SOLAR PV POWER PLANTS SITE SELECTION USING GSI: A CASE STUDY IN ANKARA

GÜNEŞ ENERJİ SANTRALLERİ İÇİN CBS TABANLI YER SEÇİMİ: ANKARA İLİ ÖRNEĞİ

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ABSTRACT

GIS BASED SOLAR PV POWER PLANTS SITE SELECTİON: A CASE STUDY IN ANKARA

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The rapidly increasing population and developing industry worldwide are increasing the demand for energy every day. The fact that non-renewable energy sources are both limited and harmful to the environment has made it necessary to meet the increasing energy demand from renewable energy sources. The increasing global warming due to the use of fossil fuels may make the world an uninhabitable place. Recently, rising concerns in this direction have led governments to turn to renewable energy policies. Turkey is also a country dependent on foreign energy sources, which not only increases the cost of energy production but also jeopardizes energy supply security. However, Turkey is rich in renewable energy resources due to its advantageous geographical location and favorable climate conditions. Especially, the solar energy potential is quite high. Considering these favorable conditions, investments in solar energy will not only reduce the existing foreign dependency but also minimize environmental damage.

However, investments in solar energy bring along a series of economic, legal, and environmental conditions. It is crucial to accurately evaluate these conditions before investment and to determine suitable criteria by analyzing the areas where Solar Power Plants (SPP) will be established. Although the Solar Energy Potential Atlas of Turkey shows the areas that can benefit the most from solar radiation, this criterion alone is not sufficient for an SPP. Evaluating the suitability of the criteria for the area where the SPP will be established and assessing the area from all aspects will maximize the efficiency obtained from the SPP.

In this study, it is aimed to determine the suitable and unsuitable areas for establishing SPPs within the province of Ankara by using Geographic Information Systems (GIS). The selection of Ankara province as the study area was influenced by its status as the second-largest city in Turkey in terms of population and its high energy demand due to its current production and consumption capacity. Criteria for the selection of the most economically, environmentally, and efficiently suitable locations for establishing SPPs were determined through literature review and expert opinions. The weighting of the determined criteria was done using the Analytic Hierarchy Process (AHP), one of the Multi-Criteria Decision Making (MCDM) methods, with the help of a survey requiring expert opinions. Subsequently, a suitability map showing the suitable areas for SPP site selection in the region was obtained using GIS. According to the analysis of the suitability map for the entire province of Ankara, the results were evaluated as 4.4% not suitable, 15% unsuitable, 36.6% moderately suitable, 42% highly suitable, and 2% very highly suitable. Using the suitability map, 103 SPPs, which were previously identified and digitized using Google Earth, were analyzed and evaluated as 9 very highly suitable, 60 suitable, 33 moderately suitable, and 1 unsuitable.

Keywords: Solar Power Plant, Sitting criteria, AHP, GSI, Ankara

ÖZET

GÜNEŞ ENERJİ SANTRALLERİ İÇİN CBS TABANLI YER SEÇİMİ: ANKARA İLİ ÖRNEĞİ

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Dünyada hızla artan nüfus ve gelişen sanayi, enerjiye olan ihtiyacı her geçen gün daha da artırmaktadır. Yenilenemez enerji kaynaklarının hem sınırlı hem de çevreye zararlı olması, artan enerji ihtiyacının yenilenebilir enerji kaynaklarından karşılanmasını zorunlu hale getirmiştir. Fosil kaynakların kullanımına bağlı olarak artan küresel ısınma, dünyayı yaşanamaz bir yer haline getirebilir. Son zamanlarda bu yönde artan endişeler, hükümetleri yenilenebilir enerji politikalarına yönelmeye teşvik etmektedir. Türkiye de enerji alanında dışa bağımlı bir ülkedir ve bu durum hem enerji üretim maliyetini artırmakta hem de enerji arz güvenliğini tehlikeye atmaktadır. Ancak Türkiye, konumu ve elverişli coğrafyası nedeniyle yenilenebilir enerji kaynakları açısından zengin bir ülkedir. Özellikle güneş enerji potansiyeli oldukça yüksektir. Bu elverişli koşullar göz önüne alındığında, güneş enerjisine yapılacak yatırımlar sadece mevcut dışa bağımlılığı azaltmakla kalmayacak, aynı zamanda çevreye olan zararı da minimum seviyeye indirecektir.

Güneş enerjisine yapılacak yatırımlar ekonomik, yasal ve çevresel koşulları da beraberinde getirmektedir. Bu koşulların yatırım öncesinde doğru değerlendirilmesi ve Güneş Enerji Santrali (GES) kurulacak alanların analiz edilerek uygun kriterlerin belirlenmesi çok önemlidir. Türkiye Güneş Enerji Potansiyeli Atlası'nda güneş radyasyonundan en fazla faydalanabilecek alanlar gösterilse de, bu kriter bir GES için tek başına yeterli değildir. GES kurulacak alanın her açıdan değerlendirilmesi, GES'den alınacak verimi maksimum seviyeye çıkaracaktır.

Bu çalışmada, Ankara ili içerisinde GES kurulacak alanlar için Coğrafi Bilgi Sistemleri (CBS) kullanılarak uygun ve uygun olmayan yerlerin belirlenmesi amaçlanmıştır. Ankara ilinin seçilmesinde, Türkiye'nin ikinci en büyük şehri olması ve yüksek enerji ihtiyacı etkili olmuştur. GES kurulacak alanlar için ekonomik, çevresel ve en fazla verim alınabilecek yer seçimine yönelik kriterler literatür taraması yapılarak ve uzman görüşleri alınarak belirlenmiştir. Belirlenen kriterlerin ağırlıklandırılması, uzman görüşleri yardımıyla Çok Kriterli Karar Verme (ÇKKV) yöntemlerinden Analitik Hiyerarşik Yöntem (AHY) kullanılarak yapılmıştır. Daha sonra ağırlıklı kriterler CBS kullanılarak bölgenin GES yer seçimi için uygun alanları gösterir uygunluk haritası elde edilmiştir. Uygunluk haritasının analizine göre Ankara ilinin tamamı için sonuçlar; %4,4 hiç uygun değil, %15 uygun değil, %36,6 orta uygun, %42 çok uygun ve %2 çok uygun şeklinde değerlendirilmiştir. Uygunluk haritası kullanılarak daha önce Google Earth programı aracılığı ile bulunan ve sayısallaştırılarak çalışmaya eklenen 103 adet GES analiz edilmiş ve bunlardan 9 adet çok uygun, 60 adet uygun, 33 adet orta uygun ve 1 adet uygun değil olarak değerlendirilmiştir.

Anahtar Kelimeler: Güneş Enerji Santrali, Yer Seçimi, AHY, CBS, Ankara

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ABBREVIATIONS

Abbreviations

AHP	Analytic Hierarchy Process
ARCGIS	Geographical Information Systems Software
B.C	Before Christ
CI	Consistency Index
CR	Consistency Ratio
DEM	Digital Elevation Model
DSS	Decision Support System
ELECTRE	Elemination and Choice Expression the Reality
EMRA	Energy Market Regulatory Authority
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
EU	European Union
GIS	Geographical Information Systems
GPS	Global Positioning System
IEA	The International Energy Agency
IRENA	The International Renewable Energy Agency
MCDM	Multi-Criteria Decision Making
MOORA	Multi-Objective Optimization on the basis of Ratio Analysis
NASA	National Aeronautics and Space Administration
OWA	Ordered Weighted Averaging
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PV	Photovoltaic Panel
RESA	Renewable Energy Source Area
SPP	Solar Power Plant

TSMS	Turkish State Meterological Service
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UN	United Nations
USA	United State of America
USD	United States Dollar
UTM	Universal Transverse Mercator
WMO	World Meteorological Organization

1. INTRODUCTION

Energy has constituted a fundamental need of humanity since ancient times. Civilisations have developed, produced, and made progress to the extent that their energy needs were met. In parallel with this, there has been a continuous increase in global demand for energy, which has been accompanied by a growth in the global population. This has resulted in the depletion of the world's existing energy resources and the search for new energy sources. The challenges in meeting the energy demand and the worsening of global warming have made energy a prominent issue worldwide. This situation has prompted numerous countries to convene meetings with the objective of identifying solutions. Developed countries are engaged in significant efforts to overcome the challenges of meeting energy demand and to establish a balance between energy supply and demand [1]. These endeavours are generally oriented towards sustainability and represent significant strides towards ensuring the future of energy in both economic and environmental terms.

Furthermore, innovations and technological advancements in the energy sector also play a significant role in this process. Research and development activities are being conducted with the objective of enhancing the efficiency of energy production, storage, and distribution systems. Such advancements support efforts to find solutions to energy-related issues.

Analyses conducted by the World Energy Forum indicate that if the consumption of fossil energy resources continues at the current rate, these resources will be completely depleted within a century [2]. In addition to being finite, oil, coal, and natural gas, which are at risk of depletion, contribute to air pollution, acid rain, the destruction of forests that provide clean air, and the depletion of our atmosphere.

The necessity to meet the ever-increasing global energy demand necessitates the establishment of new energy production facilities. However, if these facilities are constructed for non-renewable fossil energy sources, the planet could become uninhabitable in the future, with all the negative factors previously mentioned causing irreversible damage to the environment. Therefore, it is of great importance that the new facilities utilise renewable and environmentally friendly energy sources.

