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Important parameters in solar power plant installation and Analytical Hierarchy Process

B. Gülmez[1], R. Köse[2], O. O. Yolcan[2,*]

[1]*Department of Mechanical Engineering Manisa Celal Bayar University, Manisa, Turkey*

[2]*Department of Mechanical Engineering, Kütahya Dumlupınar University, Kütahya, Turkey*

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ABSTRACT

The limited reserve problems of fossil-based fuels, their environmental impacts, and being imported fuel for Turkey increase the importance of renewable energy sources. Turkey has significant potential in terms of solar energy. Solar power installed in Turkey has increased substantially in recent years and continues to grow. As of the end of March 2021, Turkey's unlicensed solar power installed capacity reached 6.5 GW.

In this study, Turkey's energy situation and long-term energy projections were examined and evaluated by Turkey's installed renewable energy sources and production values. Essential criteria for determining the solar power plant site were mentioned, and information was given about the Analytical Hierarchy Process, one of the algorithms used to determine the power plant site.

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1. INTRODUCTION

In our world, where energy consumption is increasing daily, the rate of benefiting from renewable energy sources is rising rapidly due to the limited reserves of fossil fuels and the environmental damage. According to the energy sources' electricity production values, Turkey, Europe, and the world are shown in Table 1 [1]. Turkey's total electricity production in 2018 was 304.8 TWh, while this value amounted to 308.5 TWh in 2019. While the share of renewable energy sources in electricity generation was 12.4% in 2018, this rate increased to 14.7% in 2019. Turkey's electricity generation in coal belongs to the largest share. When the electricity generation values for Europe are examined, the percentage of renewable energy sources was 18.6% in 2018 and 21% in 2019. While Europe uses nuclear energy the most in electricity generation, it is followed by renewable energy sources. The rate of renewable energy resources was 9.3% in 2018 and 10.4% in 2019. The largest share in world electricity generation belongs to coal. The Asian continent, especially China, has a significant share in these statistics. While the coal-based electricity production of the Asian continent was 7376.4 TWh in 2019, this value is 4853.7 TWh for China [1].

Table 1. Electricity generation by fuel (TWh) [1].

2018			
Res. Type	*Turkey*	*Europe*	*World*
Oil	0.3	56.1	890.4
Nat. Gas	92.5	729.9	6082.5
Coal	113.2	856.6	100091.3
Nuclear	-	935.8	2700.4
Hydro	59.9	645.3	4171.4
Ren.	37.8	756.3	2468.0
Other	1.0	87.1	248.9
Total	*304.8*	*4067.2*	*26652.7*
2019			
Res. Type	*Turkey*	*Europe*	*World*
Oil	0.2	51.8	825.3
Nat. Gas	58.1	768.1	6297.9
Coal	114.6	698.6	9824.1
Nuclear	-	928.5	2796.0
Hydro	89.2	632.5	4222.2
Ren.	45.3	836.6	2805.5
Other	1.1	77.2	233.6
Total	*308.5*	*3993.3*	*27004.7*

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**Corresponding author e-mail: oguzozan.yolcan@dpu.edu.tr*

When Turkey's licensed electricity generation installed power in Table 2 is examined, the total licensed electricity generation installed power was 83.2 GW in 2018; this value increased to about 90 GW by the end of March 2021 [2, 3]. Among the renewable energy sources, the installed power of wind energy from 6.9 GW to 9.3 GW; The installed power of geothermal energy has increased from 1.3 GW to 1.6 GW, and the installed power of solar energy from 82 MW to 515 MW [2, 3].

Table 2. Turkey's licensed electricity generation installed capacity [2, 3].

