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Multi-criteria decision-making in the location selection for a solar PV power plant using AHP

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ABSTRACT

In today's competitive and connected environment, many countries value effective management of solar energy due to both technological developments and government policies which consider renewable energy improvement along with the effective use of resources. In light of this, in this study, three different locations representing Igdir University, Melekli and Kulluk local regions of Turkey are examined to find the best place for setting up a solar PV power plant. First, the optimum azimuth angle of each location is found in terms of Ed, Em, Hd and Hm values taking daily and monthly irradiation via both pyranometer and Photovoltaic Geographical Information System (PVGIS). Then, Analytic Hierarchy Process (AHP) is used to evaluate locations taking into consideration both quantitative and qualitative factors which play an effective role on the electricity production. The problem is solved in two ways; i) using the exact amount of electricity production data achieved by measurement and ii) using linguistic data provided by a decision maker. Based on results, Kulluk is the ideal location for installation of PV power plant.

1. Introduction

Solar energy is related to a constant bombardment of high subatomic energy particles (electrons and protons). Thus, electronic systems operating in space are subjected to radiation in the form of energetic charged particles viz. protons and heavy ions [1]. Definitely, irradiation of these cells produces atomic displacements within the material. Point defects from these displacements trap the minority electric product obtained by means of illumination, which reduces the collection efficiency of the charges and characterizes the cells, electrically [2]. Several earlier authors conducted similar studies in order to control and advance the behavior of the solar cells in such a hostile (irradiated) environment [3]. The solar cell is described as a device supplying the transformation of light energy into electrical energy. A set of chemical, mechanical and thermal treatments is required for producing solar energy; therefore, these treatments have more or less negative effects on the performance of the final device [4]. These mentioned effects can be characterized by means of ohmic and recombination optical losses [5]. The quality of the solar cell is nearly correlated with its electronic [6] and electrical parameters [7]. Thus, a variety of the characterization techniques have been proposed to improve the steps of the solar cell. These techniques are taken as basis for measuring electrical effects [7,8] of the imperfections involved in the solar energy [9,10]. The photovoltaic conversion efficiency can be changed based on the solar irradiation and other parameters. The electrical performances of the solar energy are reported to be extremely sensitive to solar irradiation [11]. Much of this energy is dissipated as heat, which leads under solar irradiation, at a relatively high operating temperature if energy which is not transformed into electrical is not drained. When characterization of solar energy is taken into consideration in this regard, there were many defined methods applied before [12,13]. Generally, these methods are dependent not only on the interaction of the solar cell by an external excitation, but also the response of solar energy. The analysis of the response helps to establish the microscopic and macroscopic parameters that run of the solar energy working. In addition, another important issue for solar energy is the inconsistency and variability of solar irradiation which decreases the efficiency of solar power systems. Selecting proper locations to launch a solar PV power plant have become a significant place for researches. Many previous studies on solar energy formulated the problem as a Multi-criteria Decision Making (MCDM) problem and took the requirements of decision makers into account as well during the solution process. For example [14] studied a solar PV power plant site selection problem using a MCDM namely AHP combined with geographical information systems (GIS). In order to find the appropriate location in Saudi Arabia, the criteria which have an effect on electricity production are determined and weighed. Then, locations are evaluated based on these criteria computing a land suitability index. This model provides the best sites for solar power plants.

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AHP method is also used in the work of [15] to deal with a large scale PV sites selection problem in Eastern Morocco. Data are provided by several governmental organizations. A suitable map index is calculated using four main and eight sub-criteria. Aly et al. (2017) [16] pointed out six important criteria to evaluate solar power potential in Tanzania. These criteria are weighted to investigate locations and ranked using AHP method. Four areas are determined in terms of Concentrated Solar Power (CSP) and Photovoltaics (PV) installations. Joseph et al. (2016) [17] addressed a location selection problem on large scale photo-voltaic power plant in Imo State. 10 selected local government areas are investigated using PVSyst software to find the optimal place with respect to the output of the PV energy generator and unit cost for each proposed location. In the work of [18] suitability of locations is evaluated using Multi-criteria Decision Making (MCDM) methods considering several constraints such as topographical, legal and social factors. This study provides information about potential of the solar power generation in terms of geographical and technical aspects in rural areas of West Africa. Chakraborty et al. (2014) [19] analysed 70 locations in India to provide information about suitability of locations for setting up a PV power plant with respect to meteorological conditions of India with an acceptable range of the PV modules. In addition, a site selection problem of Indian solar PV power plant is addressed by [20]. There are several types of criteria such as availability of solar radiation, availability of vacant land, distance from highways and existing transmission lines that are taken into account to investigate the availability of locations. Moreover, in Turkey, renewable energy can be generated in various ways such as solar, wind, geothermal, bioenergy and hydropower. Atilgan & Azapagic (2016) [21] examined 305 power plants varying hydro, wind and geothermal resources to provide information about the environmental sustainability of renewable electricity generation in Turkey. Solar energy is one of the most significant renewable electricity sources in Turkey and over the past decade, there has been a growing interest in the field of solar PV power systems. In 2017, Akkas et al. (2017) [22] pointed out the importance of location selection decisions for photovoltaic power systems exploring five cities in Turkey. Four multi-criteria decision making methods, AHP, TOPSIS, ELECTRE and VIKOR are used to find the best city for the photo-voltaic power systems installation [23]. Recent research indicates that these methods produce a precise solution for a solar power plant location selection [24,25]. In conclusion, as mentioned above, solar energy has been researched by a number of researches. In most of the previous work, areas are investigated whether they are suitable or not for setting up a solar PV power plant in different countries. The areas are also mapped to inform investors. A thorough review of previous studies on solar energy, few studies are found in solar PV power plants in Turkey and to the authors' knowledge, there is no research found on the eastern part of Turkey. The motivation behind this study is that there has been a lack of extensive research in the field of solar PV power plant installation. In this study, our aim is first to find azimuth angles for three proposed places; Igdir University, Kulluk and Melekli in order to obtain their performance considering electricity produced by each place, and then select the best location among these three using AHP method. The problem is taken into consideration in two ways; i) using the exact amount of electricity production data achieved by measurement and ii) using linguistic data provided by a decision maker. Daily and monthly data are measured and used to handle the inconsistency and vagueness of solar radiation information. This paper is organised as follows. Section 2 introduces basic concepts for solar power systems and one of the multi-criteria decision making method, Analytic hierarchy Process. Section 3 provides the problem explanation and the proposed approach to select a right location for a PV plant. Section 4 presents the experimental design and computational results. Section 5 discusses the conclusions and future work.