In light of the limitations of fossil fuels, including their contribution to environmental damage and their inability to meet future energy demands, there has been a rapid increase in global demand for renewable energy sources. As a result, renewable energy, which is perceived as a significant potential source of energy, has become a subject of growing attention and investment worldwide [3].

Renewable energy sources include solar, wind, geothermal, wave, and biomass energy. Among these, solar and wind energy are the most prevalent and provide the highest energy production. Additionally, solar energy is not harmful to health, has no side effects, and does not produce waste like other sources. Moreover, it is free and can be harnessed in any area that receives sunlight. Furthermore, experts have estimated that the solar energy reaching the Earth is capable of meeting the world's energy needs by a factor of 10.000 [4].

In light of these encouraging developments, there has been a notable surge in interest and investment in renewable energy sources, particularly solar energy, in Türkiye and across the globe in recent years. With the growing investment in solar energy, the question of identifying the most suitable and efficient locations for SPP has become a pressing concern. Prior to determining the most optimal locations for SPPs, it is essential to ascertain whether the investment area has already been identified. In such instances, it is crucial to determine which criteria should be included in the suitability analysis. Subsequently, it is necessary to identify which of the chosen criteria are more important for the specific area in question. In the spatial analysis phase, geographic information systems (GIS) should be used to determine the most suitable and unsuitable locations.

GIS are technological tools frequently used in the site selection process. By utilising GIS technology, it is possible to collect and analyse predetermined criteria within a database. In this regard, during the site selection phase of SPPs, it is possible to determine which region will be more economical and efficient by using many criteria. GIS is widely used not only in the energy sector but also in many different fields. However, in the context of SPPs site selection applications, Multi-Criteria Decision Making (MCDM) methods are also frequently employed in conjunction with GIS to assess and determine the relative importance of criteria. One of the MCDM methods, the Analytic Hierarchy Process (AHP), is a technique used to identify the most optimal solution by ranking criteria according to their relative importance through pairwise comparison matrices in complex problems. A literature review revealed that the AHP method, which is employed in a variety of fields, was the most suitable for this study [5,6,7,8,9,10].

1.1 Aim, Scope and Method of the Study

The demand for electricity in Turkey and globally is increasing at an exponential rate. The required electrical energy is being met by non-renewable energy sources that are detrimental to the environment, such as natural gas, coal, and oil. Our country is among those that predominantly utilise non-renewable energy sources to meet this electricity demand. The 2021 Natural Gas Market Sector Report published by the Energy Market Regulatory Authority (EMRA) in 2022 indicates that the total amount of imported natural gas in 2021 increased by 21.98% compared to 2020, reaching 58,703.93 m^3 [11]. As a country dependent on external sources for oil and natural gas, the shift towards renewable energy sources becomes increasingly important. In addition to sustainability, the transmission of resources such as oil and natural gas is another main reason for this shift. Today, massive investments are being made in the construction of natural gas or oil pipelines, costing millions of dollars, and this situation is unsustainable. Furthermore, meeting the growing energy demand in a way that does not harm nature and people is possible with renewable energy sources. The utilisation of these sources not only mitigates the effects of global warming but also has the potential to significantly meet the electricity demand. Therefore, the deployment of renewable energy sources is of paramount importance, as they are clean and environmentally friendly.

Solar energy is one of the most practical and important renewable energy sources. Given its geographical location, Turkey has a high solar energy potential. Despite the variability in the average sunshine duration across the country, it is approximately 2.741 hours annually [62].
In terms of potential, solar energy is the most promising of the renewable energy sources. The concept of attaining maximum efficiency through the correct site selection is of paramount importance when attempting to harness this inexhaustible resource. The site selection for a SPP, which must be suitable in every respect, is only possible with sufficient and accurate criteria. However, studies have shown that these criteria can vary from region to region. Studies conducted with inadequate criteria fail to achieve the desired efficiency, which in turn hinders the attainment of sufficient levels of profit.

In the literature review, it is seen that many different productions are carried out in different fields and in the world.

Sibel Alumur used a mathematical model for hazardous waste site selection in 2003 and conducted a study to identify suitable areas in the Central Anatolia region [12].

In 2019, İlhan Keser used the Analytic Hierarchy Process (AHP) method for disaster logistics warehouse site selection and identified the most suitable locations in Gaziantep [13].

Ebru Geçici conducted a site selection study in 2021 for hydrogen fuel supply stations that will remain valid for the next 30 years within Istanbul [14].

Rüya Bayar and Bengisu Ödeker investigated suitable locations for vineyard site selection in Denizli in 2021 [5].

In 2011, Muhammed Amer conducted a site selection study for renewable energy sources, including wind, solar, and biomass energy, using the AHP method in Pakistan [15].

In 2021, Hilal İnceyavuz completed a thesis on site selection for malls in Adana city center [6]. In 2023, Fatma Bünyan Ünel conducted a site selection study for an Automatic Meteorological Observation Station in Mersin [7].

Ela Ertunç used the AHP method in 2020 to identify the most suitable locations for airport site selection in Gümüşhane and Bayburt [8].

In 2019, Ahmet Eren Kaşak used the Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) method, one of the MCDM methods, for site selection of a penitentiary institution in Sivas [16].

Besides these studies, there are also different studies available. These include nuclear power plant site selection [17], determining retail market locations in Istanbul [18], train line site selection [19], and sports betting shop site selection [20].

This study identified the necessary and appropriate criteria for the selection of new SPPs. Furthermore, the existing SPPs within Ankara were evaluated according to these criteria. The objective is to provide a guide for future SPPs site selection studies in Ankara and to demonstrate the importance of proper site selection by showing how the evaluated SPPs sites were assessed based on specific criteria. In order to determine the criteria to be evaluated, a review of national and international literature was conducted in order to achieve an accurate and sufficient number of criteria. The following section presents a selection of products related to the location selection and studies carried out in various countries around the world with regard to SPPs.

In a study conducted by H. Ebru Çolak in 2020, site selection studies for Solar Power Plants (SPP) were carried out in Malatya, evaluating multiple criteria to determine the most suitable locations [21].

In 2019, Saman Nadizadeh Shorabeh conducted a study on site selection for Solar Power Plants in the Mazandaran, Kermanshah, Razavi Khorasan, and Yazd provinces of Iran. The study aimed to identify the most suitable locations using the Ordered Weighted Averaging (OWA) method, one of the MCDM methods [22].

Juan M. Sanchez-Lozano conducted a study for Solar Power Plants site selection in the southwest region of Spain. The study used the AHP and TOPSIS methods to determine suitable locations [23].

During the site selection phase, decision-makers strive to identify the most appropriate criteria from among many demanded criteria. In this context, each criterion is considered along with its advantages and constraints. Determining the most suitable location based on the evaluated criteria is possible through the accurate and complete analysis of all data [24].

The process of determining the most suitable land requires evaluating the impacts of each alternative and making the most accurate selection among the considered locations. To achieve the optimal result, the MCDM method is utilized [9].

The MCDM system includes various methods such as the Analytic AHP, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Elemination and Choice Expression the Reality (ELECTRE), and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE). The AHP method is one of the most important methods used by decision-makers to solve complex problems, with its most notable feature being the ability to incorporate both objective and subjective considerations into the decision-making process [25]. For these reasons, the AHP method was preferred in this study.

The Analytic Hierarchy Process (AHP) has been widely used not only in various fields such as education, social, political, and industrial sectors but also frequently in engineering for addressing site selection problems. Examples of its application include:

- Identifying suitable areas for Solar Power Plants in the southern region of Morocco [27]
- Site selection for solid waste in Ethiopia [28]
- Site selection for marble waste disposal areas in Burdur [29]
- A study conducted for rural settlement site selection in Erzincan [30]
- Site selection for shipyards in İskenderun [31]

For these reasons, the AHP method was preferred in this study.

Yassine Charabi conducted a study in Oman using OWA method, one of MCDM methods, to identify suitable areas by integrating data from various sources. In this study, only 0.5% of the country was evaluated as suitable [32].

The studies in the literature demonstrate the applicability of the integration of AHP and GIS in various fields. Some of these include:

In the evaluation of sustainable urban development, AHP and TOPSIS were integrated with GIS [33].

In the mapping of flood hazard areas in the Min River basin in China, a GIS-based AHP analysis was used [34].

In the study determining agricultural suitability areas around urbanization in Pendik, Istanbul [35].

For solving urban water supply problems in the semi-arid provinces of Kermanshah and Hamedan in Iran, the TOPSIS and AHP approaches were preferred using GIS [36].

In creating forest fire susceptibility maps, the integration of MCDM analyses, such as VIKOR and TOPSIS, with GIS was utilized [37].

In the military field, AHP-TOPSIS analysis was performed to ensure the highest level of security and economy in the ammunition distribution network [38].

For the critical issue of nuclear waste storage site selection, studies were conducted in Malaysia [39].

In this study, the optimal site selection criteria for SPPs were first determined. These criteria were then weighted using the AHP, a MCDM analysis. Based on the determined weight distributions, the most suitable locations for SPPs were identified. The Ankara province was selected as the study area due to its expanding and developing industry and rising energy demand, which has been driven by population influx. Consequently, a suitable site selection study was conducted in this region.

During the criteria determination phase, an extensive literature review was conducted, taking into account all the site selection criteria for SPPs that had been established in previous studies. For this study, 17 criteria were selected to best meet current needs. A survey was conducted to determine the weights of the identified criteria. Additionally, 103 existing SPPs in Ankara were evaluated to examine their compliance with the determined site selection criteria. This study aims to provide a scientific guide for decision-makers in identifying suitable areas by encompassing all criteria that could potentially impact both the living and non-living environment. Therefore, it is expected to serve as a roadmap for future SPPs site selection projects.