Resource Type	*2018 (GW)*	*Share (%)*	*2019 (GW)*	*Share (%)*	*March 2021 (GW)*	*Share (%)*
Natural gas	25.73	30.93	25.94	30.53	25.67	28.50
Hydro dam	20.53	24.69	20.64	24.3	23.24	25.80
Lignite	9.60	11.54	10.10	11.89	10.12	11.24
Import coal	8.94	10.75	8.97	10.55	8.99	9.98
Run of river	7.75	9.32	7.85	9.24	8.08	8.97
Wind	6.94	8.35	7.52	8.85	9.29	10.31
Geothermal	1.28	1.54	1.51	1.78	1.62	1.80
Hard coal	0.62	0.74	0.81	0.95	0.81	0.90
Biomass	0.59	0.71	0.73	0.85	1.06	1.18
Asphaltite coal	0.41	0.49	0.41	0.48	0.41	0.45
Fuel oil	0.71	0.85	0.31	0.36	0.25	0.28
Solar	0.08	0.1	0.17	0.2	0.52	0.57
Naphta	0.005	0.01	0.005	0.01	0.005	0.01
Lng	0.002	0	0.002	0	0.002	0.00
Diesel	0.001	0	0.001	0	0.001	0.00
Total	*83.19*	*100*	*84.96*	*100*	*90.06*	*100.00*

When the licensed electricity generation values of Turkey given in Table 3 are examined, it is seen that the total generation value in 2018 was 296 billion kWh, while this value was realized as 294.2 billion kWh in 2019 [2]. Among the production values of 2018, natural gas has the highest share with a share of 30.96%, while in 2019, power plants with a dam have the highest percentage with a share of 30.2%. The electrical energy obtained from wind energy from 19.8 billion kWh to 21.6 billion kWh; The electrical energy obtained from geothermal energy has increased from 7.4 billion kWh to 8.9 billion kWh. The electrical energy obtained from licensed solar power plants decreased from 386 GWh to 194 GWh [2].

When Turkey's unlicensed electricity generation installed capacity given in Table 4 is examined, the total unlicensed electricity generation installed power was 5.3 GW in 2018, while this value increased to 7 GW by the end of March 2021 [2, 3]. Solar energy has the highest share in unlicensed electricity generation installed power values. While Turkey's unlicensed solar energy installed power was 5 GW in 2018, it increased by 28% and reached 6.4 GW. Unlicensed wind power installed power, on the other hand, increased from 52 MW in 2018 to approximately 71 MW [2, 3].

When the unlicensed electricity generation values of Turkey given in Table 5 are examined, it is seen that the total generation value in 2018 was 8.2 billion kWh, while this value was realized as 9.8 billion kWh in 2019 [2]. Generation values from unlicensed solar energy have a 96% share among all sources in 2018 and 2019. While electricity generation from unlicensed solar energy was 7.9 billion kWh in 2018, this value increased to 9.4 billion kWh in 2019. While electricity generation from unlicensed wind energy was 111.5 million kWh in 2018, it reached 113.6 million kWh in 2019 [2].

Table 3. Turkey's licensed electricity generation installed power generation values [2].

Resource Type	*2018 (GWh)*	*Share (%)*	*2019 (GWh)*	*Share (%)*
Hydro dam	59,902.04	20.24	88,850.17	30.2
Import coal	62,988.54	21.28	60,381.27	20.52
Natural gas	91,639.14	30.96	56,522.71	19.21
Lignite	45,087.00	15.23	46,893.73	15.94
Wind	19,827.00	6.7	21,636.28	7.35
Geothermal	7,430.98	2.51	8,929.73	3.03
Biomass	3,240.96	1.09	4,266.32	1.45
Hard coal	2,844.58	0.96	3,518.87	1.2
Asphalte coal	2,328.50	0.79	2,323.95	0.79
Fuel oil	328.89	0.11	732.92	0.25
Solar	385.86	0.13	194.37	0.07
Diesel	0.22	0	1	0
Total	*296,003.71*	*100*	*294,251.32*	*100*

Table 4. Unlicensed electricity generation installed capacity of Turkey [2, 3].