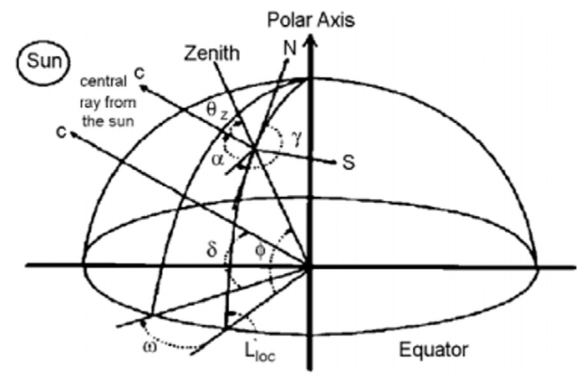

Fig. 1. Schematic representation of the solar azimuth angles [27].

2. Background

This section introduces the back ground for the techniques used as a part of the proposed approach and provides an overview of related studies in the scientific literature.

2.1. Basic concepts of solar power system

The earth itself rotates at the rate of one revolution per day around the polar axis. The daily rotation of the earth is illustrated by the rotation of the celestial sphere about the polar axis, and the instantaneous position of the sun is defined by means of the hour angle, the angle between the meridian passing through the sun and the meridian of the site. The hour angle is zero at solar noon and increases toward the east. For observers on the surface of earth at a location with geographical latitude (w), a convenient coordinate system is identified by a vertical line at the site which intersects the celestial sphere in two points, the zenith and the nadir, and subtends the angle w with the polar axis seen in Fig. 1. The great circle perpendicular to the vertical axis is the horizon [26].

The latitude (w) of a point or location is the angle made by the radial line joining the location to the center of the earth with the projection of the line on the equatorial plane. The earth's axis of rotation intersects the earth's surface at 39.59.13 latitude (North Pole) and 43.54.40 latitude (South Pole). Solar azimuth angle is the horizontal angle measured from south (in the northern hemisphere) to the horizontal projection of the sun's rays [28,29]. In this context, many former studies have been conducted to define the relationship between these parameters and the calculation of solar positions. The parameters computed and estimated were time, longitude of the sun, declination, local azimuth, elevation, sunrise and sunset in real times [27].

2.2. Photovoltaic technology overview

Photovoltaic (PV) technologies directly transform energy from sunlight into electricity. The semiconductor material is hit by sunlight and this causes electrons to leave their positions producing an electric current. Traditionally, PV cells are made using various forms of silicon (Si). Recently, some companies have commercialised thin film technologies composed of other semiconductors. Thin film technologies reduce cost and provide acceptable efficiency, but are currently less efficient than crystalline silicon solar cells. There has been significant improvement in the solar cell performance developing semiconductor material science. This led to new generation of solar cells with efficiencies of 24.7 (silicon material) and 20.3 (CIGS thin films) under standard conditions [1]. Performance of a solar cell depends mainly on excess minority carrier recombination parameters such as diffusion length, recombination velocities. It also depends on electrical parameters such as series resistance and shunt resistance. All these parameters are controlled by different impurities and defects in a semiconductor material. Thus, the quality of the solar cell depends on these parameters. It is a great interest to determine these parameters in the solar cell in order to know the effect of some design parameters on the cell efficiency before the cell fabrication. For this reason, in this study, to make an effective search and to reach solutions with better quality, parameters are investigated using daily and monthly data measured by pyranometer and PVGIS.

2.2.1. Pyranometer

The pyranometers are sensors that measure global solar radiation. The Solar radiation measurements are essential in many fields such as meteorology, climatology, material testing and solar energy. The pyranometer is most suitable to collect data which researches need to analyse. Global Horizontal Irradiance (GHI) is the most frequently measured quantity and is composed of Diffuse Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI) [30,31]. The relationship of these three components of solar radiation. In this study, we use LI-200R pyranometer used outdoors under unobstructed natural daylight conditions within the 400–1100 nm range. We were positioned on an arm and measured the pyranometer, in the exact south orientation (azimuth angle 0), away from the pole, so that the pyranometer could never be shaded.

The simpler form of LI-200R pyranometer comprises a single make black band, 3 mm wide, 6 mm long, located centrally in the plane of the upper surface of a nickel-plated copper disk 75 mm in diameter. Copper blocks insulated from the rest of the disk, but continuous with it in surface, serve to connect the insulated band with an electric heating current. The LI-200R features a silicon photovoltaic detector mounted in a fully cosine-corrected miniature head [32]. Current output, which is directly proportional to solar radiation, is calibrated against an Eppley Precision Spectral Pyranometer (PSP) under natural daylight conditions in units of watts per square meter ($W\,m^{-2}$). Under most conditions of natural daylight, the error is < 5%. A shunt resistor in the sensor's cable converts the signal from microamps to millivolts. To ensure accurate measurements, the sensor should be leveled using an LI2003S leveling fixture, which incorporates a bubble level and three adjusting screws. The LI2003S leveling fixture mounts of at the bottom using the CM225 mount [33].

