cost-effective for instance, reducing the number of extra roads which should be constructed. Also, there is a wide range of slope values. Some of these values may add more costs to the construction. Considering all of the classified alternatives, a map of the economic criterion is presented in Figure 5(d).

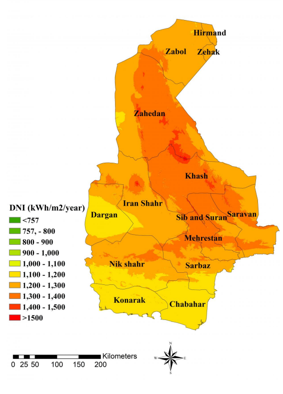
2.4. Description of solar power generation

In overall, the methods for solar power calculation have been categorized according to the theoretical, technical and economic potential assessments. Basically, the theoretical potential can be defined as the total annual solar radiation in a suitable area for installing large-scale solar power plants (outside of the built-up area). Based on the GIS tools and AHP method, by extraction of the restrictive area from solar irradiance map, the theoretical solar potential is obtained. In this case, both GHI and DNI solar irradiances are considered to evaluate the proposed area for PV and CSP power plant installation, respectively.

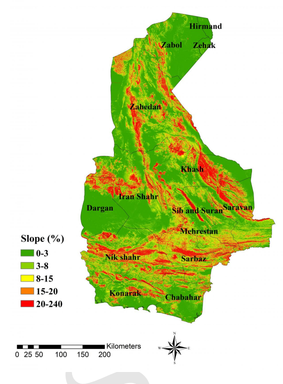
From the technical potential perspective, the solar power generation is estimated bearing in mind the theoretical potential by considering the solar power