Res. Type	*2018*		*2019*		*March 2021*	
	Inst. Cap. (MWe)	*Share (%)*	*Inst. Cap. (MWe)*	*Share (%)*	*Inst. Cap. (MWe)*	*Share (%)*
Solar	5,016.99	94.47	5,825.46	92.33	6,448.58	92.03
Natural Gas	153.04	2.88	328.66	5.21	395.51	5.64
Biomass	79.18	1.49	75.67	1.2	83.71	1.19
Wind	51.95	0.98	70.83	1.12	70.83	1.01
Hydraulic	8.91	0.17	8.65	0.14	8.65	0.12
Total	*5,310.57*	*100*	*6,309.27*	*100*	*7,007.28*	*100.00*

Table 5. Unlicensed electricity generation installed power generation values of Turkey [2].

Res. Type	*2018*		*2019*	
	The amount of energy given to the system as surplus (MWh)	*Share (%)*	*The amount of energy given to the system as surplus (MWh)*	*Share (%)*
Solar	7,860,576.89	95.71	9,425,965.29	95.9
Biomass	205,901.95	2.51	255,486.79	2.6
Wind	111,542.03	1.36	113,558.01	1.16
Hydraulic	34,750.58	0.42	34,437.65	0.34
Total	*8,212,771.44*	*100*	*9,829,447.73*	*100*

When the years 2016-2019 are examined, Turkey's licensed, installed power in 2016 was 77.6 GW, which increased by 9.5% to 85 GW in 2019; The licensed electricity generation in 2016 increased by 8% from 272.6 billion kWh to 294.3 billion kWh in 2019. In the same period, unlicensed installed power increased by 500% from 1.05 GW in 2016 to 6.31 GW in 2019; unlicensed electricity generation increased from 1.1 billion kWh in 2016 to 9.8 billion kWh by rising 765% [2, 3].

In 2040, it is predicted that Turkey's electricity generation will be 573 billion kWh. It is estimated that approximately 160 billion kWh of electrical energy, which is 28% of this amount, will be provided by solar and wind energy. It is predicted that roughly $57.5 billion will be invested in solar energy and wind energy in Turkey until 2040, and electricity generation from solar energy and wind energy will meet 25% of the total electricity production in 2040. In addition, it is predicted that 11% of electrical energy production will be provided from nuclear energy in 2040, with nuclear power plants in the installation stage in Turkey [4].