A sensitive thermo-electric couple fastened by means of thin waxed paper to the rear surface of the tapes and embedded at the other end in a recess of the copper disk serves to indicate changes of temperature of the strip. Concentric with the strip is a hollow hemispherical screen of ultra –violet crown glass, 26 mm in outer diameter and 2 mm thick. Its purpose is to admit rays of shorter wave-lengths, such as forming essentially the whole strength of the direct and scattered solar rays, but to cut- off rays of great wave-length proper to the emission of a body at ordinary temperatures. A nickel-plated hemispherical shell of polished nickel-plated copper encloses this glass and is removable at pleasure. The shutter is opened solar radiation falls upon the strip and warms it. The shutter being then closed, an equal deflection may be produced by the electric heating current. The energy dissipated in the strip by the heating current measures the energy of radiation [34,35].

3. Multi-criteria decision making

Decisions are made under conflicting criteria for different objectives such as maximising electrical performances while minimising the total cost of a solar PV power plant. Multi-criteria decision making is an approach for evaluating explicitly multiple conflicting criteria in the discrete decision spaces to determine the best one among different alternatives. Multiple-criteria decision making has become an important activity in an installation of a solar PV power plant. There are a number of MCDM methods found in literature; Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Multi Attribute Utility Technique (MAUT). In a MCDM problem, a number of alternative options are examined based upon constraints, preference and priorities of decision makers [29]. In this study, we use only AHP method which has been successfully applied to different decision making problems.

Table 1
Numerical Scale for Pairwise Comparison [31,42,43].

Linguistic variable	Numeric value
Extremely important	9–8
Very Strongly more important	7–6
Strongly more important	5–4
Moderately more important	3–2
Equally important	1

3.1. Analytic hierarchy process

The AHP method introduced by [36] depends on a series of pairwise comparisons considering the perception and evaluation of decision makers. AHP is easy to use due to its hierarchical structure and pairwise comparison that allow users to give different weight for each criterion. For this reason, the AHP method has been used in a wide variety of applications in the literature. In the work of [37], quantitative and qualitative factors were evaluated using the AHP method under different preference attitudes. In addition, some researches have combined different methods to overcome uncertainty in subjective judgments of decision makers and the lack of information. For instance, [38] proposed a fuzzy AHP method that extended the traditional view of selection problem including a fuzzy method. Galankashi et al. (2016) [39] pointed out a fuzzy AHP model and implemented that in the automotive industry to select the best supplier. Tahriri et al. (2008) [40] stated that qualitative and quantitative criteria increase the complexity of a problem. In order to find the best option, a trade-off between these criteria has been essential to MCDM problems. In order to evaluate alternatives, an AHP method is performed and developed in this study. Through the analysis of different selected papers, it is obvious that AHP is applied into various types of decision making problems. Due to the complex nature inherent to the solar PV power plant installation problem, AHP is a method which is capable of coping with tangible and intangible factors. Also, in order to carry out a good assessment of alternatives, AHP is one of the most preferred methods. This paves the way for studying an AHP approach to deal with locations predetermined for setting up a solar PV power plant in this research.

4. Methodology

This study aims to provide an evaluation of three locations for a solar PV power plant installation in Turkey using AHP method as a well-known MCDM method. Firstly, in order to estimate potentials of three locations for setting up a solar PV power plant, source of solar energy data is provided by measuring via pyranometer and PVGIS. The optimum azimuth angle of each location is obtained examining Ed, Em, Hd and Hm values of each location considering measurement of daily and monthly irradiation. Secondly, locations are evaluated based on various criteria derived from potential energy production, environmental factors, safety, distance from existing transmission line and topographical properties using the AHP method with respect to azimuth angle determined for each location.

4.1. Criteria for location evaluation

Over the last decade, there has been a growing interest on the installation location of solar energy systems. In order to achieve maximum energy with a desirable construction cost, decision making for the location of a solar PV plant has become essential. There are several different criteria which have played an important role on the efficiency

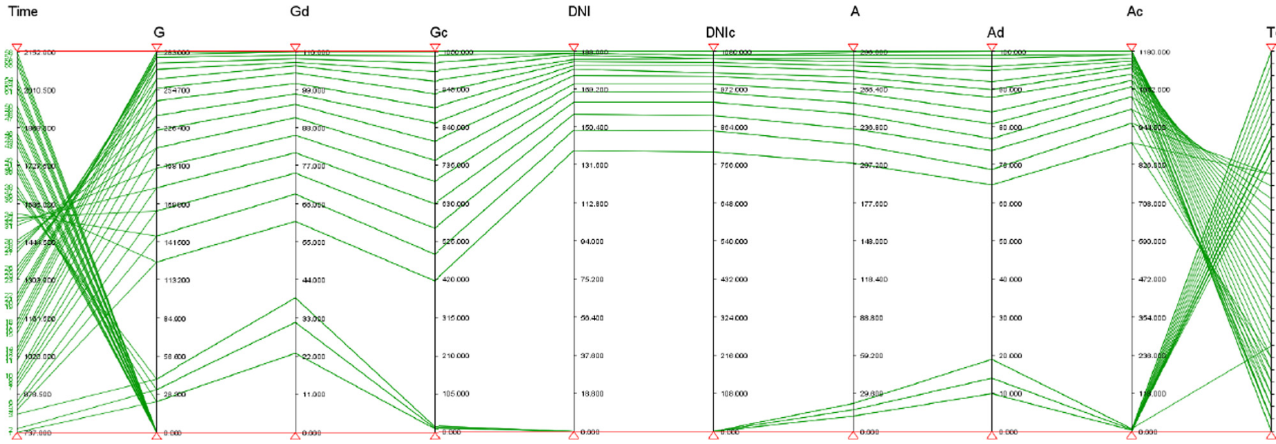

Fig. 2. Results of solar power plant in parallel coordinate for Igdir University.

