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GIS-AHP APPROACH FOR A COMPREHENSIVE FRAMEWORK TO DETERMINE THE SUITABLE REGIONS FOR GEOTHERMAL POWER PLANTS IN IZMIR, TURKIYE

[1] **Kemal KOCA**, [2,*] **Fatih KARİPOĞLU**, [3] **Emel Zeray ÖZTÜRK**

[1] *Abdullah Gül University, Engineering Faculty, Mechanical Engineering Department, Kayseri, TÜRKİYE*
[1] *Abdullah Gül University, KOCA Research Group, Kayseri, TÜRKİYE*
[2] *Izmir Institute of Technology, Energy Systems Engineering Department, Izmir, TÜRKİYE*
[3] *Konya Technical University, Engineering and Natural Sciences Faculty, Geomatics Engineering Department, Konya, TÜRKİYE*
[1] kemalkoca@agu.edu.tr , [2] fatihkaripoglu@iyte.edu.tr, [3] ezozturk@ktun.edu.tr

Highlights

- GIS-AHP approach to determine the suitable region for Geothermal Power Plants is used under physical (C1), environmental (C2), and technical (C3) main criteria.
- To construct the AHP structure, experts' opinions were taken from Geothermal DHC Summer School which was carried out in Slovenia July 2021 (CA18129).
- İzmir Province has highly suitable regions of 1037 km2 for potential GPP.
- Based on the comparing process, Dikili power plant was determined as the non-suitable score while Balçova power plant had the highly suitable score.

***Corresponding Author:** Fatih KARİPOĞLU, fatihkaripoglu@iyte.edu.tr

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[1] *Abdullah Gül University, KOCA Research Group, Kayseri, TÜRKİYE*
[2] *Izmir Institute of Technology, Energy Systems Engineering Department, Izmir, TÜRKİYE*
[3] *Konya Technical University, Engineering and Natural Sciences Faculty, Geomatics Engineering Department, Konya, TÜRKİYE*
[1] kemalkoca@agu.edu.tr , [2] fatihkaripoglu@iyte.edu.tr, [3] ezozturk@ktun.edu.tr

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ABSTRACT: Geothermal energy is gaining more reputation and importance around the world. Correspondingly, suitable location selection is a critical step and has become necessary for the successful installation and operation of geothermal power plants. This study investigated suitability of İzmir region, located in the Aegean part of Türkiye, in terms of geothermal power plants applications by using the combination of Geographical Information System and Analytic Hierarchy Process. Based on the request of power plants, thirteen important criteria were evaluated under three main categories named as physical (C_1), environmental (C_2) and technical (C_3). Moreover, expert's opinions were taken into consideration to calculate the importance of these criteria. Key results showed that İzmir was suitable for geothermal power plants. The final suitability map layer pointed out that %8.73 (1.037 km^2) of total area were determined as highly suitable regions in terms of installation. In addition, the obtained suitability map layer was compared with actual geothermal power plants. Based on the comparison study, power plants in Seferihisar were moderately suitable for geothermal power plants while the location of Balçova power plant was highly suitable. Regarding the suitability assessment in the present study, the location of Dikili power plants had the least suitability score.

Keywords: *Analytic hierarchy process, Geographical information system, Geothermal energy, İzmir, Suitable site selection*

1. INTRODUCTION

Since energy is staminal for daily life activities such as heating, fabricating, cooking and transportation, energy sources have enormously influenced the strategic policies of both developed and developing countries. These activities have been provided by different energy sources such as natural gas, fuel oil, solar, wind, geothermal, etc. Given that certain energy resources are finite while others are sustainable, the source from which energy is derived becomes of utmost significance. Hence, supplying energy from non-renewables has lagged the renewable energy sources, especially over the last two decades. In this respect, renewable energy sources such as wind, solar, geothermal, hydropower and biomass as seen in Figure 1 have been started to substitute with conventional energy sources such as coal, natural gas, and fuel oil because of increasing sustainability issues and environmental threat such as atmospheric emissions, solid waste, and water consumption [1]. These threats which will be seen in the near future have proved why utilizing appropriate renewable energy resources is important. Renewable energies provide a reduction in secondary waste and environmental impacts, the mitigation of greenhouse gas emissions, and the promotion of sustainability [2].

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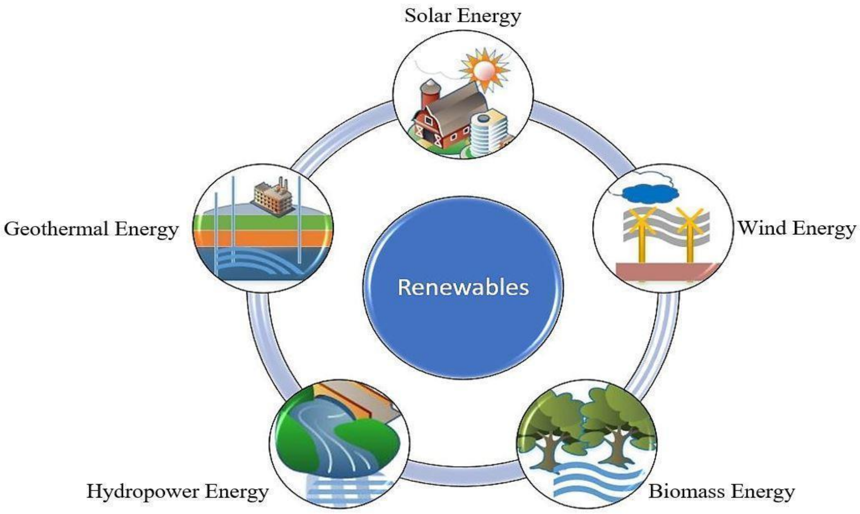

Figure 1. The types of renewable energy resources

Among renewable energies, energy production with wind and solar power could be problematic because of their intermittent nature [3-4]. Energy supply could be ensured via hydropower [5]. However, it is not continuous especially in the drought period of summer seasons. Biomass can also provide energy production. However, since a continuous biomass supply cannot be made during drought periods, the same problem arises here as well. On the other hand, geothermal energy is different. Because it is the only renewable resource which is not affected by natural events and weather conditions [5].

Hostility to renewable energies was not uncommon. Hence, the geothermal power industry tends to categorize such behavior as a social acceptance issue [6]. On the other hand, hostility should be thought of as being part of more general energy management and environmental issues than social acceptance. Those issues may be classified as local pollution, economic considerations, water conservation concerns, energy policy, quality of life, and employment effects. In such situations, finding a straightforward and unambiguous resolution is difficult. Therefore, acceptable compromise solutions to geothermal power may be ensured by suitable planning processes [7].