Various criteria are taken into consideration in determining the plant sites. In the literature, there are studies on determining the solar power plant area. Asakereh et al. Used Geographical Information System (GIS) and Analytical Hierarchy Process (AHP) methods to determine the most suitable photovoltaic power plant sites in a specified region in Iran [5]. Sun et al. investigated the suitability of photovoltaic (PV) and concentrated solar power (CSP) plants in the Ningxia region of China. GIS and Multi-Criteria Decision Making Techniques (MCDM) were used in the study. The determining annual production potential is 443 TWh for PV and 308 TWh for CSP [6]. Finn and McKenzie used GIS, AHP, and MCDM methods to determine the potential of solar power plants in Northern Ireland [7]. Aragonés-Beltrán et al. have used the AHP method to evaluate the solar power plant projects that can be installed. In the study, the necessary criteria for the projects to be accepted are specified [8]. Gouareh et al. used the GIS and MCDM method to determine the appropriate plant sites of CSP plants in Algeria. It has been stated that the electricity generation potential of the determined areas is approximately 38 times the country's requirement [9]. Pillot et al. have researched the most suitable PV plant location. The French grid system's most suitable PV plant facility installed powers with minimum cost using GIS and optimization methods [10]. Mokarram et al. used AHP and Analytic Network Process (ANP) methods and GIS to investigate the solar power plant potential of the region determined in Iran [11]. Mohamed researched suitable areas for the establishment of solar water purification points in Egypt. GIS and Multi-Criteria Analysis (MCA) methods were used for research purposes. Areas have been determined according to their suitability levels [12]. Kausika et al. used the GIS and MCDM method to determine the potential of a solar power plant in Apeldoorn, the Netherlands. The study has been developed as an example of the determined policy. It has been stated that the potential obtained meets 77% of the electricity demand of the city [13]. Tercan et al., for the city of Kayseri in Turkey, have investigated the potential of a solar power plant. AHP and various approaches were used together with GIS in the study. The potential map obtained with the existing installed power plants in the city of Kayseri has been compared [14]. Sánchez-Lozano et al. used the GIS and MCDM method to determine the most suitable solar power plant installation areas in the Cartagena region of Spain [15]. Ruiz et al. used AHP and Multi-Criteria Decision Analysis (MCDA) methods and GIS to determine the potential of solar power plants in Indonesia. It has been stated that 34% of the evaluated areas are suitable for installing the power plant [16]. Yushchenko et al. researched the potential of solar power plants in West Africa. GIS and MCDM methods were used in the study [17]. Ali et al. researched the potential of solar and wind power plants for Thailand's Songkhla region. GIS and AHP were used in the study, and the total areas of the appropriate regions were calculated [18]. Uyan has explored areas suitable for installing the solar power plant in the city of Konya, Turkey. GIS and AHP were used in the study. It has been stated that 13.92% of the area under consideration is very suitable for solar power plant installation [19]. Hassaan et al. researched areas suitable for solar power plant installation in Kuwait. Criteria that are important in installing the plant site are listed, and appropriate maps have been created [20]. Amjad and Shah researched areas suitable for solar power plant installation for the specified region in Pakistan. GIS and a new clustering approach were used in the study. As a result of the study, areas with sizes ranging from 10 km^2 to 289 km^2 were determined [21]. Sward et al. aimed to include the public's views and opinions in the GIS and MCDA methods used in determining the areas suitable for solar power plant installation [22]. Sindhu et al. researched areas suitable for solar power plant installation by the policies of the Government of India. AHP and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods were combined in the study [23]. Merrouni et al. have used GIS and AHP to identify areas suitable for solar power plant installation in Morocco. As a result of the study, it was determined that 19% of the area dealt with is suitable for power plant installation, and 15% is not suitable for power plant installation [24]. Haddad et al. researched areas suitable for concentrated solar power plant installation in Algeria. GIS and MCDM were used in the study [25]. Saraswat et al. researched areas suitable for solar and wind power plant installation in India. GIS and MCDM were used in the study. It has been determined that 4.13% of the area under consideration is suitable for solar power plants and 0.91% for wind power plant installation [26]. Ozdemir and Sahin have considered three different regions and determined the areas suitable for solar power plant installation in these regions. PVGIS and AHP were used in the study [27]. Doorga et al. researched areas suitable for solar power plant installation in Mauritius. In the study, MCDM and AHP methods were used together with GIS [28]. Zambrano-Asanza et al. investigated the most suitable regions for photovoltaic power plants by using geographic information system-based multi-criteria decision making and electric load and spatial overlap methods [29]. Colak et al. investigated the appropriate region of the photovoltaic solar power plant installations in Turkey's Malatya city. GIS and AHP were used in the study [30]. Ghose et al. researched areas suitable for solar power plant installation for the West Bengal region of India. In the study, the AHP method was used together with GIS and MCDM [31]. Aly et al. researched areas suitable for installing photovoltaic and CSP solar power plants for Tanzania. In the study, MCDM and AHP methods were used together with GIS [32]. Garni and Awasthi researched the potential of solar power plants in Saudi Arabia with a GIS-AHP based approach. Technical and economic criteria were taken into consideration to evaluate the site's suitability [33]. Habib et al. researched areas suitable for photovoltaic solar power plant installation in Egypt. In the study, MCDM and AHP methods were used together with GIS. As a result of the study, it was stated that approximately one-quarter of the area dealt with is very suitable for the installation of the power plant [34]. Giamalaki and Tsoutsos have identified suitable areas for solar power plant installation in Greece. GIS and AHP were used in the study, and the installed power potential was calculated [35]. Marques-Perez et al. have identified suitable areas for photovoltaic power plant installation in the Valencian region of Spain. In the study, AHP has used together with the GIS and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method [36]. Kaya et al. used the ANN method to determine the wind energy potential [37]. Ebrahim et al. have proposed a system that includes maximum power point tracking in a photovoltaic system [38]. Ryad et al. obtained the photovoltaic panel parameters with the help of their chosen algorithm [39].