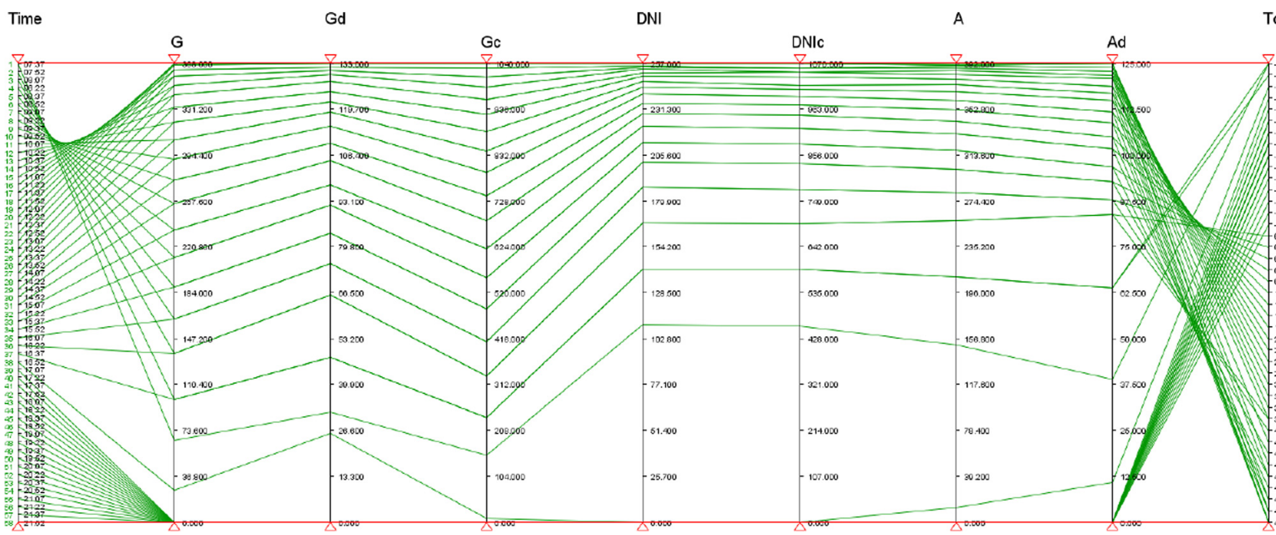

Fig. 3. Results of solar power plant in parallel coordinate for Melekli.

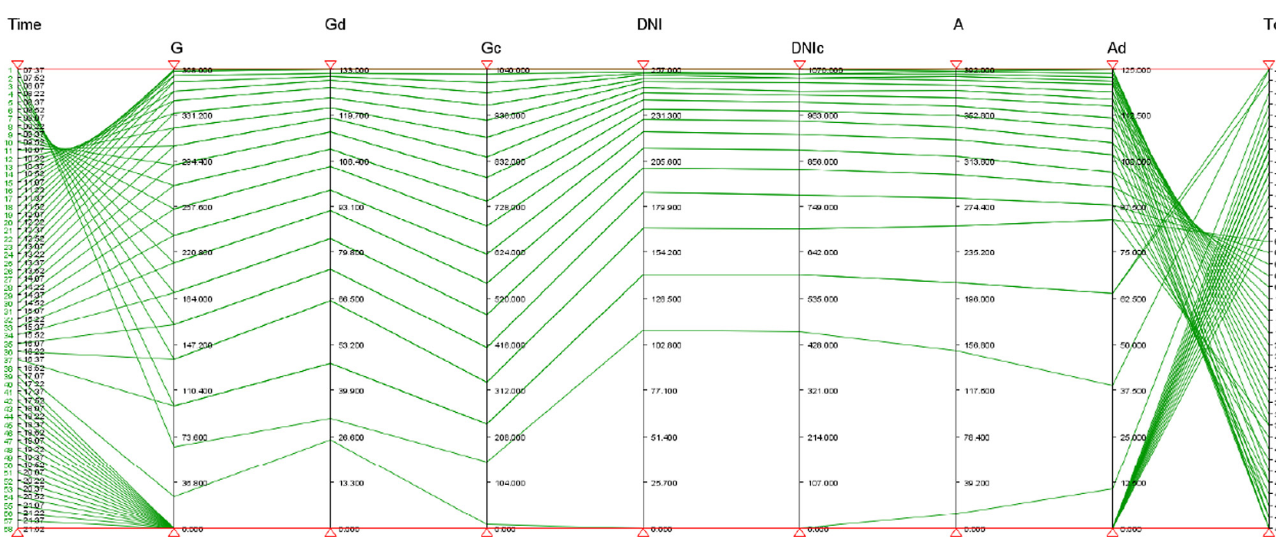

Fig. 4. Results of solar power plant in parallel coordinate for Kulluk.

of a solar PV power plant location. In this study, we consider five criteria as explained in the following:

1. Potential energy production: The location of the solar PV power plant is highly related with the solar energy potential of the location. Receiving high solar radiation for all the year provides high electricity production. This is a significant aspect for investors to set up a solar PV power plant [22]. In this research, this aspect is