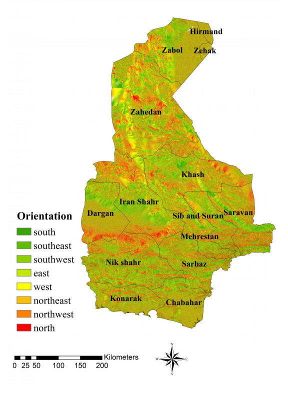
(a) Global horizontal irradiance



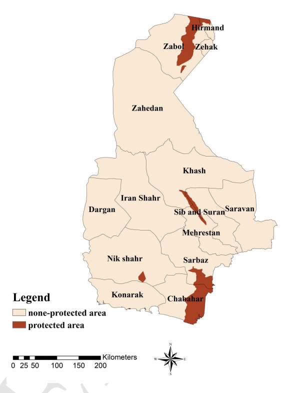
(b) Direct normal irradiance



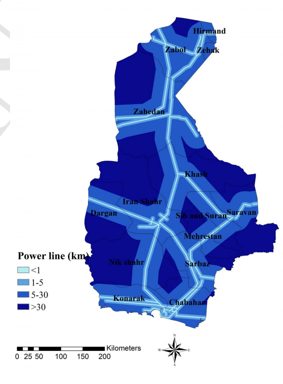
(c) Slope



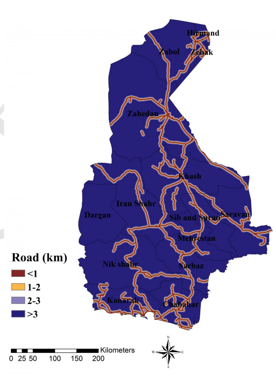
(d) Slope Orientation



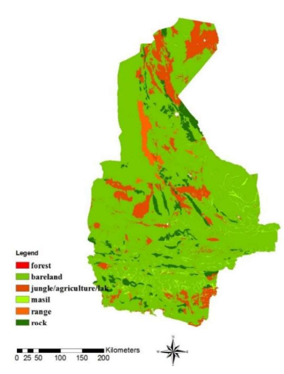
(e) Protected area



(f) Distance from power line

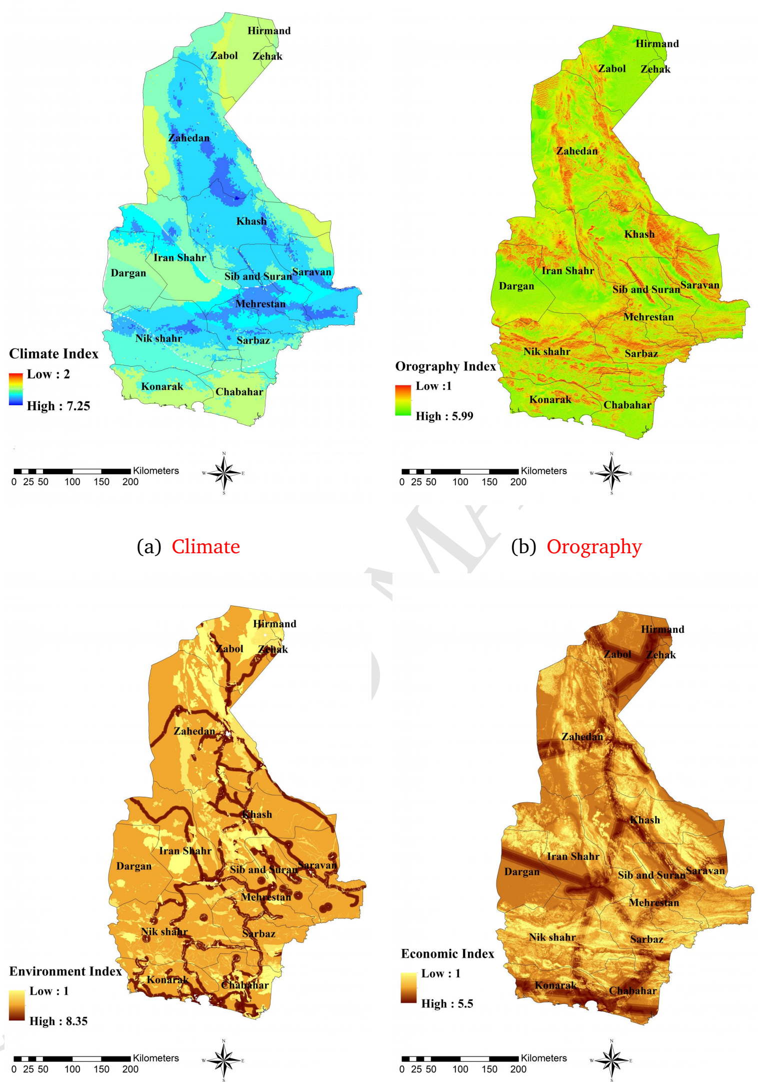


(g) Distance from roads



(h) Land use

Figure 4: Physical factors of the study area



(a) Climate (b) Orography

(c) Environmental (d) Economic

Figure 5: Criteria classification of the case study

technologies. To calculate annual power generation potential based on the solar radiation technical characteristic, PV and CSP solar technologies are presented in Table 10. Also, the PV modules tilted at the latitude angle with the south surface orientation [26]. Accordingly, the power generation potential is calculated by Eq. 5,

$$\text{Solar Electric Generation}(\text{SEG}) = (\text{GHI})\text{or}(\text{DNI})(\text{Efficiency})(\text{Available Area})(\text{pr}_{PV}) \tag{5}$$

where GHI and DNI are measured as (kWh/m^2/year). The term "efficiency" describes how efficient the solar system is in converting sunlight into electricity. The term "available area" refers to the total suitable area for PV or CSP installation. pr_{PV} is the assumed performance of the PV system.

Table 10: PV and CSP technologies considered to calculating the technical potential.

Technology	Type of modules	Efficiency(%)	Pr
PV	Mono crystalline silicon	15-22	70-85
CSP	Parabolic trough steam cycle	15-21	-

The economic potential method estimates the cost of the total technical solar power generation in comparison to the conventional electricity sources. The total initial costs including construction, maintenance, and solar technology costs are considered to be constant. In this study, we considered this issue for a view of the theoretical and technical power potential of PV and CSP systems.