1.2 Methodology of the Study

In the first part of the study, summary information about the study is provided to inform the reader. Additionally, the literature review analyzes previous studies, discussing what has been done and what kinds of studies have been conducted on the topic.

The second part, which contains the main reason for our study, provides general information about solar energy and its uses, explaining the importance of solar energy. This section is supported by various reports from renowned international organizations. Subsequently, it addresses topics such as energy production in the world and Türkiye, the current status of renewable energy sources, and the use of non-renewable energy sources. At the end of this section, a review of the legislation related to the establishment of SPPs is conducted, covering relevant laws and regulations.

In the third part of the study, the importance of selecting the correct site for SPP establishment is discussed. The potential consequences of incorrect site selection are described, and the variables that influence site selection are examined. Factors affecting site selection are presented within a general framework.

In the fourth part, the basic functions of GIS are briefly explained, and the integration of MCDM methods with GIS is discussed. The types of MCDM methods are described, and the AHP method used in our study is defined. Its application stages and areas of use are explained. Additionally, the use of AHP in our study area is discussed after the criteria determination phase in the sixth section.

The determination of the study area and the criteria to be considered in our study are presented in the fifth section. This section examines the study area's social, economic, commercial, and demographic aspects, considering the changes it has undergone from past to present. In addition to the general characteristics of the study area, an extensive literature review was conducted to identify the criteria used in studies conducted in our country and around the world. This was done to aid in determining the appropriate criteria for the study area. Subsequently, the 103 existing SPPs sites within the Ankara province were digitized and displayed.

In the sixth section, the criteria identified through previous literature reviews and surveys were weighted and ranked for importance using the AHP method applied via a survey. The weighted criteria were then applied to the study area using GIS, with separate evaluations conducted for each criterion. At the end of the evaluations, suitable and unsuitable areas within the Ankara province were displayed on a map. An analysis of the suitability of the previously digitized 103 SPPs was conducted based on this map.

In the final section, the results of the study were evaluated, and insights that may be useful for future investments were presented.

2. GENERAL INFORMATION AND CURRENT STATUS OF SOLAR POWER

2.1 General Information About Solar Power

The sun, a major source of energy that provides heat and light to Earth and many other planets, has been an integral part of human life for centuries. Before the invention of compasses and Global Positioning System (GPS) technology, explorers, sailors, and travelers used the sun to find their direction and determine their location. By calculating the position of the sun and the shadows it cast, they were able to navigate across deserts and oceans. The utilization of the sun has been ongoing since the dawn of humanity. However, using the sun as an energy source dates back to around 400 B.C.

In 218 B.C. the renowned mathematician Archimedes used concave mirrors to focus solar radiation on the Roman fleets besieging the Italian coasts, setting them ablaze to protect Italy from the Roman armies. The astronomer, physicist, and engineer Galileo Galilei paved the way for using the sun as an energy source by discovering the lens in the 1600s. By 1725, French engineer Belidor invented a solar-powered water pump. In the early 1900s, Frank Shuman successfully used solar energy to heat water to the boiling point, producing steam.

Solar energy is a type of radiant energy that results from fusion reactions occurring in the core of the sun. In the sun's core, nuclear fusion reactions produce an immense amount of energy. However, not all of this energy reaches the Earth's surface. As solar radiation reaches the outer surface of the atmosphere, it is absorbed by gases such as water vapor, carbon dioxide, and ozone. Additionally, it must travel vast distances to reach the Earth's surface, reducing the energy amount from approximately 173,104 kilowatts to about 1,395 kilowatts. Consequently, only a very small portion of the energy generated at the sun's core reaches the Earth's surface. However, the amount of energy that does reach the surface is still many times greater than all the energy currently needed and consumed globally. [40].

Today, solar energy is utilized in various fields and in different ways. In 1958, a 1-watt panel was used on the Vanguard I satellite to receive and transmit radio signals. Subsequently, developed photovoltaic technology was used in the Vanguard II, Explorer III, and Sputnik-3 satellites, which were launched into orbit. The National Aeronautics and Space Administration (NASA) launched the Nimbus spacecraft, a meteorological research and development satellite entirely powered by solar panels. In 1966, NASA established the first astronomical observatory in Earth's orbit, powered by a 1-kilowatt solar energy panel [41].

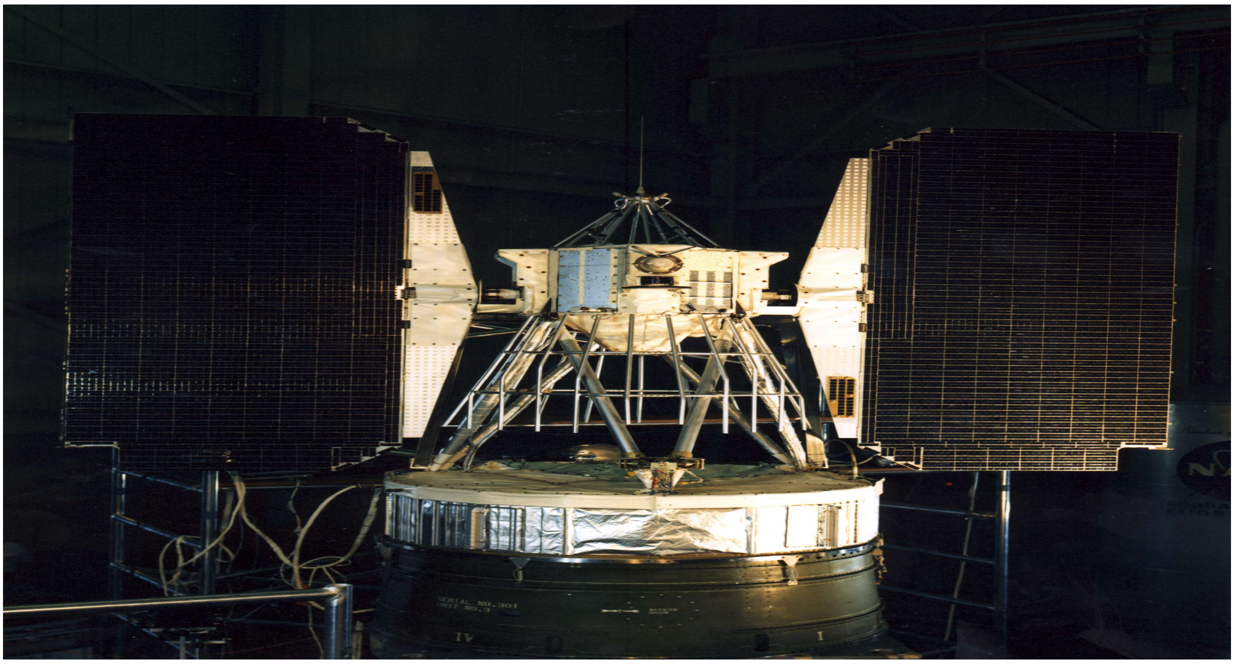

Figure 2.1 Nimbus 1 Space Craft

There are two main types of SPPs used to generate electricity from solar energy. The first type consists of photovoltaic panels (PV), also known as solar panels or photovoltaic cells. PV panels are devices that operate using semiconductor technology and are portable, ergonomic, low-maintenance, easy to use, and aesthetically pleasing. These panels can be used in any application that requires electrical energy. Solar panels are often combined with batteries, inverters, battery charge controllers, and various electronic support circuits to form a solar panel system, depending on the application. These systems offer an economical solution, especially in remote areas without access to the electrical grid, where transporting fuel for generators is difficult and costly [42]. Photovoltaic panels form solar farms, also known as SPPs. This study focuses on SPPs.

2.2 The Importance of Solar Power Plants

In recent years, due to the increasing energy demand, the demand for solar energy has risen, and policies in this direction have begun to be implemented worldwide.

SPPs are clean energy sources that convert sunlight into electrical energy. These plants are of great importance for ensuring the sustainability of global energy consumption. According to a report published by the World Meteorological Organization (WMO) in 2021, the levels of the three main greenhouse gases carbon dioxide, methane, and nitrogen oxide resulting from the consumption of finite resources such as coal, oil, and natural gas to meet the world's energy needs, have reached record levels in the atmosphere [43].

In 2022, the European Union (EU) set a target in its "Fit for 55" package to reduce net greenhouse gas emissions by 55% and increase the share of renewable energy to 40% [44]. From this perspective, SPPs are one of the renewable energy sources directed towards reducing air pollution and combating climate change as an environmentally friendly energy source.

Although the installation cost of SPPs is not low, they are economical because, once constructed, they can operate for many years without any operating costs, have no electricity generation costs, and allow for stable energy prices. Unlike fossil fuels, SPPs generate electricity from sunlight and do not require fuel, making them a low-cost energy source.

SPPs can be constructed in many different locations, including remote areas. According to the 2022 Energy Development Report jointly published by the World Bank, the United Nations, and the International Renewable Energy Agency (IRENA), in 2020, there were 759 million people worldwide without access to electricity [45]. SPPs have the potential to be a game-changer in this situation. This is because they can localize the production and use of electricity, which is traditionally generated at a central location and then distributed, thereby breaking the limitations on the production and usage areas of electrical energy.