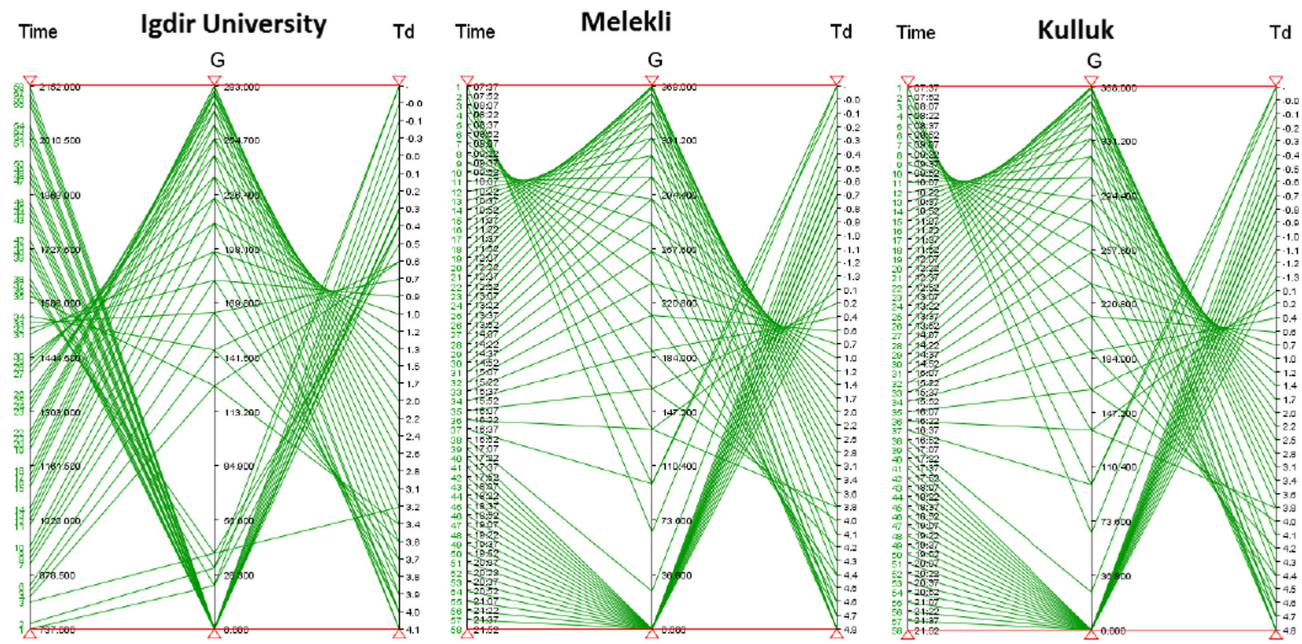

Fig. 5. Results of solar power plant in parallel coordinate for three parameters; Time, G and Td.

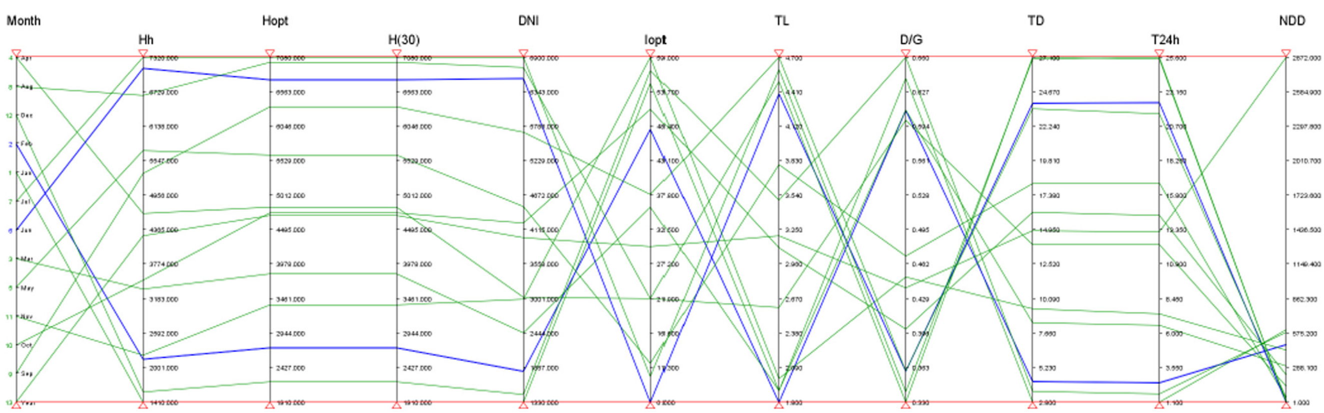

Fig. 6. Monthly data results of solar power plant in parallel coordinate for Igdir University.

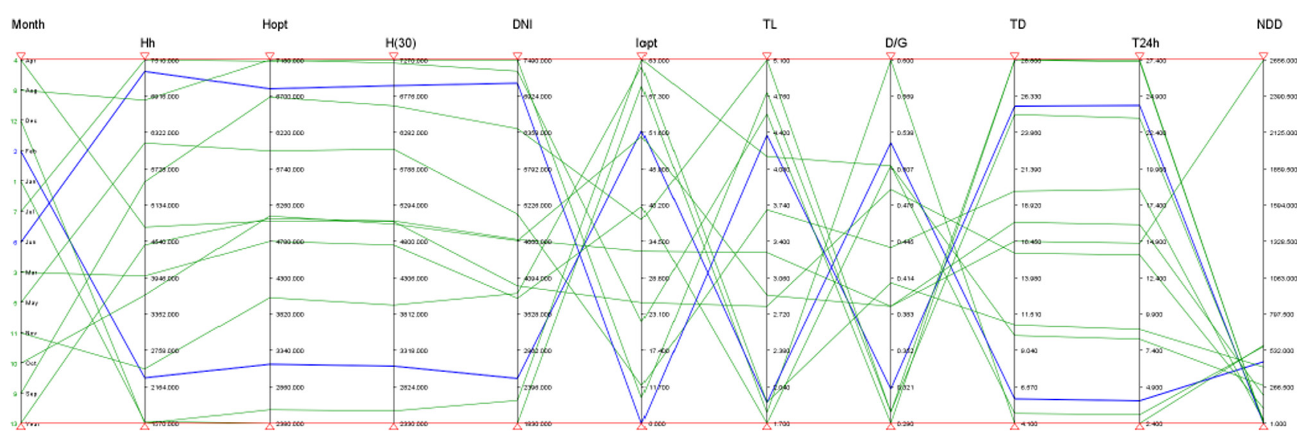

Fig. 7. Monthly data results of solar power plant in parallel coordinate for Melekli.

captured measuring daily and monthly irradiation of each location proposed and analysing them.