3. Results and Discussion

Having processed a combination of GIS and AHP tools, this paper has identified a suitable land for the logical location of solar power plants. In order to calculate the suitability index, a pairwise comparison matrix obtained from the AHP method is calculated, and the weights of the criteria and alternatives for assessing the most proper location for solar power generation from both PV and CSP systems are determined. The main criteria are divided into four categories including orography, climate, economy, and environment. As discussed, the climate was identified to be the most important criterion. Orography stands in the next stage which extremely depends on a land-oriented to the south and a flat area. In comparison, a distance to river, road, airport, power line and urban area were found to have a less prominence on the economic and environmental criteria.

The results of the process are shown in Figure 6 and Figure 7 which is the final comparison of PV and CSP solar maps driven by GHI and DNI radiation, respectively. In our case study, the final outputs (Figure 6 and Figure 7) were sorted into five separated categories: best suitable, suitable, moderate and less suitable and unsuitable. The unsuitable area showed the restrictive factors, referred to roads, rivers, power line, airports, build-up area and protected area, were not accounted in land potential calculations. The results demonstrate the high potential of PV power compared to CSP power. This result is due to the fact that the annual variation in solar irradiation is from 1546 kWh/m^2/year - 2191 kWh/m^2/year in the case of the global solar radiation and from 1188 kWh/m^2/year-1666 kWh/m^2/year in the case of the direct solar radiation. In the proposed GIS models, most of the region demonstrated a suitable land area for both PV and CSP power plants rather than the other classified area. Based on the results, the central and east areas were endowed with remarkable solar energy resources.