Recently, the territorial planning and suitable site selections for the installation of those renewable energies have enormously gained popularity in the literature. Some researchers have studied the suitable site selections for onshore wind farms [8-10] and offshore wind power [4], [11-12], whilst some of them have tended to investigate the territorial planning for PV power plants [3] and biomass power plants [10], [13-14]. Unlike those renewable energies, the suitable site selection for geothermal power plants was rare in the literature [15-17]. Coles et al. studied the spatial decision analysis for geothermal resource to provide a guideline selecting the best locations as a case study [15]. For the investigation of the detected criteria, nine exploratory wells were drilled to select the suitable locations. Coro and Trumpy carried out the novel research which was predicted the geographical suitability for geothermal power plants by considering lots of criteria [16]. The study presented the first suitability map of globally geothermal power plants. Mostafaeipour et al. studied an interesting topic which ranked the locations for geothermal power plants integrated hydrogen production in Afghanistan [17]. In the scope of study, nine criteria were assessed to evaluate the 17 provinces in Afghanistan regards with suitability locations for hybrid system. According to results, the number of refineries and distance from distribution centers were determined as the most important criteria for the geothermal based hydrogen production systems [17].

The process of determining the best location for installation has been detected deficient even though Türkiye has huge geothermal energy potential. In order to assess this huge geothermal energy potential, an accepted roadmap is not available currently. Within the renewable energy policies and targets of Türkiye, the mentioned gap must be filled with the best method. The main objective of the present study was to provide a suitable site for the installation of a geothermal power plant in Izmir and to compare it with the locations of current geothermal power plants in order to understand if they were installed in a reliable region. In addition, this study aimed to fill the detected gap in assessing the huge geothermal potential in Türkiye. To select the best suitable regions, the multi-criteria should be assessed and suitable locations should be selected with suitable methods. Based on the literature, necessary and crucial criteria were detected and ranked by relevant experts. Hence, the obtained information and experience from experts provided guidance for creating a successful roadmap. The rest of this study was categorized into four main sections. In Section 2, a preliminary definition of materials and methods including the Analytical Hierarchy Method (AHP) and Geographical Information Systems (GIS) was performed. In section 3, the case study for selected areas and multi-criteria was evaluated. In Section 4, the results that emerged from the analysis was discussed. In Section 5, the conclusions with the key findings were put forward.

2. MATERIAL AND METHODS

The present study analyzed the suitable site selection of geothermal power plants in İzmir province of Türkiye. This section revealed the study area, methods and tools, expert panel analysis by means of AHP.

2.1. Study Area

The most suitable topography for geothermal power plants depends on a number of factors that ensure the most efficient use of geothermal resources. Project planning and location selection is a process that requires many details, taking into account all of those factors. İzmir province, which was chosen as the study area, is located in the west of Türkiye within an area of 11.891 km^2. It is one of the important regions with geothermal energy potential in Türkiye and has suitable geothermal resources to evaluate this potential. At first glance, some factors that provide geothermal energy potential in Izmir can be listed as follows:

- **Geothermal Resources:** Izmir has huge potential in geothermal resources and hosts many geothermal resource areas. These sources support the production of hot water and steam.
- **High Temperature:** Most of the geothermal resources in Izmir have high temperatures, which provides an advantage in terms of energy efficiency.
- **Climate Factors:** Izmir's climate is suitable for geothermal energy production. The temperature values are above average values which are 14 °C. It is sunny and mild throughout the year, which supports solar and geothermal energy.
- **Infrastructure:** Izmir has a developed region in terms of energy transmission and infrastructure, which is important for energy production and distribution.

Fault line densities for İzmir are classified as second degree [18]. There are also a few geothermal plants for different purposes. As a result of those factors, İzmir was selected as a pilot region due to its high utilization potential of geothermal energy. Aydın and İzmir could be named as geothermal capitals because of existing plants and continuing research activities. Therefore, the selection of the most suitable region for geothermal power plants could be very useful for researchers and investors. Another main reason is to check the accuracy of existing plants' position. The study area was illustrated in Figure 2.

2.2. Data Collection and Preparation

As seen in Figure 3, 13 criteria that were important for the installation of a geothermal power plant in Izmir province were determined and they were evaluated by an expert group including hydrogeologists, geologists, power engineers, geotechnical engineers, geoscience engineers and energy systems engineers.