Over the past decade, the significant surge in electric vehicles has been paralleled by the growth in charging stations. The increasing number of electric vehicle charging stations, when powered by traditional methods, places a strain on the existing urban electricity distribution grid and affects voltage stability. The primary alternative for powering electric vehicle charging stations is SPPs, and their application is growing day by day [46].

Although global energy policies are shaped by factors such as environmental impact and cost, the employment and export opportunities generated by these policies are also significant. Therefore, the positive impact of investments in renewable energy sources on employment has gained attention recently [47]. According to a report published by IRENA in 2019, solar energy ranks first among renewable energy sources, with an employment capacity of 3.605 million people worldwide [48].

With the developing industry, the demand for energy has increased globally and in our country, bringing the issue of energy independence to the forefront. Considering that Türkiye, with its rapidly developing and growing economy, has limited oil and natural gas reserves and is dependent on foreign sources for energy, energy independence becomes crucial. Energy dependency limits the economic development of countries and compromises the continuity of energy supply. Therefore, it necessitates the adoption of policies aimed at utilizing existing resources [49].

SPPs are one of the best options for harnessing the solar energy potential that our country possesses. By utilizing this potential, Türkiye can ensure its energy security and reduce geopolitical tensions.

In summary, energy derived from solar power offers several significant benefits:

- Reducing dependency on external energy sources and ensuring energy independence,
- Providing opportunities to reduce greenhouse gas emissions and combat climate change,
- Allowing for local installation, unlike centralized electricity storage plants,
- Creating employment opportunities and increasing export shares through requirements for installation, maintenance, repair, and operation,
- Being a renewable, inexhaustible resource, thereby eliminating depletion concerns,
- Contributing to the economy by meeting the needed energy demand,
- Offering long-term use with a lifespan of 20-30 years without requiring heavy maintenance and repairs.

In conclusion, the use of energy derived from solar power is essential to meet the increasing energy demand in cities, transportation, and industry [50].

2.3 World Solar Power Status

With rapidly developing industries and increasing populations, the global energy demand is growing exponentially. All countries worldwide are adopting policies aimed at meeting the rising energy demand through renewable energy sources for a cleaner and more livable world. Investments in renewable energy sources are rapidly increasing to reduce the use of fossil fuels and shift towards sustainable resources.

One of the main reasons for this increase is the Paris Agreement, which came into force on November 4, 2016. This agreement, accepted with the approval of at least 55 parties responsible for 55% of global greenhouse gas emissions, aims to keep the global temperature rise caused by human-induced greenhouse gas emissions well below 2 degrees Celsius above pre-industrial levels in the long term, emphasizing the importance of limiting the increase to 1.5 degrees Celsius [51].

Investments may have been disrupted during the COVID-19 pandemic, but they are now continuing at a rapid pace. Among these investments, solar energy has become the most preferred renewable energy source in recent years due to its decreasing operating costs and ease of installation. Consequently, investments in SPPs are increasing. As shown in Figure 2.2, while the share of fossil fuels in global energy production has been declining since 2015, the proportion of electricity generated from solar energy has risen from 1.1% to 3.7%, and this upward trend continues.

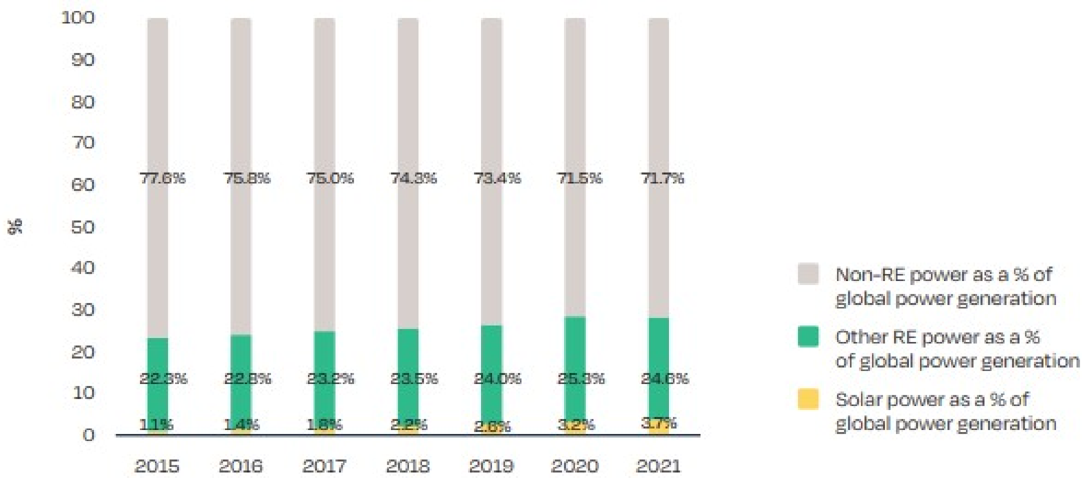

Figure 2.2 Solar and Renewable Power as a Share of Global Power 2015-2021 [54]

According to a report published by the International Energy Agency (IEA) in 2022, investments in solar energy in India and the United States are expected to increase sevenfold, reaching $25 billion during the 2022-2027 period. Additionally, China plans to double its renewable energy sources by 2027 [52].

According to a report published in April 2023 by EMBER, a UK-based think tank, China saw a massive 26% growth in electricity generation from wind and solar energy in 2022 due to its investments. In contrast, the United States, which still generates 60% of its electricity from fossil fuels, experienced a 15% growth in wind energy and a 25% growth in solar energy. India achieved the highest growth rate with a 39% increase in solar energy [53].

In a comparison of investments made by Europe, the Americas, Asia-Pacific countries, China, and Middle Eastern countries, China and the United States are seen to have made the most significant investments. As shown in Figure 2.3, the installed capacity for electricity generation from solar energy worldwide, which was close to 1 gigawatt in the 2000s, has made a substantial leap, reaching 170 gigawatts by 2021, especially in the last decade. [54].

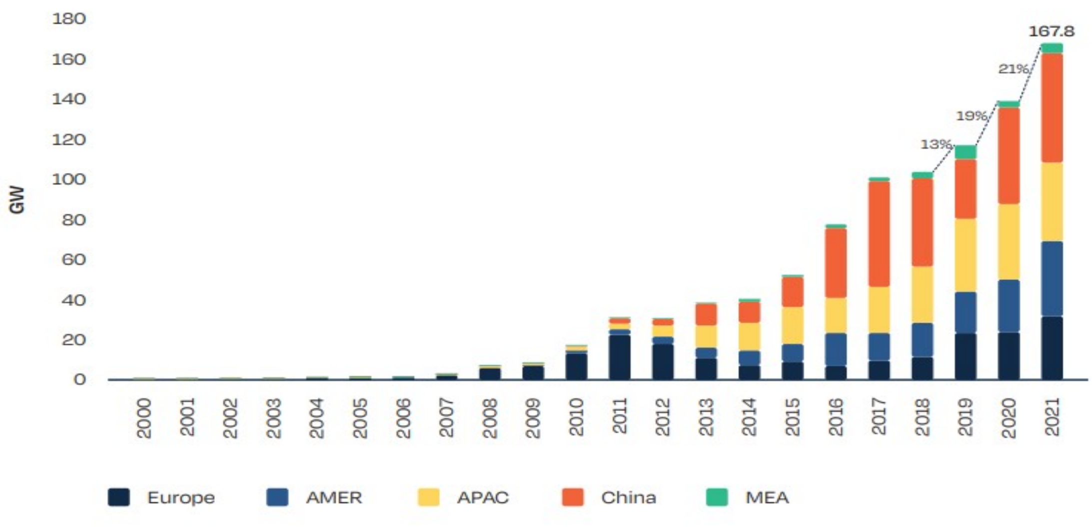

Figure 2.3 Annual Solar PV Installed Capacity 2000-2021 [54]

According to a report published by the IEA, investments in renewable energy sources worldwide reached a record level of $440 billion in 2021, with half of these investments directed towards solar energy [55]. This increase has been significantly influenced by the reduced production costs of solar panels and the development of financial models.
All these investments also contribute to addressing the global employment issue. The number of jobs created by renewable energy sources, particularly solar energy, exceeds 10 million [48].

The increase in solar energy investments highlights the global shift towards clean energy sources. Countries are boosting investments in solar energy to combat global warming, ensure energy security, and benefit from sustainable national energy resources.

The Russia-Ukraine war that emerged in 2022 has brought the issue of energy supply security and the importance of utilizing national and local renewable energy sources back into focus. This situation has accelerated Europe's investments in renewable energy. Figure 2.4 presents a map showing the installed SPPs in Europe. This map illustrates that despite being in northern Europe with relatively low solar energy potential, Germany and the United Kingdom are leading in terms of installed SPPs [56].