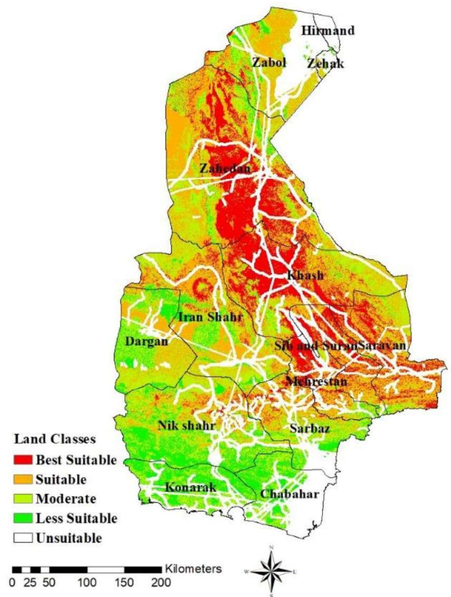


Figure 6: Suitability classes of technical solar potential in the PV case

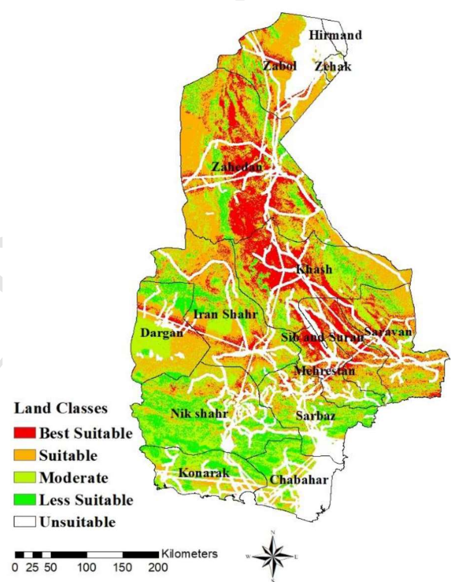


Figure 7: Suitability classes of technical solar potential in the CSP case

247 According to the assessment methodology, the theoretical and technical poten-

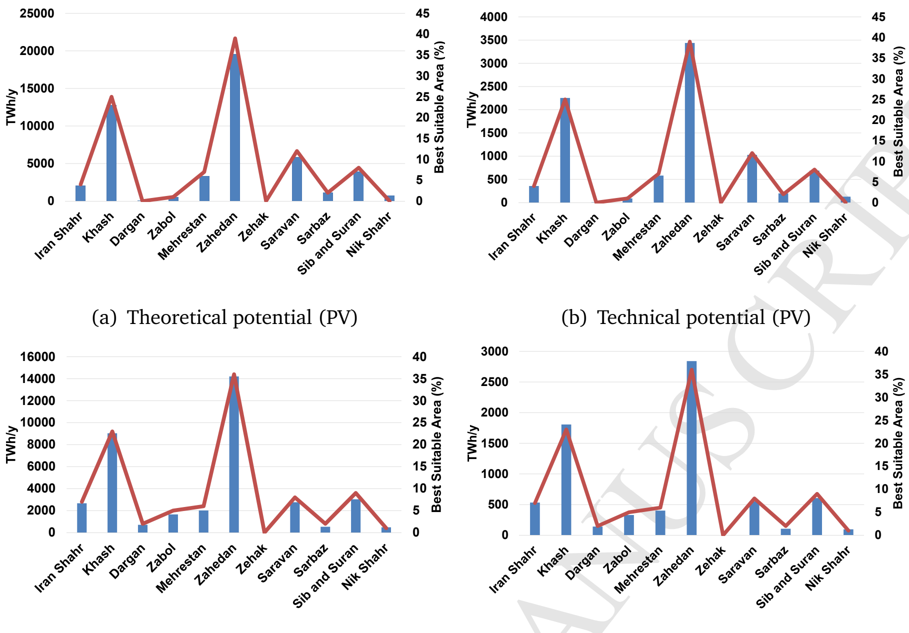
tial of the selected region have been estimated in order to find out the suitable area for solar installations. The classified area values, the theoretical and technical potential and installed power in 14 cities are summarized in Table 11 and Table 12. It should be noted that the capacity factor of 23% [26] and 20% [38] are considered to calculate the installed power in the PV and CSP cases, respectively. Due to the differences in solar radiation in cities and the land area, the amount of solar power potential is significantly variant. Consequently, about 14% of the chosen case study represents the best suitable area for PV system installation and around 12% would fit for CSP system installation. Hence, Zahedan is specified as the best suitable area since it shown an excellent proportion of solar energy sources in both PV and CSP cases. In Zahedan, the highest theoretical potential is 19537 TWh/year and 14206 TWh/year in PV and CSP cases, respectively. Likewise, the technical potential of PV and CSP cases based on the selected technologies is calculated 3438 TWh/year and 2841 TWh/year, respectively. On the other hand, Hirmand and Chabahar are found as the lowest theoretical power potential by less than 1% best suitable area for both types of technologies. Figure 8 compares the solar power generation in cities with the best suitable location percentage on each case. In our case study, the total technical solar power potential is assumed annually 8758 TWh/year and 7419 TWh/year for PV and CSP systems in the best suitable area. Figure 9 shows the solar electricity generation capacity in the classified land suitability (less suitable, moderate, suitable and best suitable area) in each case, in which the PV electricity generation is at higher level in comparison the CSP case. Overall, the technical potential of solar energy generation is highly dependent on the type of the selected solar technology, including the efficiency of PV or CSP systems which has a dramatic effect on the proposed potential compared to the theoretical potential.

Table 11: and technical potential of PV power generation in Sistan and Baluchistan province