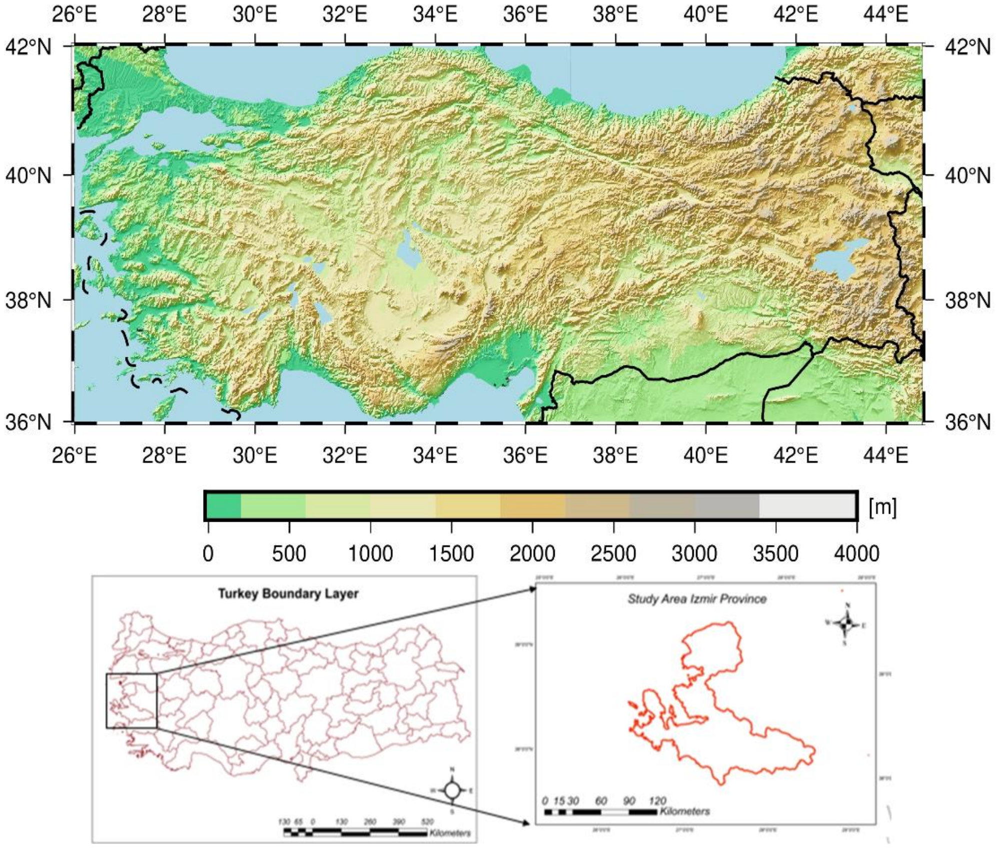

Figure 2. Geographical location of study area

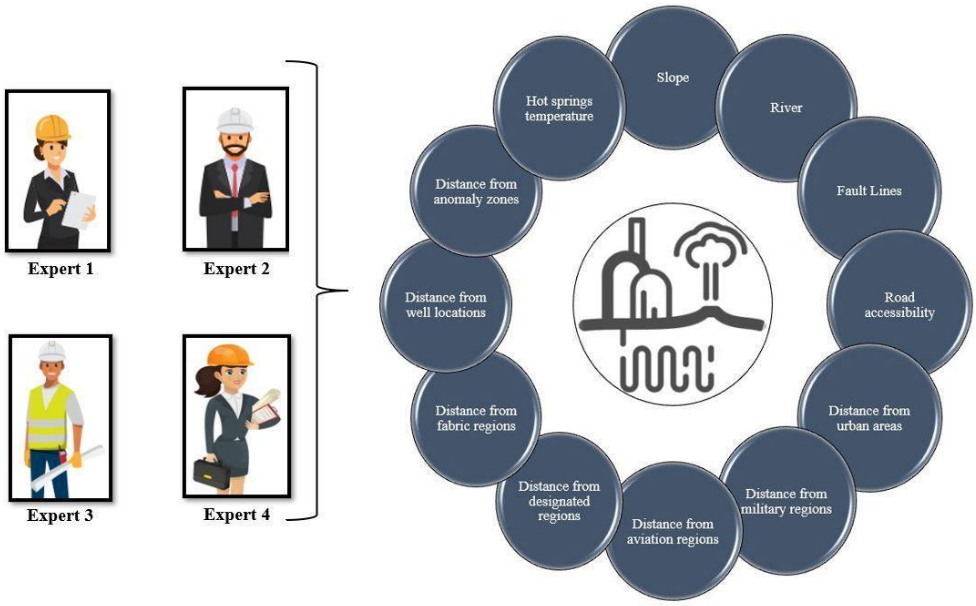

Figure 3. Criteria for suitable location of geothermal power plant installation

2.3. Geographical Information System (GIS)

The geographic information system (GIS) is a system that creates, manages, analyzes, and maps all types of data. GIS connects data to a map, integrating location data with all types of descriptive information. This provides a foundation for mapping and analysis that is used in science and almost every industry. GIS helps researchers understand patterns, relationships, and geographic context. The benefits include improved communication and efficiency as well as better management and decision making. In this study, the creation of visual map layers was performed by utilizing GIS tools.

2.3. Multi-attribute Decision Making Techniques

So far, different techniques including the Additive Ratio Assessment (ARAS) method [19], technique for order preference by similarity to an ideal solution (TOPSIS) [20], Stepwise Weight Assessment Ratio Analysis (SWARA) method [17] have been employed for several purposes in the literature of renewable energy. It can be foreseen that multi-attribute decision making (MADM) technique is the most popular one. Because MADM can select between potential alternatives and evaluate them under multiple criteria even though some of them conflicted with each other. It may also be said that determination of the most appropriate energy resources, assessment of energy resources performance and identification of the most optimal location of energy facilities could be performed with these methods. Moreover, MADM techniques are immensely effective in order to achieve the solutions since these problems have different factors including social, environmental, financial, etc., which must be taken into consideration. In this study, AHP as a MADM method was employed for the installation of a geothermal power plant.

2.3.1. Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is an additive weighting technique among MADM methods in order to solve the renewable and sustainable energy problems. Complicated problems in a hierarchical structure form the core of AHP. Essential aim is at the top of hierarchy, whilst decision alternatives are positioned at the bottom [21]. The implementation of AHP method applies under three main principles: (*i*) determining the problem and creating the hierarchy, (*ii*) creating a comparative decision-making preference matrix and (*iii*) determining the factor weights for each criterion [3]. The AHP uses a pairwise comparison of criteria to determine which criteria is more important than other criteria [22]. Firstly, each criterion must be compared as a binary value using the pairwise comparison method and the relative values must be assessed based on the level of importance among themselves to each other. Afterwards, a matrix, showing the paired comparison value of criteria, is formed easily. Level of importance value was shown in Table 1.

Table 1. AHP binary comparison scale

Importance level	Meaning
1	Indifferent (equal)
3	Weak preference (moderately more important)
5	Preference (more important)
7	Strong preference (strongly more important)
9	Very strong preference (extremely more important) (Intermediate values 2,4,6 and 8 are also possible)

After obtaining comparison matrices, the weighted vectors are normalized. The normalized weight vector values are obtained according to the level of importance value of the used criteria. With the resulting vector values, the consistency ratio (CR) values are calculated, and these calculated values are used in the application to determine whether it is valid. CR formula is given in Equation 1. CC represents the consistency index and RI represents the random consistency index.

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

Because of the best solution research, an upper limit of CR is determined. If the CR value is less than 0.1, it can be said that the binary comparisons are acceptable [13]. If not, the binary comparisons contradict each other. The factor weights were analyzed for use in practice in accordance with the CR and the spatial analysis performed. The results obtained from surveys from 20 experts were provided the proper consistency ratio.