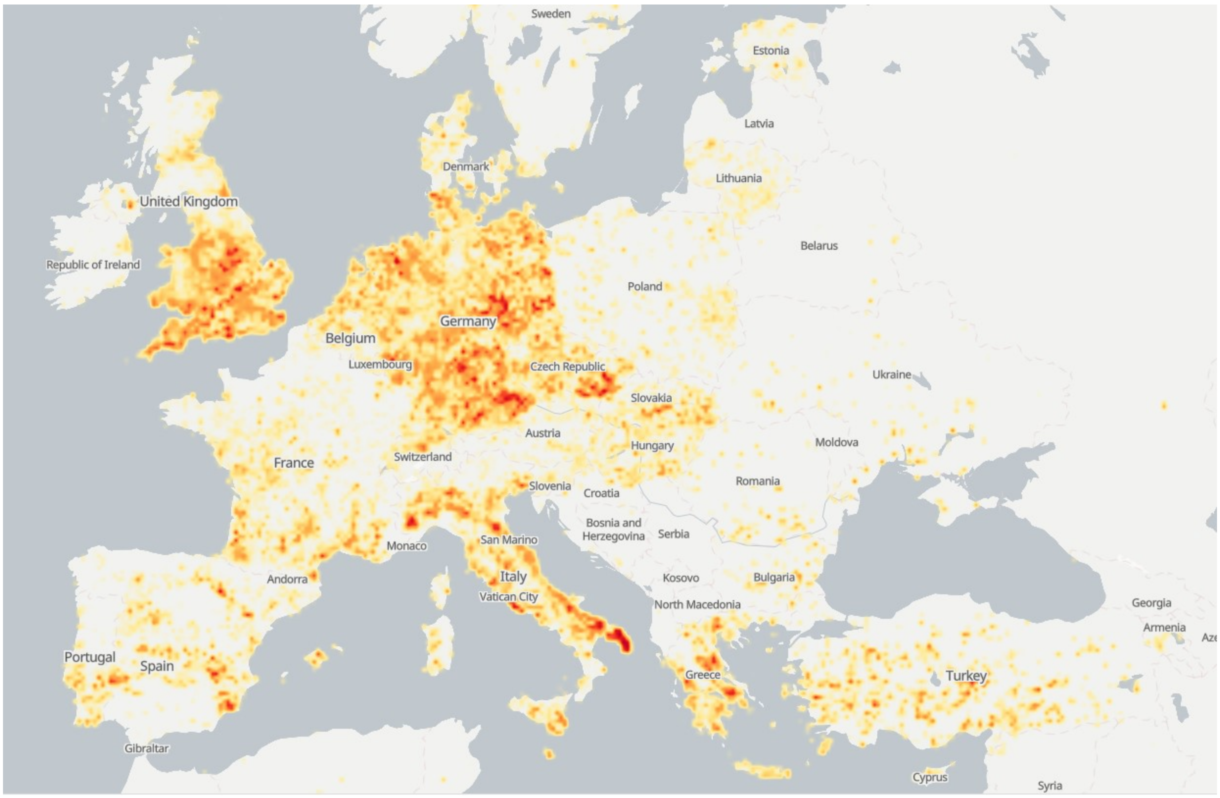

Figure 2.4 Installed Solar Power Plants in Europe and Türkiye [56]

Furthermore, the investments in solar energy by economically strong and highly developed countries around the world indicate that the advantages of SPPs are universally recognized. [57].

2.4 Türkiye Solar Power Status

Türkiye relies on imported energy sources both economically and for energy production. In 2021, 58,703.93 million cubic meters of natural gas were imported, marking a 21.98% increase compared to 2020. The largest share of imports, 44.87%, came from Russia [11]. However, Türkiye has been increasingly turning to domestic resources each year. According to a graphic report published by the Turkish Electricity Transmission Corporation in 2022, the installed capacity from domestic sources increased from 52.9% in 2004 to 64.2% in 2021, representing an 11.3% rise [58].

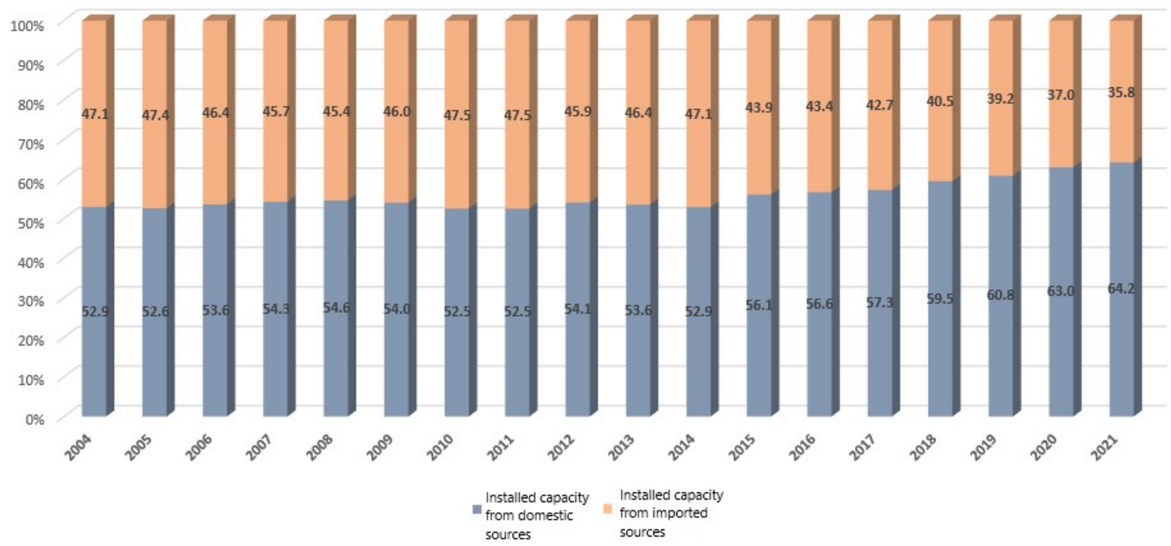

Figure 2.5 Electricity Production Distribution by Sources in Türkiye (2004-2021) [58]

According to the annually published report "Distribution of Installed Power by Primary Energy Sources," the distribution for 2021, shown in Figure 2.6, indicates that renewable sources outweigh non-renewable energy sources [59]. However, a significant portion of these renewable sources is composed of hydroelectric energy, while the shares of solar and wind energy are relatively lower. Nevertheless, to support solar and wind energy, the government provides various incentives and facilitates the legal processes involved.

In this context, significant progress was made by EMRA through regulations for the storage of wind and solar energy. On November 19, 2022, a legal regulation titled "Amendment to the Regulation on Storage Activities in the Electricity Market" was published in the Official Gazette. This regulation supports investments by granting license exemptions for the establishment of storage facilities for wind and solar energy. Following this legal incentive, the investment demand, initially expected to be around 20-25 billion USD, exceeded expectations and reached over 230 billion USD, as witnessed by the EMRA. This development has accelerated investments in renewable energy sources in our country and provided significant economic benefits by creating substantial employment opportunities. This regulation for green energy projects represents a major step towards achieving sustainable development goals. [60].

PRIMARY ENERGY SOURCES	MW	%
IMPORTED COAL	8.840,3	8,86
BITUMINOUS COAL + ASPHALTITE	812,5	0,81
LIGNITE	9.988,7	10,01
LIQUID FUELS	135,4	0,14
BIOMASS ENERGY	4.897,8	4,91
WASTE HEAT	408,3	0,41
NATURAL GAS	21.502,5	21,54
RENEWABLE WASTE	1.642,7	1,65
WIND	10.607,0	10,63
SOLAR	7.815,6	7,83
DAM	23.280,4	23,32
LAKE AND STREAM	8.212,2	8,23
GEOTHERMAL ENERGY	1.676,2	1,68
TOTAL	**99.819,6**	**100**

Figure 2.6 Distribution of Installed Power in Türkiye [59]

Due to its geographical location, Türkiye has a high solar energy potential. The General Directorate of Meteorology uses the HELIOSAT method to calculate the distribution of global solar radiation. The HELIOSAT method, a hybrid model, is based on solving a radiation transfer equation and simple statistical relationships [61].

Using this method, The General Directorate of Meteorology evaluated solar data observed between 2004 and 2021, creating a daily global solar radiation data archive. Validation studies showed that the model predicted radiation data with an error margin of approximately 2-3%. Global solar distribution maps for the relevant time period were created using GIS. Radiation data obtained with the HELIOSAT method at approximately 20 km resolution were interpolated with GIS to produce Türkiye Total Solar Radiation Map at about 1 km resolution, as shown in Figure 2.7 [62].

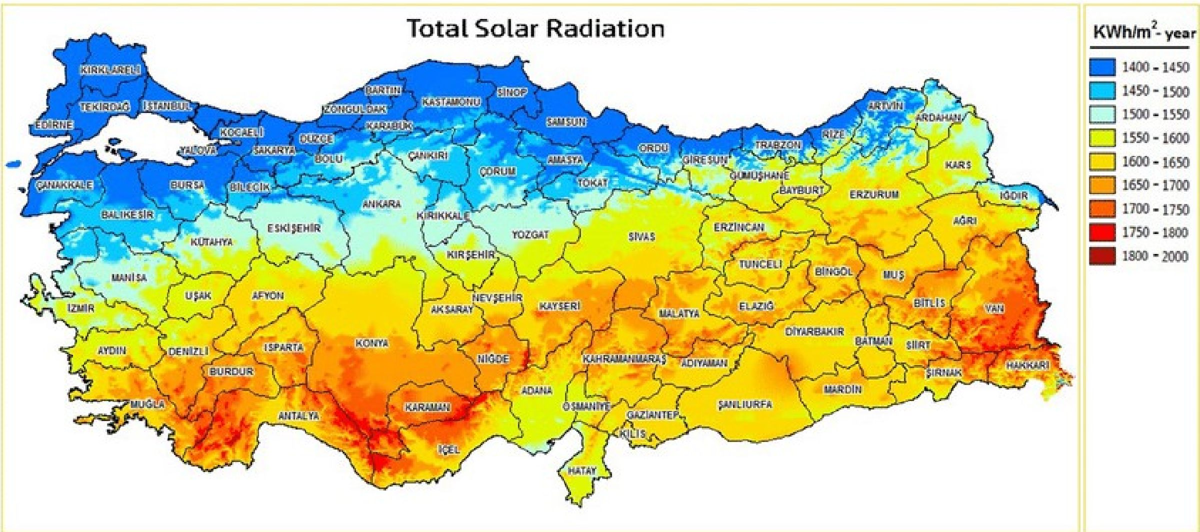

Figure 2.7 Türkiye Total Solar Radiation Map [62]

According to Türkiye Total Solar Radiation Map Türkiye's annual average sunshine duration is 2,741 hours (daily average of 7.5 hours), and the average annual total radiation value is 1,527.46 kWh/m² (daily average of 4.18 kWh/m²/day). Ranking Türkiye's geographical regions based on Türkiye Total Solar Radiation Map, the southern regions receive more solar radiation compared to the northern regions. The Southeastern Anatolia Region, the Mediterranean Region, and the Eastern Anatolia Region rank at the top, while the Central Anatolia Region, the Aegean Region, the Marmara Region, and the Black Sea Region have lower radiation values, placing them at the bottom.