Parameters	Total Area	Less Suitable Area	Moderate Area	Suitable Area	Best Suitable Area	Annual Average Solar Radiation	theoretical Potential (Best Suitable)	Technical Potential (Best Suitable)	Technical Potential (Best Suitable)
	km^2 / %	km^2 / %	km^2 / %	km^2 / %	km^2 / %	$kWh/m^2/y$	TWh/y	TWh/y	GW
Iranshahr	20131/ 11	1534/ 8	6569/ 14	8285/ 15	1159/ 4	1750	2028.25	356.97	177.2
Khash	20123 / 11	279/ 2	3816/ 8	6297/ 12	6714/ 25	1900	12756.6	2245.16	1114.3
Dargan	11534/ 6	2152/ 12	5218/ 11	3005/ 6	21/ 0.1	1710	35.91	6.32	3.1
Zabol	15044/ 8	775/ 4	3441/ 8	4910/ 9	293/ 1	1730	506.89	89.21	44.3
Mehrestan	6418/ 4	150/ 1	856/ 2	1930/ 4	1776/ 7	1860	3303.36	581.39	288.6
Zahedan	36022/ 20	905/ 5	7176/ 16	13628/ 25	10229/ 39	1910	19537.39	3438.58	1706.7
Zehak	802/ 0.44	48/ 0.26	140/ 0.31	102/ 0.19	0/ 0	1700	0	0.00	0.0
Saravan	13274/ 7	115/ 1	2059/ 5	5886/ 11	3056/ 12	1910	5836.96	1027.30	509.9
Sarbaz	11146/ 6	1109/ 6	3073/ 7	2830/ 5	628/ 2	1790	1124.12	197.85	98.2
Sib and suran	7157/ 4	48/ 0.3	527/ 1	2816/ 5	2128/ 8	1840	3915.52	689.13	342
Konarak	8968/ 5	3694/ 20	2754/ 6	3/ 0	0 / 0	1700	0	0.00	0.0
Nikshahr	20409/ 11	5164/ 28	7964/ 17	3780/ 7	422/ 2	1710	721.62	127.01	63
Hirmand	1012/ 1	23/ 0.1	23/ 0.1	9.7/ 0	0/ 0	1700	0	0.00	0.0
Chabahar	9739/ 5	2418/ 13	1999/ 4	21/ 0	0.1/ 0	1700	0.17	0.03	0.0
Total	181779	18414/10	45615/ 25	53502/29	26426/ 15	1779	49766	8758	4347.3

Table 12: Theoretical and technical potential of CSP power generation in Sistan and Baluchistan province

Parameters	Total Area	Less Suitable Area	Moderate Area	Suitable Area	Best Suitable Area	Annual Average Solar Radiation	Theoretical Potential (Best Suitable)	Technical Potential (Best Suitable)	Technical Potential (Best Suitable)
	km^2 / %	km^2 / %	km^2 / %	km^2 / %	km^2 / %	$kWh/m^2/y$	TWh/y	TWh/y	GW
Iranshahr	20131/ 11	1884/ 10	5315/ 12	8741/ 16	1606/ 7	1660	2665.96	533.19	304.5
khash	20123/ 11	1142/ 6	4656/ 10	5930/ 11	5378/ 23	1680	9035.04	1807.01	1031.4
Dargan	11534/ 6	1544/ 8	4428/ 10	3981/ 7	442/ 2	1600	707.2	141.44	80.7
Zabol	15044/ 8	491/ 3	1911/ 4	5818/ 10	1198/ 5	1380	1653.24	330.65	188.7
Mehrestan	6418/ 4	453/ 2	1157/ 3	1664/ 3	1437/ 6	1400	2011.8	402.36	229.7
Zahedan	36022/ 20	2361/ 12	7000/ 15	14071/ 25	8507/ 36	1670	14206.69	2841.34	1621.8
Zehak	802/ 0.4	2.7/ 0	131/ 0.3	150/ 0.3	5.7/ 0	1380	7.866	1.57	0.9
Saravan	13274/ 7	634/ 3	3187/ 7	5309/ 4	1987/ 2	1390	2761.93	552.39	315.3
Sarbaz	11146/ 6	1670/ 9	3352/ 7	2234/ 4	383/ 2	1380	528.54	105.71	60.3
Sib and suran	7157/ 4	204/ 1	907/ 2	2243/ 4	2164/ 9	1400	3029.6	605.92	345.8
Konarak	8968/ 5	1875/ 10	3145/ 7	1412/ 3	1.3/ 0	1350	1.755	0.5	0.2
Nikshahr	20409/ 11	5640/ 29	7752/ 17	3594/ 6	342/ 1	1410	482.22	96.44	55
Hirmand	1012/ 1	0.03/ 0	28/ 0.1	26/ 0	0.4/ 0	1380	0.552	0.11	0.1
Chabahar	9739/ 5	1329/ 7	2204/ 5	904/ 2	0.8/ 0	1310	1.048	0.21	0.1
Total	181779	19229/ 11	45173/ 25	56077/ 31	23452/13	1456	37093	7418	4234.4