3. RESULTS AND DISCUSSION

The present study discussed the required criteria and roadmap for suitable site selection of Geothermal Power Plants (GPP) in İzmir province, Türkiye. Combination of GIS and MCDM has been determined as the most preferable method [23]. According to the MCDM results, environmental concerns have the highest degree of importance, while both other criteria have similar rankings. For any energy investment, it was expected that the technical criteria must have the most critical impact [4], [24]. However, this study revealed that environmental issues could need to be analyzed in detail. In the literature, some studies have not included the environmental criterion for suitable site selection of GPP [25-27]. Thus, the present study filled the vital lack area in the literature by assessing the possible environmental issues. Furthermore, GPP did some significant environmental damage and gathered negative impacts on social acceptance [28-29]. However, this objective and scientific site selection process will cause social acceptance positively. It clearly makes comments that biodiversity, groundwater sources, and agricultural production will not be jeopardized. The factors selected for suitable location were obtained as a result of a wide literature review and experts' opinions. For this study, 20 experts provided the pairwise value for AHP analysis. As a result of provided values, importance values of main and sub-criteria were calculated, and they were shown in Table 2. Furthermore, twelve different map layers were made ready for use in the GIS. These map layers consisted of slope, river, fault lines, road accessibility, urban areas, military regions, aviation regions, designated regions, fabric regions, well locations, anomaly zones and hot springs temperature. For all those criteria, the buffer zones were carefully determined. In this study, all restrictive regions based on buffer zones of criteria were excluded from the analysis. Therefore, visual pollution and confusion that occurs in the reader's brain were prevented in analysis map layers. The datasets and determined criteria set were taken into account in determining the optimum location for geothermal power plants shown in Table 2.

Table 2. Factors, sub-factors, and factor weights for geothermal power plants

Criteria/ Data sources	Sub-Criteria	Buffer Zone	Unit	Suitability Score/Ranking *		Importance Weights
C1. Physical *- Earth Data - Copernicus Land Monitoring CLC2000 - General Directorate of Mineral Exploration and Research*	Slope	<15°	%	(1) 12-15 (2) 6-12 (3) 0-6	0,065	**0,34**
	Water Bodies	outside	m	(1) 0-500 (2) 500-1500 (3) 1500-3500	0,075	
	Fault Lines	<200	m	(1)200-500 (2) 500-1000 (3) 1000-2000	0,12	
	Road Accessibility	<100	m	(1)100-200 (2) 200-1000 (3) 1000-2000	0,074	
C2. Environmental *- Copernicus Land Monitoring Service - Earth Data*	Dist. from urban areas	<500	m	(1) 500-700 (2) 700-1500 (3) 1500-3000	0,086	**0,35**
	Dist. from military regions	<5	km	(1)5-7 (2) 7-12 (3) 12-20	0,062	
	Dist. from aviation regions	<3	km	(1)3-5 (2) 5-15 (3) 15-30	0,058	
	Dist. from designated regions	<3	km	(1)3-4 (2) 4-5 (3) 5-6	0,072	
	Dist. from fabric regions	<500	m	(1)500-800 (2) 800-1500 (3) 1500-2500	0,072	
C3. Technical *-Earth Data - (MTA, 2020). -Copernicus Land Monitoring CLC2000*	Dist. from well locations	<200	m	(1) 200-500 (2) 500-1000 (3) 1000-2000	0,107	**0,31**
	Dist. from anomaly zones	<3	km	(1) 5-7 (2) 4-5 (3) 3-4	0,109	
	Hot springs temperature	<10	°C	(1) 10-13 (2) 13-18 (3) 18-25	0,097	

**(1) Lowest suitable/ (2) moderately suitable/ (3) most suitable*

A comparison of the importance level of sub-criteria in conjunction with their standard deviation was illustrated as seen in Fig. 4. The blue dashed line demonstrated the mean values of sub-criteria, while the red solid line showed their standard deviation. As seen in the Figure, there were weak fluctuations in the sub-criteria including slope, river, road access, military regions, aviation distance, designated regions, and fabric regions. However, there were bigger peaks at the sub-criteria including fault lines, urban areas, wells, anomalies, and hot springs. This revealed that four sub-criteria which had bigger peaks were more important than other criteria in terms of installation of a geothermal power plant.

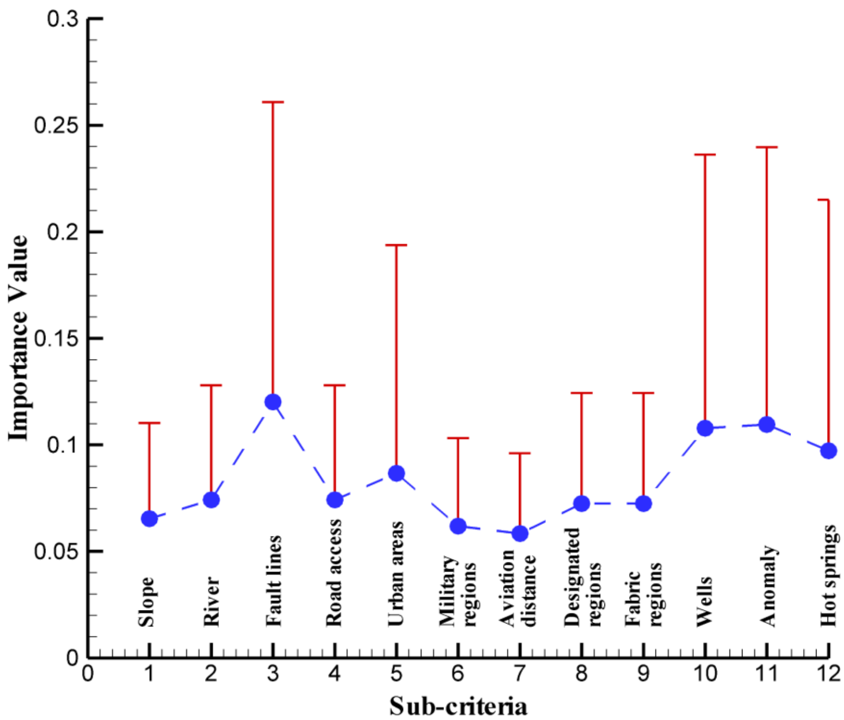

Figure 4. The importance level of sub-criteria with their standard deviations, blue dashed line: mean values, red solid line: standard deviation

3.1. Physical Factors

Physical factors which were one of the main factors consist of slope, river, fault lines and road accessibility. These sub-factors could define almost all geological feasibility and technical infrastructure for power plants. The weight of physical factors was calculated in 0,34 as a result of experts' opinions. Based on the literature review and other research studies the buffer zones of sub-criteria were determined and ranking processes were created between 1 (most suitable) and 3 (low suitable). Afterwards, the suitability score was assigned according to the distance from buffer zones of criteria. Obtained map layers based on buffer zones and ranking were shown in Figure 5.