2. Environmental factors: Associated with generating electricity from solar energy in these three locations can be listed as;
   - Climate conditions,
   - The existence of many clear days per year,
   - Distance to bird migration locations.
3. Safety: Protecting infrastructure and equipment from hazards has become necessary to examine suitability of locations for a solar PV power plant. For this reason, safety is considered as a criterion in this study.
4. Distance from existing transmission line: The number of lines and

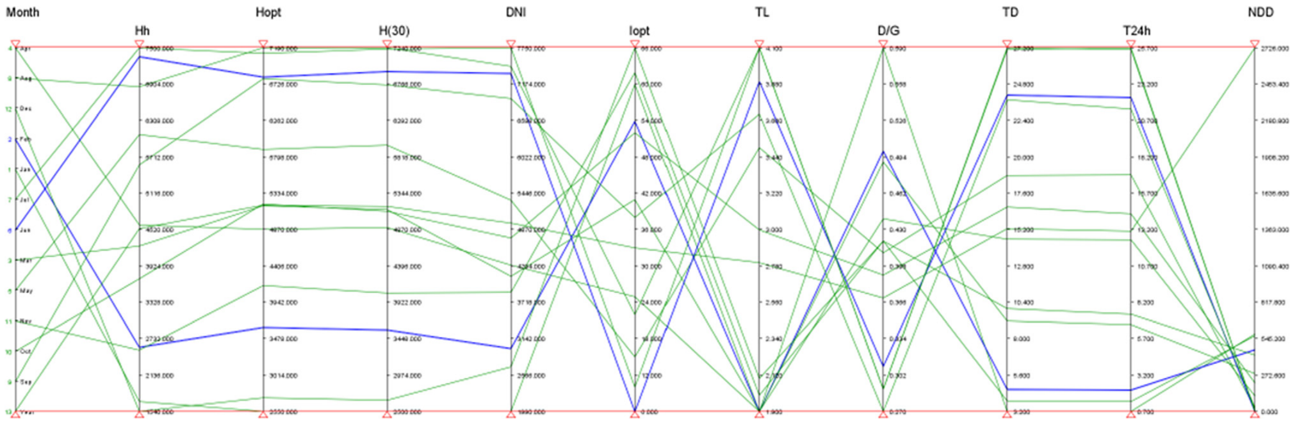

Fig. 8. Monthly data results of solar power plant in parallel coordinate for Kulluk.

Table 2
PV estimation data for three proposed locations; Igdir University, Melekli and Küllük.

Igdir University					Melekli				Küllük			
Month	Ed	Em	Hd	Hm	Ed	Em	Hd	Hm	Ed	Em	Hd	Hm
1	1.49	46.1	1.87	58	1.82	56.5	2.28	70.7	1.95	60.5	2.44	75.5
2	2.1	58.7	2.68	75.1	2.38	66.1	3.04	85.1	2.74	76.6	3.48	97.4
3	2.83	87.9	3.75	116	3.51	109	4.67	145	3.82	118	5.04	156
4	3.52	105	4.75	142	3.69	111	4.99	150	3.54	106	4.82	145
5	4.07	126	5.52	171	4.34	135	5.95	184	4.31	134	5.87	182
6	4.77	143	6.62	199	4.86	146	6.79	204	4.89	147	6.81	204
7	4.93	153	6.93	215	5.03	156	7.11	221	5.03	156	7.09	220
8	4.87	151	6.85	212	4.99	155	7.06	219	5.02	156	7.08	219
9	4.05	135	6.17	185	4.7	141	6.47	194	4.77	143	6.59	198
10	3.48	108	4.62	143	3.67	114	4.91	152	3.75	116	4.98	154
11	2.57	77.1	3.31	99ç3	2.98	89.4	3.85	115	3.08	92.4	3.96	119
12	1.76	54.7	2.17	67.2	2.01	62.2	2.44	75.6	2.09	64.7	2.58	79.9
Average	3.41	104	4.61	140	3.67	112	4.97	151	3.75	114	5.07	154