(a) Theoretical potential (PV)

(b) Technical potential (PV)

(c) Theoretical potential (CSP)

(d) Technical potential (CSP)

Figure 8: Solar power generation in each city

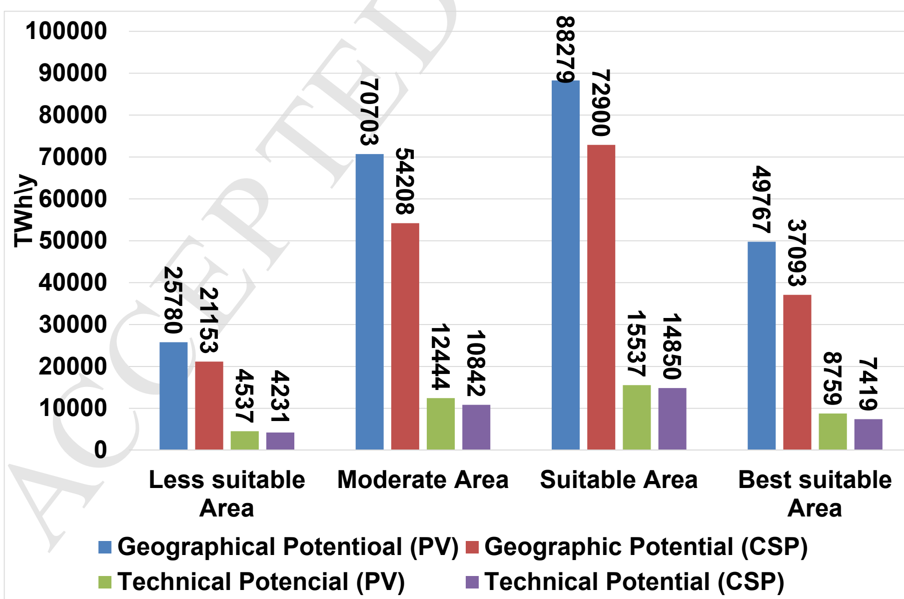


Figure 9: Solar energy potential in classified suitability land area

4. Conclusion

This paper evaluated the potential of CSP and PV power plants in Sistan and Baluchistan province, southeast Iran. Multi-criteria decision making methods using GIS as a digital-based spatial computation tool was conducted to estimate the theoretical and technical potential of the non-build-up area. Basically, having a solar power plant installation would necessitate a consideration of the economic, climate, environmental, and orography criteria for which all the limiting parameters are measured. The restrictive factors, for instance, roads, rivers, airport, build-up area, and protected area were not accounted to define the suitability of the solar land. In addition, the climate criterion and the total land area were demonstrated to have a significant direct effect on the potential of solar power generation. Based on the outcomes, it is confirmed that the choice of a solar farm provides a high supplying electricity is very encouraging for investors. Furthermore, the proposed methodology in this paper can be performed in other locations and scales. The following conclusions were drawn from the present study,

- The study applied to select the best suitable area of solar power plant potential using a combination of GIS and MCDM methods.
- The final output maps demonstrate that the climate criterion has a significant effect on the solar power potential.
- about 14% and 12% of the selected area host the best suitable area for PV and CSP solar power generation, respectively.
- Theoretical potential of solar energy generation in the best suitable area is about 49766TWh/year in the PV case and 37093TWh/year in the CSP case.
- The solar power potential of the best suitable area based on the technical method for estimating the solar energy was calculated and determined to be 8758TWh/year and 7419TWh/year for PV and CSP systems.
- The choice of PV solar farm provides a high potential in supplying the electricity demand compared to the CSP solar plants.

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Highlight

- An integration between geographic information system and analytical hierarchy process methods has been developed to assess solar power potential.
- Four main criteria including environmental, economic, orography and climate are defined and nine alternatives with six restrictive areas.
- The methods have been applied in the theoretical and technical evaluation of solar power plants in both photovoltaic and concentrated solar power.
- 14% and 12% of the selected area host the best suitable area for photovoltaic and concentrated solar power technologies, respectively.