- ***Slope:*** Slope is a very important and principal criterion for installing any energy power plant. If the selected land does not meet the requirement, excavation in the area causes losses in terms of both time and cost [3]. Also, for the accessibility requirement of power plants, slope is a key factor. Even though there is no regulation related to the maximum slope range, areas with a slope of less than 15 were assumed as suitable for geothermal power plants [30]. In this analysis, areas with land slopes of more than 15 were evaluated as unsuitable regions. In addition, areas with land slopes less than 15 were classified shown in Table 2 and were analyzed to obtain the optimal regions.

- ***Rivers:*** Rivers are carrying importance for the next generation due to the lack of water supply. Therefore, these water sources should not be used for different purposes. Also, regions maintaining a maximum water level should not be used to avoid negative effects from stronger river flowing when precipitation is high during the year [2]. Finally, in this study, relevant buffer zones were expected outside of river regions and ranking was classified based on this assumption.

- ***Fault lines:*** One of the key components to analyze a region of geothermal potential is to understand the role of fault lines [13]. Noorollahi et al. [26] determined the dominant distance between fault lines and geothermal wells. According to the results, 95% of the existing wells are located in a zone within a 6000 m distance to active fault lines. However, another study [4] showed the optimal maximum distance should be 2000 m from fault lines. Therefore, this study deemed regions with far above 2000 m are unsuitable regions. Fault lines have the highest importance weight among all sub-criteria shown in Table 2 and Fig 4.

- ***Road accessibility:*** Road accessibility is the one criterion of the technical infrastructure. Distance to main roads is very important for every energy power plant. The buffer zone for maintenance and other activities of the roads was accepted as 100 m and the ranking was classified according to a maximum distance of 2000 m [3].

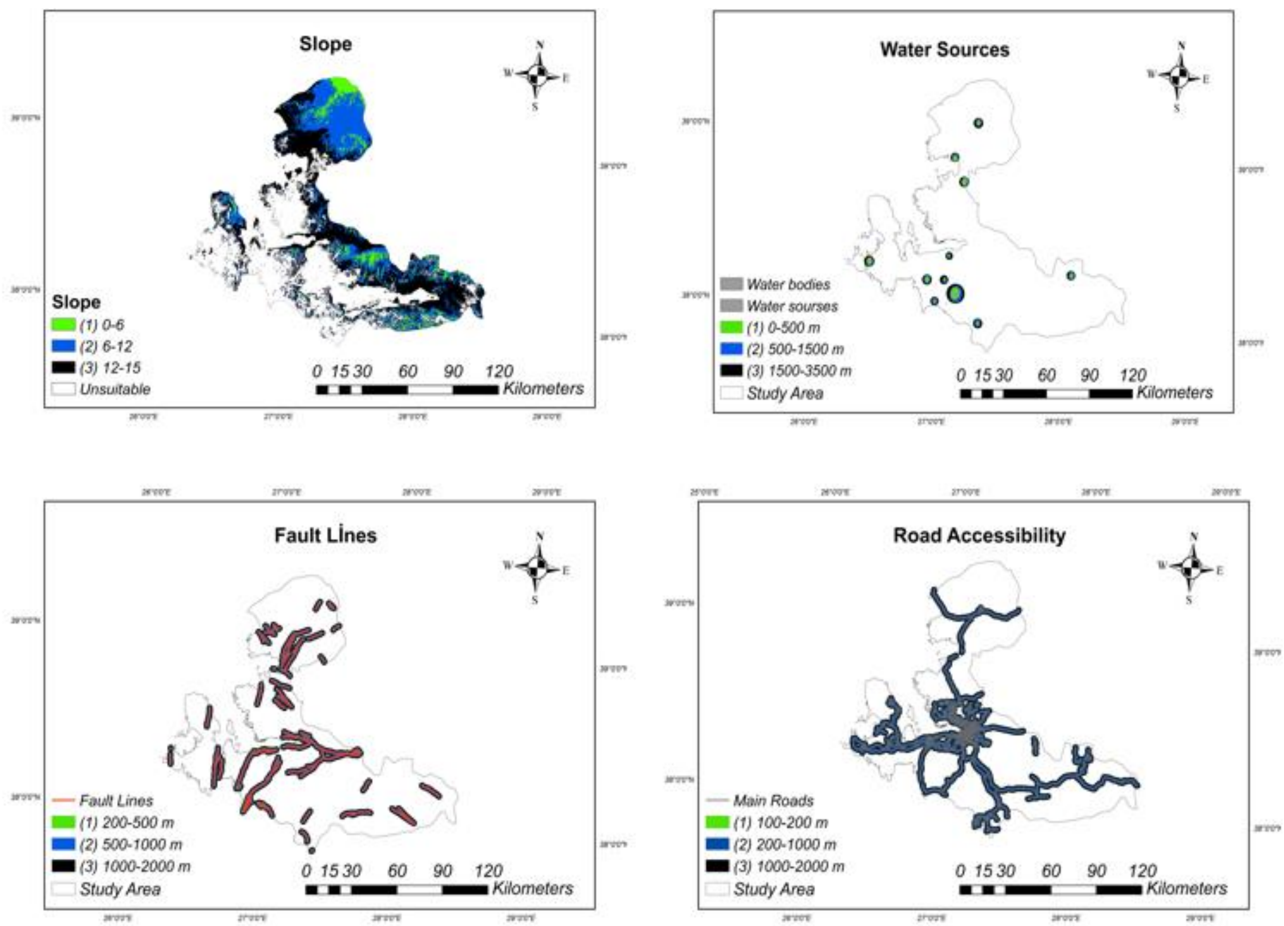

Figure 5. The map layers belonging to the physical factors

3.2. Environmental Factors

The analysis of environmental factors is a basic requirement for optimal location selection of energy power plants such as wind, solar energy [4]. It can be useful and accurate to analyze too many factors related to directly or indirectly environmental issues. According to the expert's opinion, the environmental factors have gained a 0.35 weight score which is the highest score among the main factors. Therefore, this study represents important and necessary factors which consist of distance from urban areas, military regions, aviation facilities, designated regions, and fabric regions. It was determined that there were no special criteria or restrictions for the study area. CLC 2018 and Earth Data sources were used to analyze the determined environmental criteria. The buffer zones of sub-criteria can be seen in Table 2. Reclassified environmental map layers were shown in Figure 6.

- ***Distance from urban areas:*** Using land is a very important criterion for geothermal power plants. Although the analysis of existing urban areas is important, the prediction of future settlement directions must be taken into consideration in detail [30]. Also, energy demand, and energy costs of regions must be taken into consideration under urban areas criteria. The spatial data of urban areas used in this study was determined by CLC 2018 and Earth Data. To prevent any negative effect, the buffer zone of urban areas was determined as 500 m and was classified based on distance from urban areas [30].