Türkiye's solar energy potential continues to increase the installed capacity of SPPs. In 2021, the share of solar energy in the distribution of installed capacity by primary energy sources was 7.83%, which rose to 8.35% by June 2022. With ongoing investments, the number of unlicensed operational SPPs in Turkey reached 9315, while the number of licensed SPPs was 38. The total installed capacity of SPPs reached 9,425.4 MW [63]. The ever-increasing energy demand places the issue of ensuring the security of electricity and other energy supplies at the top of the government's agenda in Türkiye [21].

To support domestic and renewable energy sources, the Directorate General of Renewable Energy established the Renewable Energy Resource Areas (RESA) Model under the Renewable Energy Resource Areas Regulation, which was published and came into effect on October 9, 2016. The RESA Model aims to reduce the cost of electricity purchased from renewable energy production facilities while also promoting the development of domestic production in renewable energy production [64].

One of the power plants to be established under the YEKA framework is the Karapınar Solar Power Plant in the Karapınar district of Konya. Covering an area of 20 million square meters, it features approximately 3.5 million photovoltaic solar panels capable of preventing 2.5 million tons of carbon emissions, with a capacity of 1000 MW. Karapınar Solar Power Plant is the largest Solar Power Plant in Turkey and Europe (Figure 2.8).

Figure 2.8 Konya Karapınar Solar PV Power Plant

The largest SPP built to date is the Golmud Solar Park in Qinghai province, northwest China [141]. With an installed capacity of 3.3 gigawatts, it prevents approximately 1.4 million tons of carbon dioxide emissions annually.

Figure 2.9 Golmud Solar Park China

2.5 A Legislative Review for Solar Power Plants Site Selection

There are numerous repealed and current laws, regulations, and decrees related to SPPs which are renewable energy sources. Some of these include:

The Electricity Market Licensing Regulation, published on November 2, 2013, in issue 28809 of the Official Gazette. This regulation was last updated on August 23, 2019, in issue 30867 of the Official Gazette. The purpose of this regulation is to establish the procedures and principles related to pre-licensing and licensing applications in the electricity market [65].

The Law on the Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy, numbered 5346 and dated May 10, 2005. The purpose of this law is to promote the use of renewable energy sources for generating electrical energy, to integrate these sources into the economy in a reliable, economical, and high-quality manner, to increase the diversity of energy sources, to reduce greenhouse gas emissions, to utilize waste, to protect the environment, and to develop the manufacturing sector needed to achieve these objectives [66].

Another fundamental law is the Electricity Market Law, numbered 6446 and dated March 14, 2013. The purpose of this law is to establish a financially strong, stable, and transparent electricity market operating under private law provisions in a competitive environment, ensuring that electricity is provided to consumers in a sufficient, high-quality, continuous, low-cost, and environmentally compatible manner. It also aims to ensure independent regulation and supervision within this market [67]. The authority and competence to implement this law belong to the EMRA , a public institution affiliated with the Ministry of Energy and Natural Resources.

The Environmental Law, numbered 2872, dated August 9, 1983, and amended by Law No. 5491 on April 26, 2006. The purpose of this law is to ensure the protection of the environment in line with the principles of sustainable environment and sustainable development. [68].

The Forest Law, numbered 6831 and dated August 31, 1956, imposes restrictions on Solar Power Plants that are to be established or are likely to be established in forest areas. In such cases, public interest must be taken into consideration [69].

Another law that regulates SPP installation areas is the Soil Protection and Land Use Law, numbered 5403 and dated July 3, 2005 [70]. The purpose of this law is to determine the size of agricultural lands, prevent their fragmentation, and establish procedures and principles for the planned use of agricultural lands and sufficient income-generating agricultural lands in accordance with the principle of environmentally prioritized sustainable development.

The Pasture Law, numbered 4342 and dated February 25, 1998, was enacted to identify and allocate pastures, highlands, wintering grounds, and public meadows, as well as to ensure the protection of such areas [71]. This law requires an application for pasture status change for areas where SPPs are to be established on land that no longer retains its pasture quality.

The National Parks Law, numbered 2873 and dated August 9, 1983, includes legal regulations for the selection and protection of national parks and nature parks in our country. Under this law, SPPs cannot be constructed in areas designated as national parks or nature parks [72].

In addition, other laws that include restrictive and regulatory procedures and principles for SPPs include:

- The Industrial Zones Law, numbered 4737
- The Wildlife Conservation Law, numbered 4915
- The Agricultural Reform Law on Land Arrangement in Irrigation Areas, numbered 3083
- The Law on the Improvement of Olive Cultivation and Grafting of Wild Olives, numbered 3573
- The Coastal Law, numbered 3621
- The Military Forbidden Zones and Security Zones Law, numbered 2565
- The Turkish Civil Aviation Law, numbered 2920.

However, it is not only the laws but also the issued regulations that serve as guides during the installation and operation phases of SPPs. Some of these include:

The Regulation on Certification and Support of Renewable Energy Sources, numbered 28782 and dated October 1, 2013. This regulation establishes the procedures and principles regarding the duties and authorities of public legal entities and the rights and responsibilities of real and legal persons, with the aim of promoting electricity generation based on renewable energy sources [73].

The Regulation on Solar Energy-Based Electricity Generation Facilities, which determines and ensures the compliance of equipment used in electricity generation facilities with required standards and oversees the amount of electricity generated by SPPs [74].

The Regulation on the Technical Evaluation of Applications for Solar Energy-Based Electricity Generation, amended in certain articles by the Official Gazette numbered 32076 and dated January 17, 2023 [75].

The Regulation on Unlicensed Electricity Production in the Electricity Market, which came into force with the Official Gazette numbered 30772 and dated May 12, 2019. The purpose of this regulation is to allow consumers to benefit from the nearest electricity generation facility, to integrate small-scale production facilities into the national economy, and to ensure the efficient use of electricity generated from these facilities [76].

3. THE IMPORTANCE OF SOLAR POWER PLANTS SITE SELECTION

Correct site selection is essential for the efficient and effective operation of clean energy sources such as SPPs. Therefore, choosing the right location for SPPs plays a crucial role in their production and operation.

The location of a facility is of paramount importance for the seamless operation of its core functions, including production, distribution, and supply, as well as for providing returns to investors. The future efficiency of the enterprise is largely dependent on the establishment location, as all functions are somewhat reliant on the production site. While it is possible to implement changes within the production site, relocating the facility in the future can result in significant expenses. Moving an operation to a more suitable area would mean writing off previous expenses in one stroke and incurring the same costs again. Additionally, relocating a business to a different region can bring about challenges related to logistics, workforce, and raw material supply, leading to unnecessary expenditures and extra costs. For these reasons, site selection is crucial for the success of the enterprise.

3.1 Factors Affecting Site Selection

Site selection is of great importance for all facilities. The area chosen for the establishment of a business must meet certain conditions. Key considerations include operating costs, infrastructure, transportation, labor, topography, environmental factors, and security. Operating costs can be reduced by taking into account criteria such as land prices and taxes. Additionally, having appropriate infrastructure to support the facility's operations is crucial. Security is also a critical factor; the region must be safe and free from threats of terrorism or attacks, as this is essential for sustainability and return on investment.

Although these are the general factors influencing the site selection of a facility, literature studies have shown that different types of facilities have their own specific criteria.

For example, when selecting a site for a healthcare facility, the criteria to be considered include the population distribution, defined as demographic values, its proximity to public transportation in spatial terms, and its economic feasibility [77].

For instance, when selecting a site for a biogas facility in Sweden, factors such as the proximity to raw material supplies, existing industries, demand areas, and the availability of infrastructure are considered [78].

In Ankara, the site selection for entertainment venues has shown that, in addition to political and legal reasons, urban lifestyles and urban planning are significant factors [79].

For an offshore wind farm, criteria include areas with minimal wave activity and wind speeds of at least 6 m/s, while avoiding special environmental protection zones [80].

In selecting an airport location, factors such as the size of the site, suitable meteorological data, urban development, noise, and bird migration paths are taken into account [81].

For cemetery site selection, criteria such as the distance from dry and wet streams, aspect, and proximity to residential areas are considered [82].