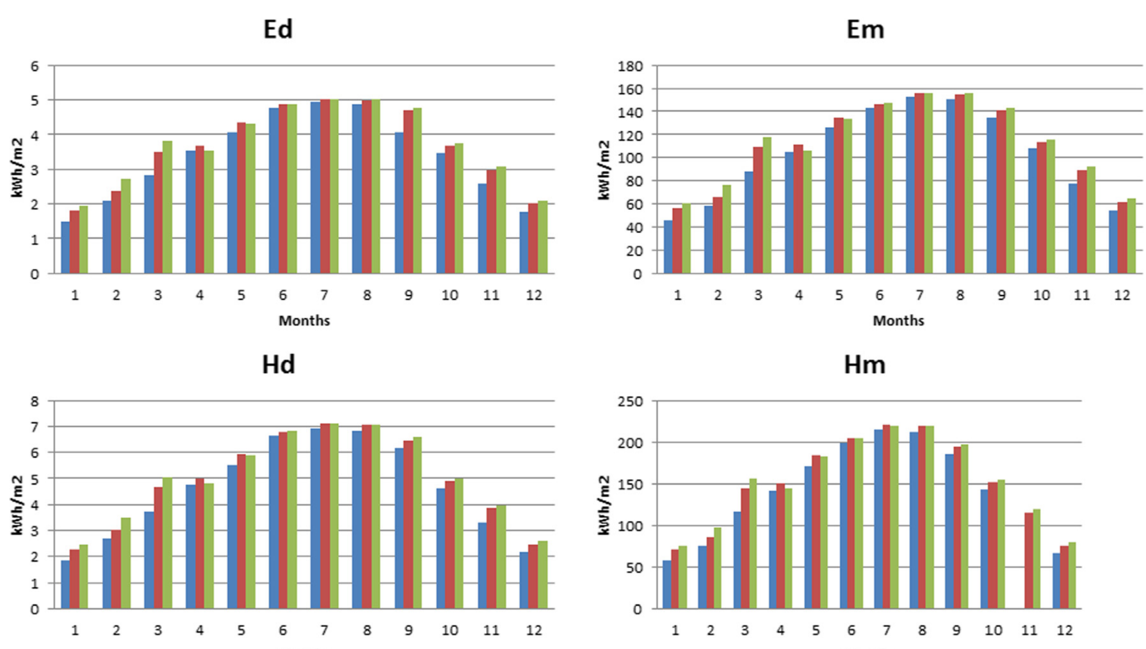

Fig. 9. Plot tables for PV estimation data for three proposed locations.

capacities of the transformer have affected the cost and performance of the plant. Thus, distance from existing transmission line should be investigated when a solar PV power plant is built up.

5. Topographical properties: In the northern hemisphere, acceptable locations for a solar PV power plant are defined as flat or slightly south facing slopes. In addition, modules soiled affect the efficiency of a PV power plant inevitably [22]. In Turkey, the government policy for solar installations is also to keep them away from farming

Table 3
Pairwise comparison matrices.

Comparison	Criterion1	Criterion2	Criterion3	Criterion4	Criterion5
P1/P2	1/9	1/8	1	5	1/9
P1/P3	1/4	5	7	1/4	1/7
P2/P3	8	8	7	1	7

lands. Therefore, it is significant to take into account geological structure and land types as a criterion.

4.2. Applying AHP method

The main idea behind the AHP method is to find ratio scales using pairwise comparisons in a hierarchy process. The basic concept of AHP can be summarised in the following steps (detailed in [35]):

1. Determine the aim, candidates and criteria,
2. Generate a pairwise comparison matrix ($P = n \times n$) where n is the number of criteria and m is the number of candidates. It is shown in Eq. (1) where p_{mn} is the element of *m*th row, *n*th column of matrix P, and depicts the intensity of importance of *m*th candidate over *n*th determinant (see Table 1).

$$P = \begin{bmatrix} p_{11} & \cdots & p_{1n} \\ \vdots & \ddots & \vdots \\ p_{m1} & \cdots & p_{mn} \end{bmatrix} \tag{1}$$

3. Calculate the relative importance of two criteria using a numerical scale from 1 to 9 as shown in Fig. 1. When first criterion compared to second criterion is assigned with a number between 1 and 9, this second criterion compared to first criterion becomes its reciprocal.
4. Normalise the matrix to obtain the required relative criteria weights.
5. Decide percentage importance distribution of the candidates. The column vector A is shown in Eq. (2) and it is calculated using $a_{im} = P\ p_{in}\ m\ i = 1\ p_{in}$.

$$A = \begin{bmatrix} a_{11} \\ \vdots \\ a_{n1} \end{bmatrix} \tag{2}$$

6. Calculate the criteria weight vector w averaging the entries on each row of P.
7. Compute the matrix of option scores ($n \times m$) to obtain a score matrix (S).
8. Rank candidates based on this score matrix (S).

5. Preliminary experiments and results

5.1. Screening azimuth angle for potential locations

In this research, a number of parameters are generated to investigate energy output for three locations. In order to handle imprecise and inconsistency in solar irradiation properly, daily and monthly measurements are taken into consideration. For daily measurements on a fixed plane, there are several parameters considered such as global irradiance (G), diffuse irradiance (GD), global clear-sky irradiance (Gc). In addition, direct normal irradiance (DNI), clear-sky direct normal irradiance (DNIc) and some measurements on 2-axis tracking plane such as global irradiance (A), diffuse irradiance (Ad) and global clear-sky irradiance (Ac) are taken into account along with average daytime temperature (Td). In addition, for monthly measurements, all parameters considered are listed as follows: Irradiation on horizontal plane (Hh), Irradiation on optimally inclined plane (Hopt), Irradiation on plane at a certain angle (H), Direct normal irradiation (DNI), Optimal inclination (Iopt), Linke turbidity (TL), Ratio of diffuse to global irradiation (D/G), Average daytime temperature (TD), Average of temperature for 24 h (T24h), Number of heating degree-days (NDD).

Using these measurements, average daily electricity production (Ed), average monthly electricity production (Em), average daily sum of global irradiation per square meter (Hd) and average sum of global irradiation per square meter (Hm) are estimated as an output.

Table 5
Percentage importance of potential criteria.

Criteria	Criterion1	Criterion2	Criterion3	Criterion4	Criterion5
Criterion1	1.00	7.00	0.20	0.33	0.11
Criterion2	0.14	1.00	7.00	5.00	0.33
Criterion3	5.00	0.14	1.00	3.00	3.00
Criterion4	3.00	0.20	0.33	1.00	0.20
Criterion5	9.00	3.00	0.33	5.00	1.00

Table 6
AHP result locations are found the same.

Locations	Score	Rank
P1	0.28	2
P2	0.59	1
P3	0.13	3

5.2. Azimuth angle results

In this section, a comparison between three different places representing Igdir University, Kulluk and Melekli is also provided. To visualise relationship among the parameters as mentioned above, 'parallel coordinates' (Inselberg, 2009) [40] is generated. Each green line represents each measurement and indicates change through times from one to another. Firstly, daily measurements which consist of different azimuth angles between 0 and 90 in interval 5 are examined and the best efficiency is found at 0 azimuth angle for three places is proposed. Figs. 2–4 display the same data set for these three places using daily data at 0 azimuth angle. From the visualisation, we can observe that there is obvious inverse-correlation between time and global irradiance as seen in Fig. 2 for Igdir University. Fig. 3 depicts the same inverse-correlation between time and global irradiance for Melekli but after sunrise, it is clearly seen that there is no relationship. In this sense, Fig. 4 shows the same behavior for Kulluk. The correlation between other parameters is also quite as obvious. Therefore, the relationship between time and other parameters may be associated with temperature. This relationship is investigated in Fig. 5. It is obviously seen that

Table 4
Matrices normalised.