- ***Distance from military regions:*** Military regions are carrying the secret and special value for countries. Therefore, military exercise, training, storing or other regions should not be used for different purposes [24]. In the study area, there are some critical military ports, hence this study is accepted as 5 km in the buffer zone of military regions.

- ***Distance from aviation regions:*** Aviation regions that consist of civil, military or load airports are very important points like military regions. Therefore, these regions cannot be used for different purposes because of their value. To determine the location of airports, CLC 2018 airport data sources were used and proceeded in GIS. There were 2 airports in the study area. Based on aviation rules, energy power plants have to be 3 km far from aviation points [30].

- ***Distance from designated regions:*** Designated regions are identified and protected by national or international institutes. The study area has some natural and historical places protected by UNESCO. To protect the natural and historical places, the buffer zone of designated regions was determined as 3 km. Based on the determined buffer zone, ranking was classified between 3 km and 6 km so as not to narrow the fields [31].

- ***Distance from fabric regions:*** The study area is a very important commercial center because of its location. Therefore, 30 fabric regions exist in the study area dispersedly. To predict the location of the future residential area, it is necessary to analyze the growth of factory areas and determine buffer zones. For this opinion, the buffer zone of the fabric region was determined as 500 m and ranking values were classified based on these opinions [32].

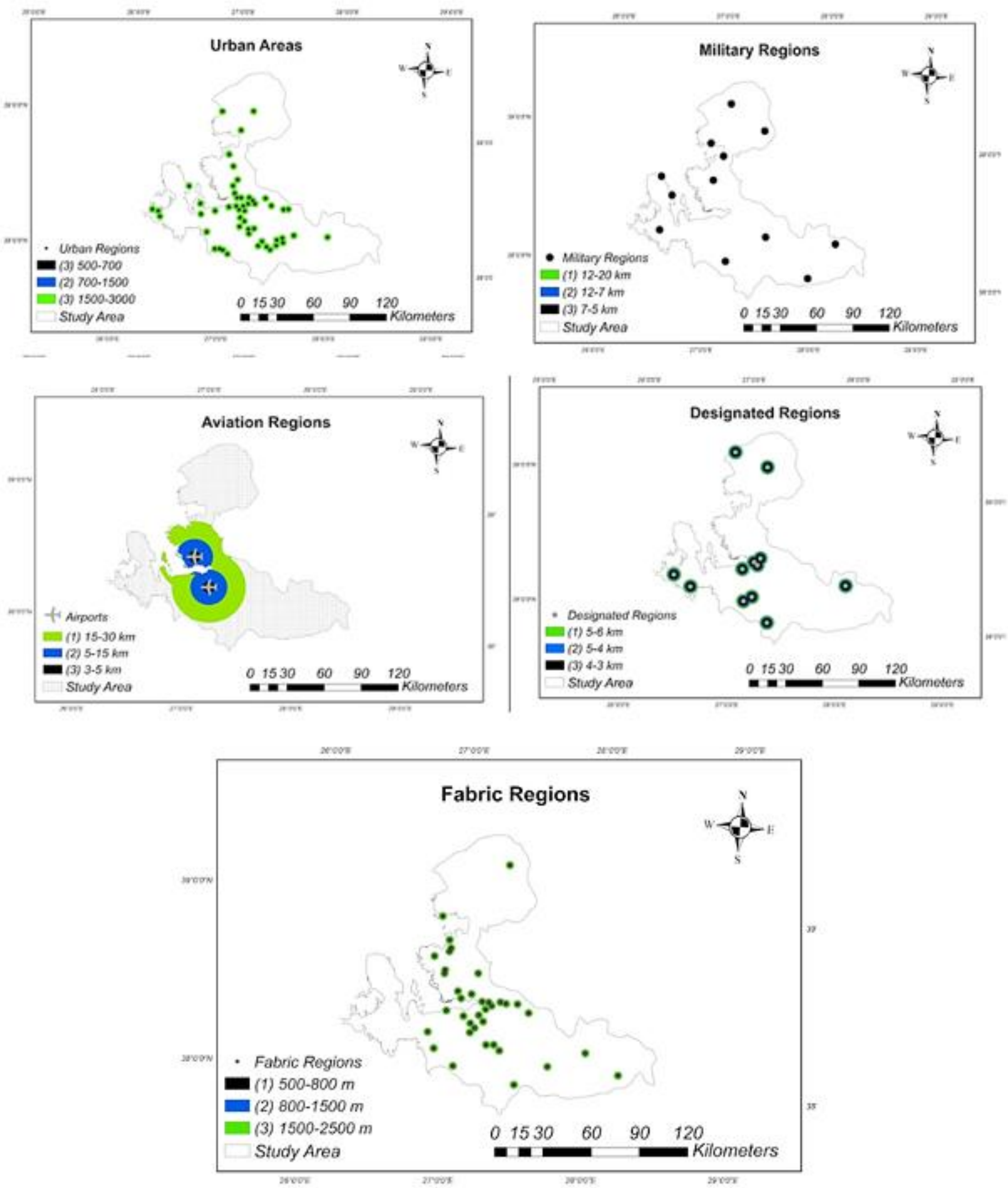

Figure 6. The map layers belonging to Environmental factors analysis

3.3. Technical Factors

Technical factors were categorized under three sub-criteria which were distance from well location, distance from anomaly zones and hot springs temperature. In the geothermal energy potential assessment could be evaluated to measure the temperature of underground waters. Thus, existing wells could be useful and guide to selecting the optimal location. In the scope of this study although general information will be obtained, potential measures must be taken certainly for the determined suitable regions. Used datasets, determined sub-criteria and then buffer zones shown in Table 2. Also, reclassified map layers for technical factors were created in Figure 7.

- ***Distance from well location:*** Existing well locations can give information to researchers, investors, and energy planners about potential locations. Analyzing well locations is a rather vital step for technical factors. General Directorate Mineral Research and Exploration Institution measures underground water temperature and determines well locations. This study used General Directorate Mineral Research and Exploration [34] map layers which are in ".TIFF" format and these map layers were processed in GIS. In the study, the buffer zone of the well location was determined as 200 m [13]. When geothermal power plants must be near the well location, a distance from well with between 200 and 500 m was classified as the most suitable region in Table 2.