The site selection for SPPs is also of critical importance. Choosing the right location for a SPPs is a demanding process that significantly affects the efficiency and benefits derived from the plant. The site selection process involves several stages, and the chosen location must meet certain natural and artificial conditions suitable for the construction of a SPPs.

For example, if the area where SPP is to be established has an elevation on only one side due to a difference in elevation, this could pose a natural obstacle, but it can be eliminated through excavation. Additionally, if a soil survey report indicates that the ground structure of the proposed SPPs site does not meet the required criteria, soil improvement can be carried out. These are some of the processes that can be undertaken to meet the natural and artificial conditions necessary for the establishment of a SPP.

The Project Development Guide published by the International Finance Corporation, affiliated with the World Bank, emphasizes that site selection for SPPs is a complex and crucial step, critical for the project's implementation and sustainability.

Permits and Planning: This process is typically highly bureaucratic. Applications must be submitted to various central and local authorities, providing documentation that the SPPs sites meet the established standards and limitations. The laws and regulations mentioned in the legislative review for SPPs are applicable at this stage.

Environmental and Social Assessment: To prevent potential future issues, an environmental and social analysis should be conducted before the project begins, and the SPP should be designed accordingly. Otherwise, any problems that arise could increase costs due to time and financial losses.

Engineering, Procurement, and Construction: At this stage, it is important to divide tasks and plan exactly what each unit needs to do during the procurement and construction phases. This stage includes critical areas such as various risks and project management. Sometimes, an engineer with the authority of the plant owner or proprietor can manage this part, but the most reliable method is to contract a company for a turnkey project. A firm specialized in this field will minimize all risks and ensure follow-up from the beginning to the end of the project.

Operation and Maintenance: In this phase, the plant owner or the contractor will regularly conduct maintenance and operations. Regular maintenance, such as cleaning the panels, should be carried out by trained personnel. In case of a malfunction, spare parts and maintenance will be the responsibility of the mentioned company. Additionally, monitoring the plant's performance and ensuring efficiency are among the tasks [83].

3.2 Effects of Wrong Site Selection

Incorrect site selection for SPPs often stems from inadequate criteria or choosing an unsuitable location. Such mistakes can result in significant decreases in efficiency, increased costs, and even project cancellation.

For example, the DESERTEC project, which was planned to be established in the Sahara Desert and would supply electricity to European Union countries via undersea cables, was canceled despite its 400 billion Euro budget. This project aimed to produce 100 GW of electricity and meet almost 20% of Europe's electricity needs by 2050. However, it was canceled before completion. Factors such as insufficient consideration of desert temperature criteria and the production site's distance from Europe played a role. The cancellation of DESERTEC was also influenced by technological developments and the project's multinational nature [84].

In conclusion, incorrect site selection leads to the waste of investor resources, time, and labor.

Figure 3.1 DESERTEC Project [84]

3.3 Effects of Right Site Selection

Selecting the right location for the construction of a SPP is of utmost importance. Proper site selection ensures the efficient use of available resources and increases the profit obtained. The primary reason for correct site selection is the identification of appropriate criteria throughout the process and planning the project based on these criteria.

As the accuracy of the chosen location for a new SPP increases, so does efficiency in economic, environmental, and sustainability terms. This ensures that the investment in the SPP quickly pays for itself and helps prevent potential environmental drawbacks in the future.

With the correct site selection for a SPP

- The construction costs for the SPP are significantly reduced,
- The facility can become profitable in a short time through efficient output,
- Environmental damage is minimized by steadfastly applying environmental criteria,
- The site can accommodate future technological advancements, ensuring upgradability,
- Proper site selection offers attractive opportunities for investors interested in solar energy projects,
- The performance of the SPP can be maximized,
- The electricity needs of areas with limited access can be met by choosing such locations,

- Large-scale SPP projects contribute to the local economy and create employment opportunities.

4. GEOGRAPHIC INFORMATION SYSTEMS AND DECISION SUPPORT SYSTEMS

GIS collects, stores, analyzes, and visualizes complex geographic information that includes human interactions, physical, and natural events. By processing spatial data and integrating it with various systems, GIS provides users with the capability to evaluate and make decisions at critical points. Since one of its core components is geography, the data obtained is typically spatial in nature [85].

The analysis of geographic data and the mapping of the Earth's surface have been conducted by humans for a long time. However, the foundations of modern spatial analysis were laid in 1854 with John Snow's map during the cholera outbreak. Snow's map demonstrated the association of the outbreak with contaminated water sources, highlighting the importance of systematically using geographic information. This event laid the groundwork for the concept of GIS [86].

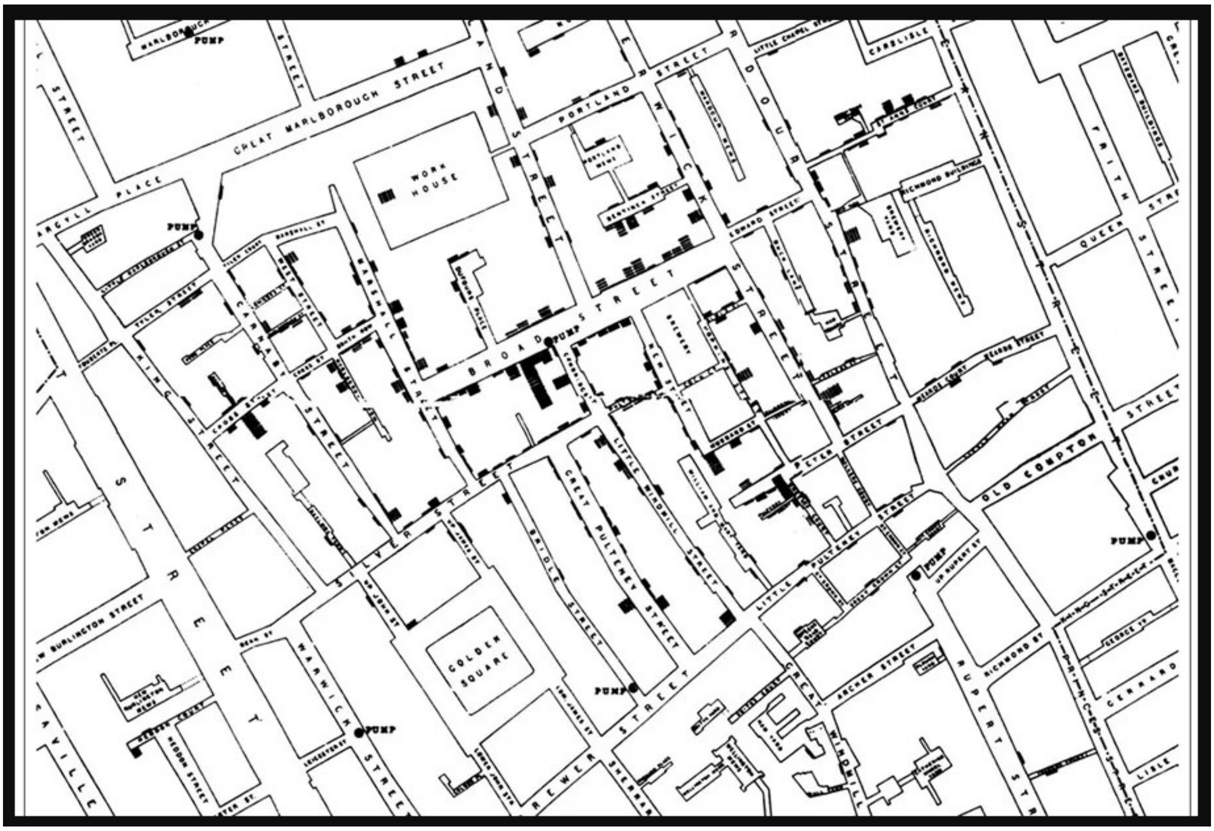

Figure 4.1 Dr. Jon Snow’s Map [86]

The conceptual introduction of GIS into the literature was achieved by Roger Tomlinson in Canada in 1963. GIS efforts increased with government support in the 1970s, and GIS software became widespread in the 1980s and 1990s with the emergence of new systems like ESRI's Arc/Info software. With technological advancements, particularly after 2005, access to data became easier, and the emergence of open-source software further increased the use of GIS [87].

Geographic Information Systems (GIS) are extensively utilized in numerous fields today. To exemplify some of these:

- Using GIS, real estate valuation encompasses the assessment of properties by evaluating their location, environmental characteristics, land use purposes, legal status, and zoning regulations. [88],
- In the Harran Plain of Şanlıurfa, the utilization of geological maps in conjunction with GIS facilitates the determination and modeling of groundwater potential [89],
- In the advertising sector, the evaluation of factors such as population density, traffic conditions, income distribution, city maps, and satellite imagery through GIS aids in deciding whether outdoor advertising billboards should be positioned as billboards, bus stop ads, advertising towers, or megaboards within a city [90],
- In the planning and monitoring phases, combining technology and engineering enables the measurement of the sensitivity of flood events in assessing flood incidents [91],
- In determining the optimal location for wind energy farms [92],
- In basic mining activities such as detecting surface deformations in mining areas, determining mining field boundaries, and conducting risk assessments throughout the process [93],
- n urban infrastructure systems such as drinking water and sewage [94],
- By analyzing traffic accidents, identifying locations where accidents frequently occur, and determining measures to prevent them [95],
- Throughout the supply chain, processes such as procurement, storage, inventory management, and transportation of goods [96],
- Considering social, economic, and environmental factors, conducting a drought risk assessment in Thailand for both existing and potential future occurrences [97],

- In solid waste management, it is used for the transfer of solid waste from consumption sites, its separation, and recycling to prevent environmental damage [98].