Criterion1				Criterion2				Criterion3				Criterion4				Criterion5			
	P1	P2	P3		P1	P2	P3		P1	P2	P3		P1	P2	P3		P1	P2	P3
P1	1.00	0.11	0.25	P1	1.00	0.13	5.00	P1	1.00	1.00	7.00	P1	1.00	5.00	0.25	P1	1.00	0.11	0.14
P2	9.00	1.00	8.00	P2	8.00	1.00	8.00	P2	1.00	1.00	7.00	P1	0.20	1.00	1.00	P1	9.00	1.00	7.00
P2	4.00	0.13	1.00	P3	0.20	0.13	1.00	P3	0.14	0.14	1.00	P1	4.00	1.00	1.00	P1	7.00	0.14	1.00

there is negative relationship between global irradiance and temperature, and between time and global irradiance. Secondly, for monthly examination, different azimuth angles ranging from 0 to 90 degrees in interval 5 are investigated. Based on findings, the best solar efficiency was obtained at 30 azimuth angle for three locations. In order to visualise relationship among parameters, parallel coordinate plots are generated for proposed locations. Each green line represents a month and indicates change through parameters from one to another. The blue line shows months selected. Figs. 6–8 display the same data set for different locations but this time, there are two lines and each line represents a solution for a month. We chose February and June to investigate. In Fig. 6, the solution for February with a low Hh has low DNI, TL and TD while the solution for June represents high Hh scenario with high DNI, TL and TD values. Also, the high Iopt solution consists of relatively low NDD. It might be related to the length of a day from sunrise to sunset.

Although we investigate daily measurements, we only consider the azimuth angle found by using monthly data in order to estimate the electricity production. Based on these results, the azimuth angle is determined as 30 degrees for three locations. Table 2 indicates monthly estimation results as an average daily Ed, Em, Hd and Hm values for three locations. In Table 2, the best values are highlighted and it is clearly seen that Kulluk is the best option to set up a solar PV power plant. It is also worth mentioning that according to Table 2, it is understandable that superior solar radiation is observed during summer months and inferior in the winter months for three locations. A maximum value of 5.03 kWh/m^2/day is found in July while the minimum of 1.95 kWh/m^2/day in January for Kulluk. The seasonal blueprint of the solar radiations matches with the electrical load pattern in Turkey. In order to show the differences of values for each location clearly, column plots are also used where blue columns represent Igdir University, red columns depict Melekli and green columns demonstrate Küllük as shown in Fig. 9. In the following subsection, application of AHP method on this problem is explained.

5.3. Applying AHP to potential locations

Our aim is evaluating three places, Igdir University (P1), Küllük (P2) and Melekli (P3) to build a solar PV power plant. For this reason, five criteria are determined as potential energy production, environmental factors, safety, distance from existing transmission line and topographical properties.

Pairwise comparison matrices are generated for five criteria as shown in Table 3.

Matrices for each criterion is normalised and results can be found in Table 4.

Percentage importance of potential criteria is decided as depicted in Table 5.

A score matrix is computed and locations are ranked as seen in Table 6.

Based on crisp score that we obtained, the locations are ranked as shown in Table 6. Based on this result, it is clear that Kulluk is found as the best place to build a solar PV power plant. In comparison to examining locations in terms of daily and monthly irradiation information and using AHP, the rank of locations is found the same.

In addition, in order to investigate performances of two methods, results of real data and AHP are compared with each other. Although, AHP assumes that decision makers provide precise information to evaluate candidates, uncertainty can arise in judgments of decision makers. However, in this study, based results found, AHP provides same results as achieved using real measurements. Without exact Ed, Em, Hd and Hm values, AHP also found Kulluk as the best place for installation of a solar power plant. Collecting real data can take time and avoiding time consumption, this study proves that AHP is an alternate way for users.

6. Conclusions

In this study, we addressed a solar PV power plant installation problem considering both qualitative and quantitative factors and solved the problem in two ways; investigating real data measurements and using AHP method. In this research, first, azimuth angle is found for three locations proposed and then each location at the certain azimuth angle is investigated in terms of several parameters such as Ed and Em. Based on results, Kulluk is revealed as the best place for installation of a solar PV power plant. Second, in order to take several conflicting criteria into account, AHP is applied to this location selection problem proposed considering five main criteria; potential energy production, environmental factors, safety, distance from existing transmission line and topographical properties. The same result is achieved using AHP method. In this study, we provide an examination of different places using both tangible and intangible information. This analysis also helps decision makers to select an appropriate place to set up a solar PV power plant. Meanings of the words can be varied from different decision makers to decision makers. Uncertainties could also arise while consequents of the same problem are defined by different experts, linguistically. For this reason, there could be several sources of uncertainties in judgments of decision makers [41,44]. Due to uncertainty in subjective judgments of decision makers, the lack of information and conflicts among the criteria, fuzzy logic could be applied to the same problem as a future study. In addition, another possible research direction which can be pursued to extend the work presented in this work, is about taking a smaller interval than 5 for azimuth angle range. In this way, we will be able to examine changes between 30 and 35 azimuth angles.

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Corrigendum

Corrigendum to “Multi-criteria decision-making in the location selection for a solar PV power plant using AHP” [Measurement 129 (2018) 218–226]

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The authors would like to draw your attention to the fact that the first author’s surname has been changed from Seda Ozdemir to Seda Turk.

The authors would like to apologise for any inconvenience caused.

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