- ***Distance from anomaly zone:*** Geothermal fluids can be transported easily and economically by pipelines to a few kilometers [27]. Therefore, consumption facilities or generating plants should be located near anomaly zones. To determine the suitable regions, a buffer zone of 3 km was applied in the study area. Reclassified ranking distance was given in Table 2. Additionally, the distance from the anomaly zone was identified as the most important criterion among technical factors with a 0.109 weight score.

- ***Hot springs:*** Hot springs are the basic evidence of the hot waters and subsurface heat source [33]. The location of hot springs can give information about geothermal potential. As hot springs can be used for commercial facilities, geothermal power plants must be located at a certain distance because of noise and visual impacts. Also, the minimum hot spring temperature must be 10 °C. According to this information, the ranking section was edited between the minimum and maximum temperature of the study area.

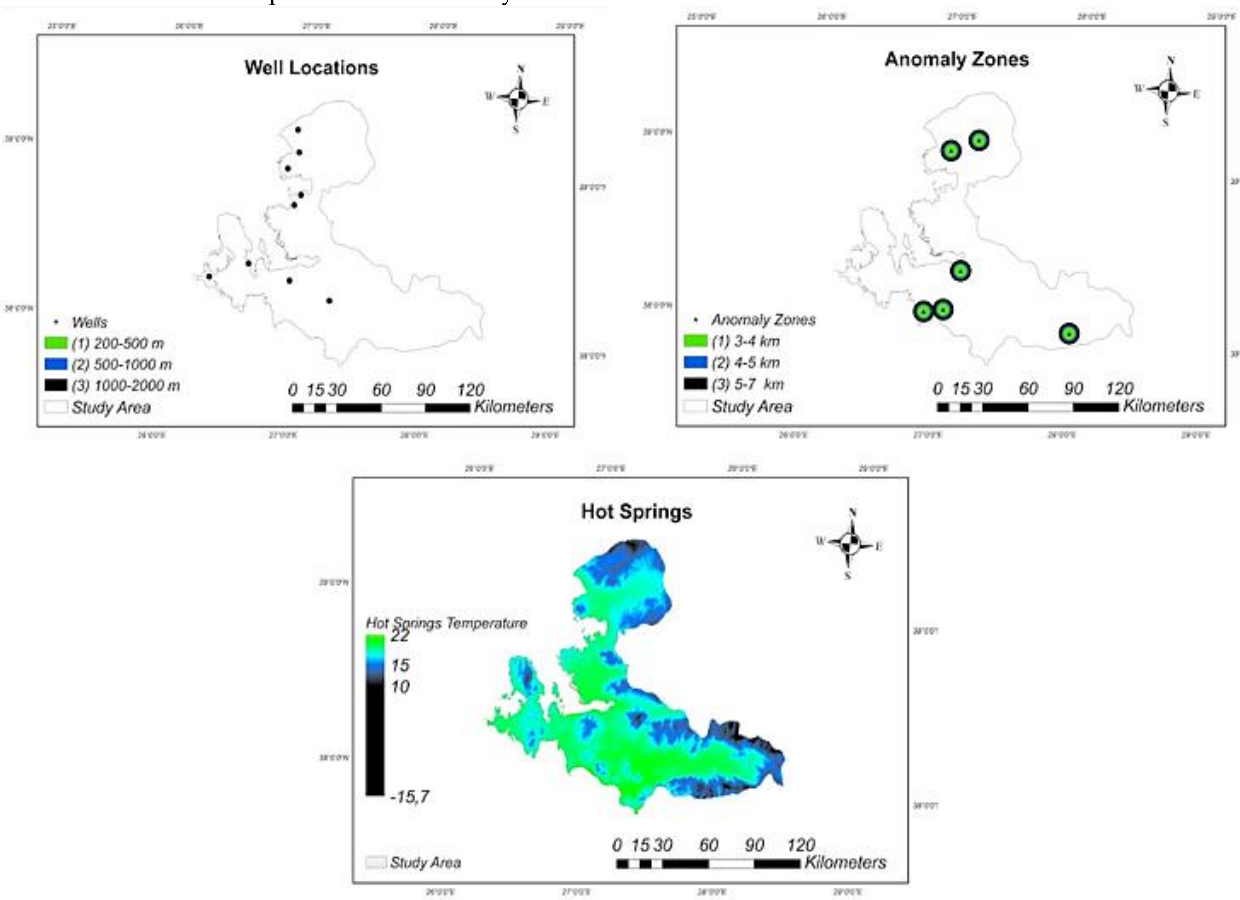

Figure 7. The map layers belonging to technical factors analysis

3.4. Determination of Suitable Location and Comparison

Fig. 8 shows the suitable regions which were determined in this comprehensive analysis study. Intensive black points were presented in the non-suitable regions where there were restrictions or buffer zones. Green points demonstrate the suitable regions based on the experts' opinions. The south direction of the study area could be a new geothermal region center in order to produce geothermal energy. Although the north of Izmir Bay had huge potential and was a suitable region, these regions were utilized intensively for settlement and residential facilities. In addition, the Balcova region which was located on the Izmir Bay had the suitable region although it was a small region. Furthermore, the sensitive areas including lakes and rivers were identified in the detailed study [35]. According to the study, those sensitive areas were found especially at the center of the region which was far away from the suitable areas of desired geothermal power plants. This proved that the suitable sites for geothermal power plants indicated as green color would not disturb the areas of wetlands, drinking water and fertile agricultural lands. It was also found that Türkiye's agricultural activity including wild and cultivated olives which were too crucial for export was studied [36]. The desired geothermal power plant with green color did not jeopardize the lands of wild and cultivated olives.