Above, Turkey's current energy situation is mentioned, and long-term projections are mentioned. According to long-term forecasts, renewable energy sources such as solar energy and wind energy will significantly share in Turkey's electricity generation in 2040 [4]. Making the most efficient use of solar energy is a significant issue. For this purpose, various criteria are affecting the solar power plant site selection.

In this study, the parameters affecting the solar power plant site installation are mentioned. Information is given about the Analytical Hierarchy Process, one of the algorithm methods used in plant site selection.

2. SOLAR POWER PLANT SITE SELECTION

Energy resources are evaluated according to various criteria [40]. Multiple criteria should also be considered in assessing solar energy and determining the solar power plant site. Power plant site efficiency and legal regulations are some of them [41]. Some restrictions have been made to determine the Republic of Turkey Energy Market Regulatory Board. The "Procedures and Principles Regarding the Determination of the Power Plant Sites of the Generation Facilities subject to Pre-license or Licenses in the Electricity Market" has been published by the Energy Market Regulatory Board of the Republic of Turkey. In addition, the "List of Information and Documents to be Submitted in Applications for Associate Degree and License Transactions" has been published by the Energy Market Regulatory Board. In this context, there are "Sensitive Areas Statement" and "Restricted Areas Statement" that affect the solar power plant site installation. Within the scope of the Responsible Regions Statement, National Parks, Nature Parks, Natural Monuments, Nature Protection Areas, Wildlife Protection Areas, Wildlife Development Areas, Wild Animal Settlement Areas, Cultural Heritage, Natural Assets, Protected and Protected Areas, forest areas Cultural Heritage and Natural Cultural, historical and natural areas with heritage status, regions protected by the RAMSAR Convention, various agricultural areas, various wetlands, lakes, rivers and groundwater operation areas are protected. In the installation of the power plant site, there should be no obstacles within the scope of the Sensitive Regions Statement, and if there is an obstacle, how to overcome the barrier should be specified. Within the Prohibited Areas Declaration, absolute agricultural lands, irrigated agricultural lands, immense plains, planted agricultural lands, special croplands and olive groves are protected by the Soil Conservation and Land Use Law No. 5403. In the installation of the power plant, there should be no obstacles within the scope of the Restricted Areas Declaration, and if there is an obstacle, how to overcome the barrier should be specified [42]. While evaluating the efficiency of the plant site, the topographic features of the land, the climate and meteorological characteristics of the ground, and the location of the land should be taken into consideration. Some criteria that are important in evaluating land productivity are given in Table 6 [43].

Table 6. Solar power plant site selection criteria and requirements [43].

Criterion	*Necessity*
Solar radiation	>1100 kWh/m^2.yr
Slope	<5^o – 15^o
Aspect	Flat, south, southeast and southwest
Prox. to the. res. area	>500 meters
Prox. to enterprises	<3500 meters
Prox. to the road network	<500 meters
Temperature	15 ^{o}C – 40 ^{o}C
Land cover	The land on which the power plant will be installed should not be forest land and should not include fertile agricultural lands.

3. ANALYTICAL HIERARCHY PROCESS

One of the algorithms frequently used in the literature is the Analytical Hierarchy Process (AHP). Thomas Saaty developed the analytical Hierarchy Process in 1980 [44]. In the Analytical Hierarchy Process, the determining criteria are ranked according to each other [45]. By analyzing the listed criteria according to each other, the weight ratio of the criterion is obtained. The grading criteria prepared by Saaty are given in Table 7 [45]. Comparison matrices are formed by using the scales in the table.

Table 7. Analytical Hierarchy Process fundamental scale [45].