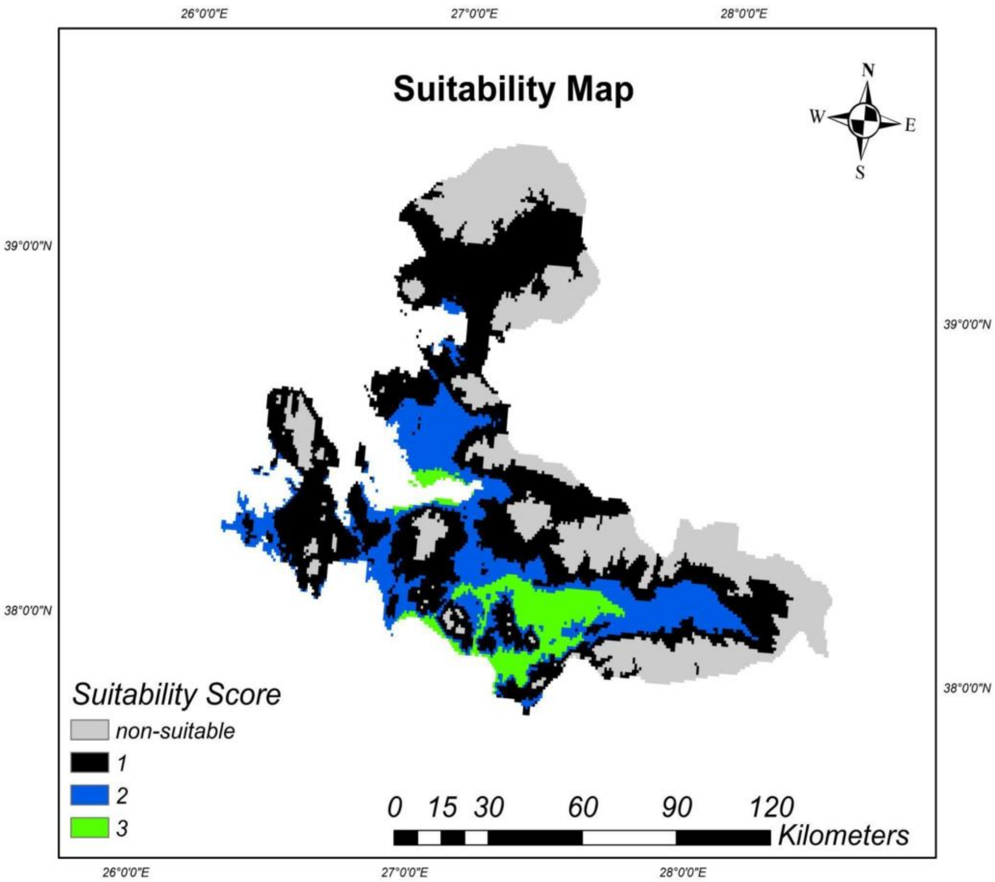

Figure 8. Suitability map layer in the study area

In terms of comparison of the key findings, Fig. 9 pointed out the actual geothermal energy power plants in the Aegean region obtained from the General Directorate of Mineral Exploration and Research [34]. Geothermal power plants were shown with temperature values and locations. It was seen that the Balcova region, which was determined as a highly suitable region, had an energy power plant. Moreover, Seferihisar, situated in the southwestern part of the area, was identified as a region of moderate suitability in both of the conducted studies. It is clear that the two existing geothermal power plants are closely aligned with the findings shown in Figure 8 of this paper. Apart from the existing geothermal power plants, the results clearly indicated that the areas in the northwest of Balçova (near the shore) and the eastern section of Seferihisar are enormously well-suited for the establishment of geothermal power plants. On the other hand, there was an actual geothermal power plant in the Dikili region even though there was not any suitable region in that area to the findings. The study also proved that the South and South-west parts of the region were the most suitable areas.

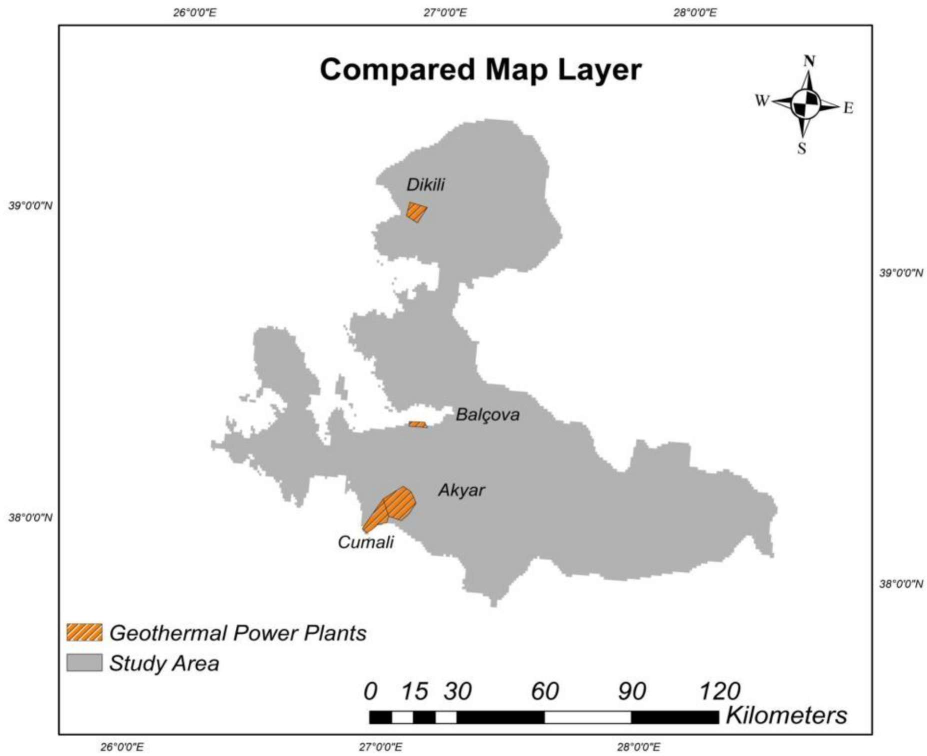

Figure 9. Current geothermal energy power plant in the study area

4. CONCLUSIONS

For any country, it was obvious that possessing and governing a high geothermal energy potential makes the transition from fossil fuels to renewable energies easier. In the present study, a comprehensive framework was performed to determine the suitable sites for the installation of a geothermal power plant under three main criteria by evaluating twelve sub-criteria. So as to calculate the suitability and show the criteria effectiveness for the study area, the combination of GIS-AHP was conducted. For the AHP structure, experts' opinions were ensured. Türkiye could be a leader in geothermal energy with correct and effective new projects. Therefore, the installation of new applications requires a comprehensive feasibility study. This study investigated the İzmir province which had high geothermal energy potential. Based on the results, the presence of fault lines was calculated as the most important criterion while the distance from aviation regions was the slightly unimportant criterion. In addition, the obtained suitability map layer discussed the locations of the existing geothermal power plants in terms of the determined criteria. The study can give important information and may be a vital guideline for energy planners, investors, policymakers, etc. For future studies, the use of geothermal potential for district heating and cooling processes will be discussed. Besides, a social multi criteria decision will be taken into consideration.

Declaration of Ethical Standards

Authors declare that all ethical standards have been complied with.

Declaration of Competing Interest

The authors declare that there are no declarations of interest.

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Data Availability

The all presented data used in the present study is available online.

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