Intensity of importance	*Definition*
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Extreme importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

The flow chart of the analytical hierarchy process is given in Figure 1 [46]. In the hierarchy process, the consistency ratio (CR) should be less than 0.1. The consistency ratio is calculated as Equation 1 [44].

$$CR = CI / RI \tag{1}$$

In this equation, CI represents the consistency index, and RI represents the random index. The RI varies depending on the number of criteria. The consistency index is calculated with Equation 2 [44]. In this equation, λ is the eigenvalue of the paired comparison matrix.

$$CI = \frac{\lambda - n}{n - 1} \tag{2}$$

The hierarchy structure for the analytical hierarchy process is shown in Figure 2 [44]. In this direction, alternatives are obtained by determining criteria and sub-criteria for the targeted purpose.

A hierarchical structure should be established to use the analytical hierarchy process in determining the solar power plant site. For this, the criteria affecting the power plant site installation and their sub-criteria should be selected. An example hierarchical structure created to determine the optimum solar power plant site is shown in Figure 3 [43].

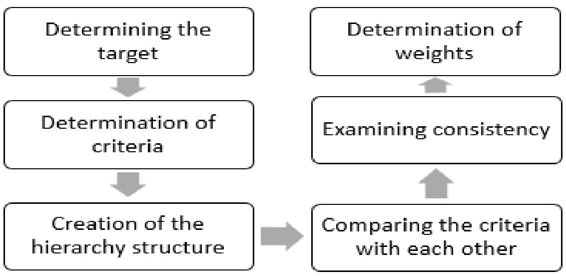

Fig. 1. AHP flow chart [46].

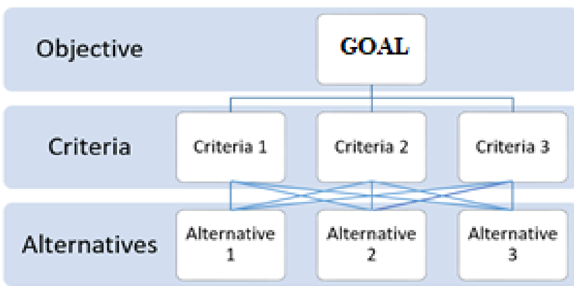

Fig. 2. Hierarchy structure for AHP [45].

After the criteria determine suitable solar power plant installation areas, pairwise comparisons are applied to the requirements. While creating pairwise comparisons, the preference scales with 1-9 points in Table 7 are used when determining how vital one criterion is compared to the other criterion. After the weights of the criteria are determined, the consistency ratio is calculated using Equation 1 [45].

4. CONCLUSION

The importance of renewable energy sources globally and Turkey and their use is increasing day by day. Given that solar energy is a clean and infinite source of energy and the solar energy potential of Turkey is relatively high and is currently dependent on energy in terms of energy, increasing investments in solar energy in Turkey should be strongly encouraged. In this study, Turkey's energy and solar energy situation has been mentioned, and the criteria that are important in the selection of the solar power plant have been evaluated. These criteria directly affect costs during plant installation and operation. In this study, Turkey's energy outlook, electricity production from renewable energy sources in Turkey and Turkey's long-term energy projections are mentioned. To make the most efficient use of solar energy, one of the renewable energy sources, the solar power plant site installation factors were discussed. Information was given about the Analytical Hierarchy Process, which is one of the methods used in determining the plant site.

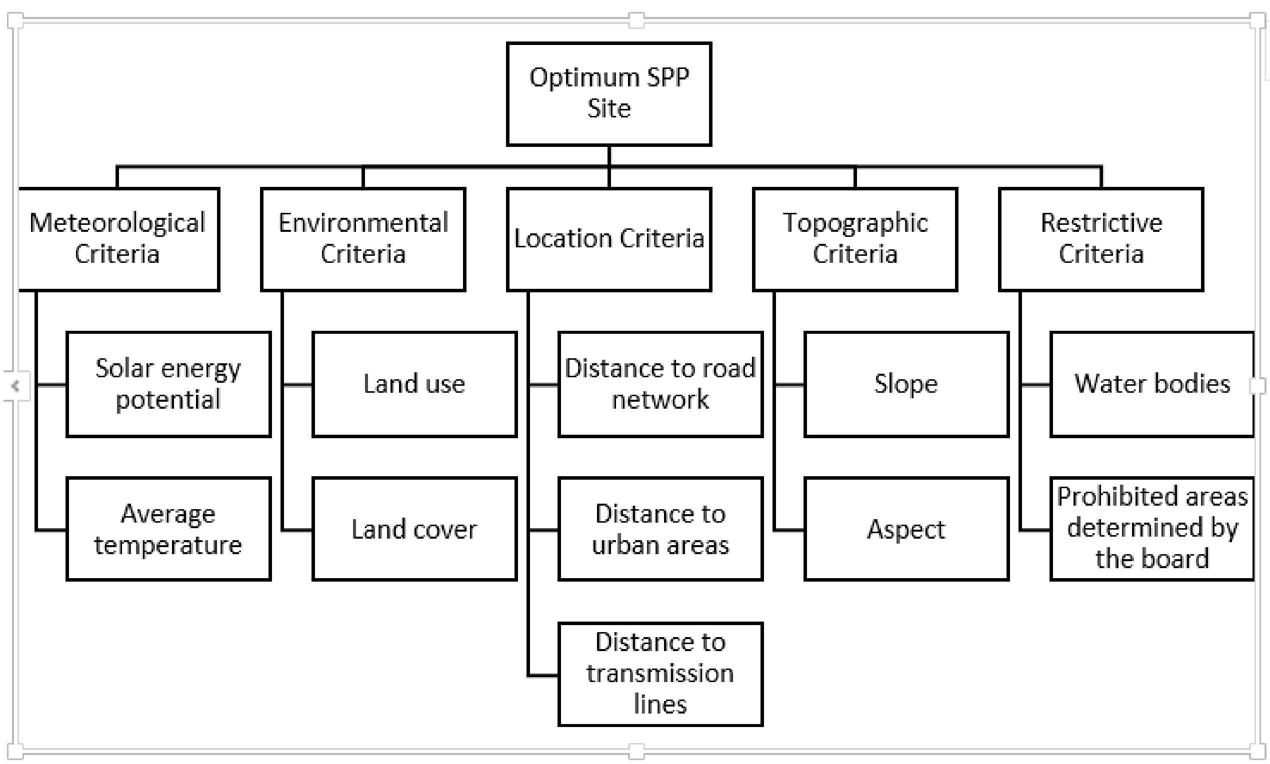

Fig. 3. AHP criteria table for optimum SPP site [43].

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Biographies

Burcu Gülmez completed her undergraduate education in Manisa Celal Bayar University, Department of Mechanical Engineering, in 2016. She completed her master's degree in Manisa Celal Bayar University, Department of Mechanical Engineering, in 2020. She has studies on thermodynamics, heat transfer and solar air collectors.

E-mail: burcugulmez@gmail.com

Ramazan Köse completed his undergraduate education in Eskişehir Osmangazi University, Department of Mechanical Engineering, and his master's and doctoral studies at Yıldız Teknik University. Prof. Köse is a faculty member at the Department of Mechanical Engineering at Dumlupınar University, Kütahya. He is a member of the Chamber of Mechanical Engineers, Turkish Society of HVAC and Sanitary Engineers and Turkish Society of Thermal Sciences and Technology. He has many studies on thermodynamics, heat transfer, renewable energy systems and energy efficiency. His h-index value is 15.

E-mail: ramazan.kose@dpu.edu.tr

Oğuz Ozan Yolcan completed his undergraduate education in Eskişehir Osmangazi University Mechanical Engineering Department in 2014 and his master's degree in 2017 from Kütahya Dumlupınar University Mechanical Engineering Department. He has studies on thermodynamics, heat transfer, heat pumps and renewable energy systems.

E-mail: oguzozan.yolcan@dpu.edu.tr