GIS can be employed as a flexible component of Decision Support Systems (DSS). DSS assists professionals, scientists, and managers in making informed decisions by integrating technology. It optimises the decision-making process by swiftly and accurately performing tasks such as information gathering, analysis, and reporting [99].

The historical development of DSS commenced in the 1970s, coinciding with the advent of computer technology. This period saw the emergence of a new emphasis on the role of computer technology in facilitating more effective decision-making processes. In the 1980s, the advent of expert systems and document-based systems further emphasised the role of DSSs in enhancing efficiency in decision-making. In the contemporary era, the advent of the internet and technological advancement has led to the proliferation of DSSs in a multitude of novel systems and industries [100].

In the future, DSS will become more robust with the integration of new technologies such as artificial intelligence and machine learning, expanding its impact significantly. These advancements will enable businesses to play a crucial role in innovation and sustainability, aiding in the development of products and services through data analysis and AI algorithms, thereby providing a competitive advantage and supporting faster business growth. Success in the future will be closely associated with businesses' ability to make data-driven decisions and effectively leverage decision support systems [101, 102].

4.1 Basic Functions of Geographic Information Systems

GIS have become an indispensable technology in the modern world. GIS has become a pervasive technology, with applications in a diverse range of fields, including geology, environmental science, urban planning, emergency management, healthcare, real estate, and insurance. Nevertheless, it is widely acknowledged for its capacity to collect, analyse and visualise spatial data on maps. Such data may include geographic location, climate, soil structure, population, and a variety of other factors. GIS enables the comprehension of intricate relationships and the visualisation of spatial patterns through the presentation of geographic data in layered map formats. For example, a dataset may comprise layers including boundaries, addresses, transportation, elevation, and water data. This facilitates the retrieval of desired information from the dataset. The accessibility of data required for a specific concept or analysis can be enhanced, thereby facilitating more detailed and meaningful analyses.

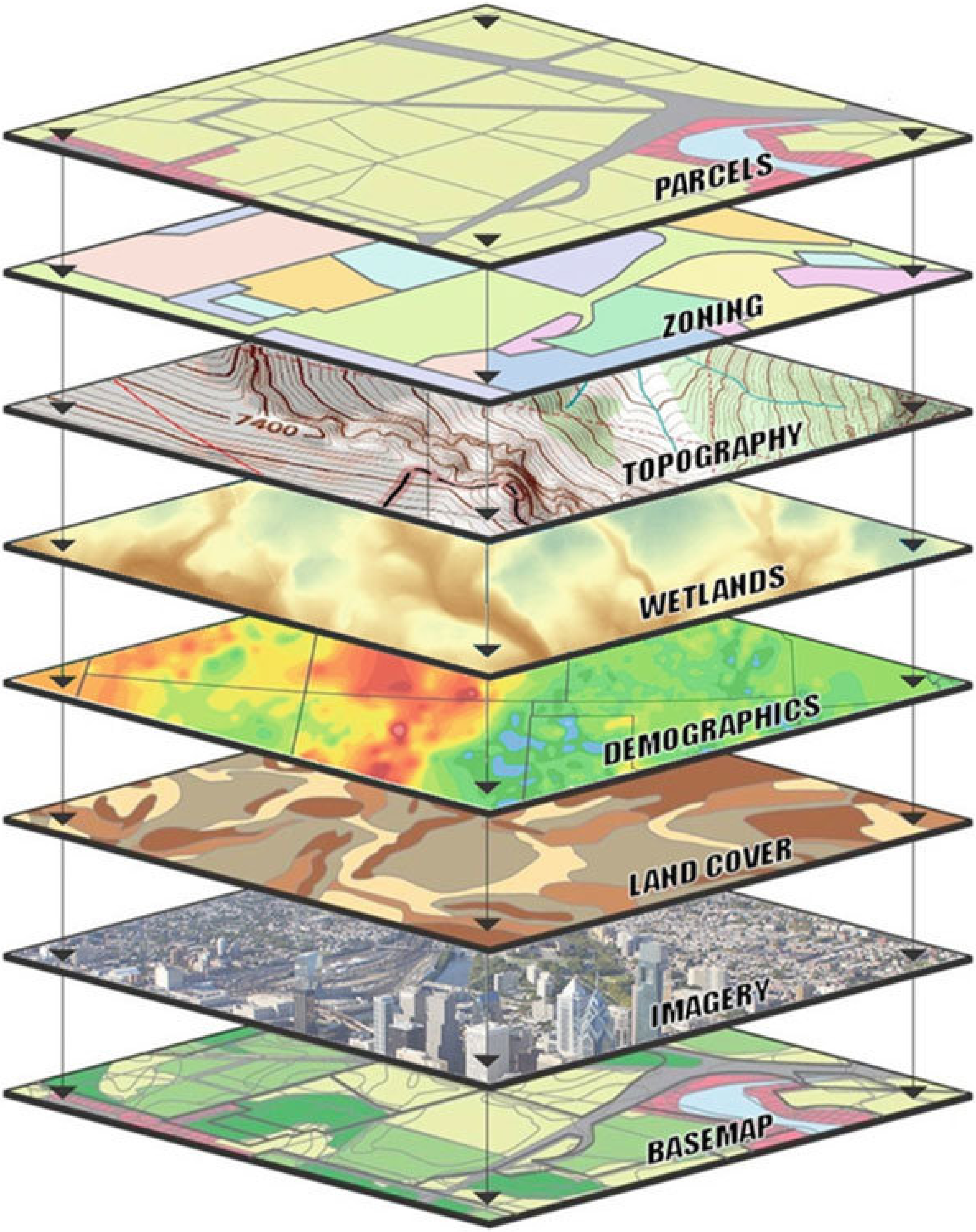

Figure 4.2 GIS Data Layers

The fundamental components of GIS can be grouped under five main headings:

- Software
- Hardware
- People
- Methods
- Data [103].

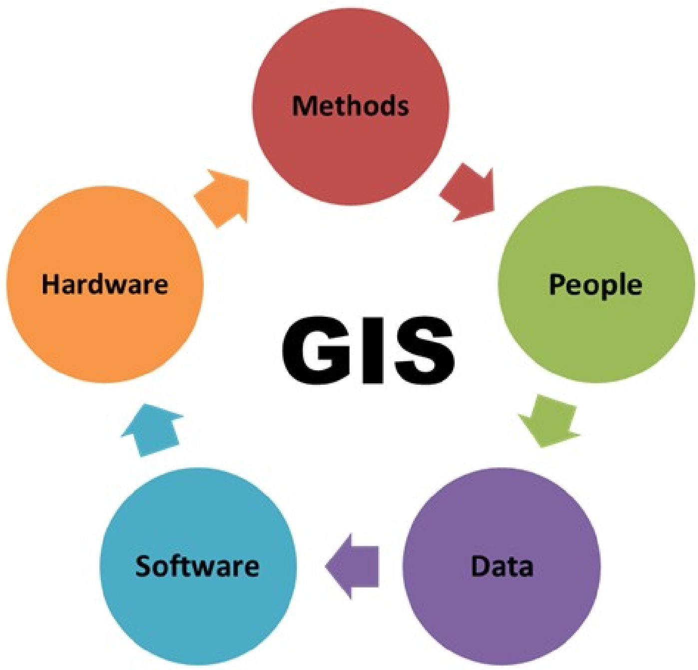

Figure 4.3 Key Components of GIS

Software represents a crucial element in the provision of the functionality associated with GIS. Algorithms, created with the aid of specific programming languages, are employed to analyse, store and visualise geographic information. Such software programs facilitate the effective management of data, the creation of maps, and the performance of analysis. Examples of such software include Arc/Info, ArcView GIS, MapObjects, QGIS, and Microstation Geographics. The principal elements of these software programs can be summarized as follows:

1. Database systems that store all spatial, linear, and attribute data.
2. Interfaces that allow users to interactively perform operations.
3. Input tools that read geographic data and allow input to software.

4. Tools developed for the design, evaluation, or analysis of geographic data entered into the system.

The term hardware encompasses computers, servers, storage devices, printers, plotters, scanners, and digitizers, which are necessary for the processing and storage of GIS data.

In general, people are the individuals who use GIS technologies. Users are required at various stages, including the design of the system and its subsequent use and maintenance. These individuals may be well-versed engineers, technicians, operators, or analysts who are proficient in the effective use and capabilities of GIS, as well as in software usage and database concepts.

A functional and versatile plan and design are essential for the successful implementation of a GIS. While approaches to GIS may vary from individual to individual and between institutions, the fundamental quality is that they facilitate information flow and data analysis. Consequently, the methods to be developed or designed are of vital importance [104].

Data is a fundamental component of GIS. Various types of data are utilised within GIS, including temporal, spatial, and attribute data. Spatial data, also known as geographic data, can be obtained through local measurements, satellite imagery, or laser scanning results. Geographic data refers to data that indicates the location on the surface, and GIS enables the integration of this data with temporal and spatial data.

Spatial data can be stored as raster and vector data. Raster data is represented by pixels, with the pixel size decreasing in precision. Vector data, on the other hand, represents spatial data with points, lines, and polygons. Each of these geometric shapes is stored with location coordinates and other attribute information. Figure 4.4 provides an example of data representation [105].

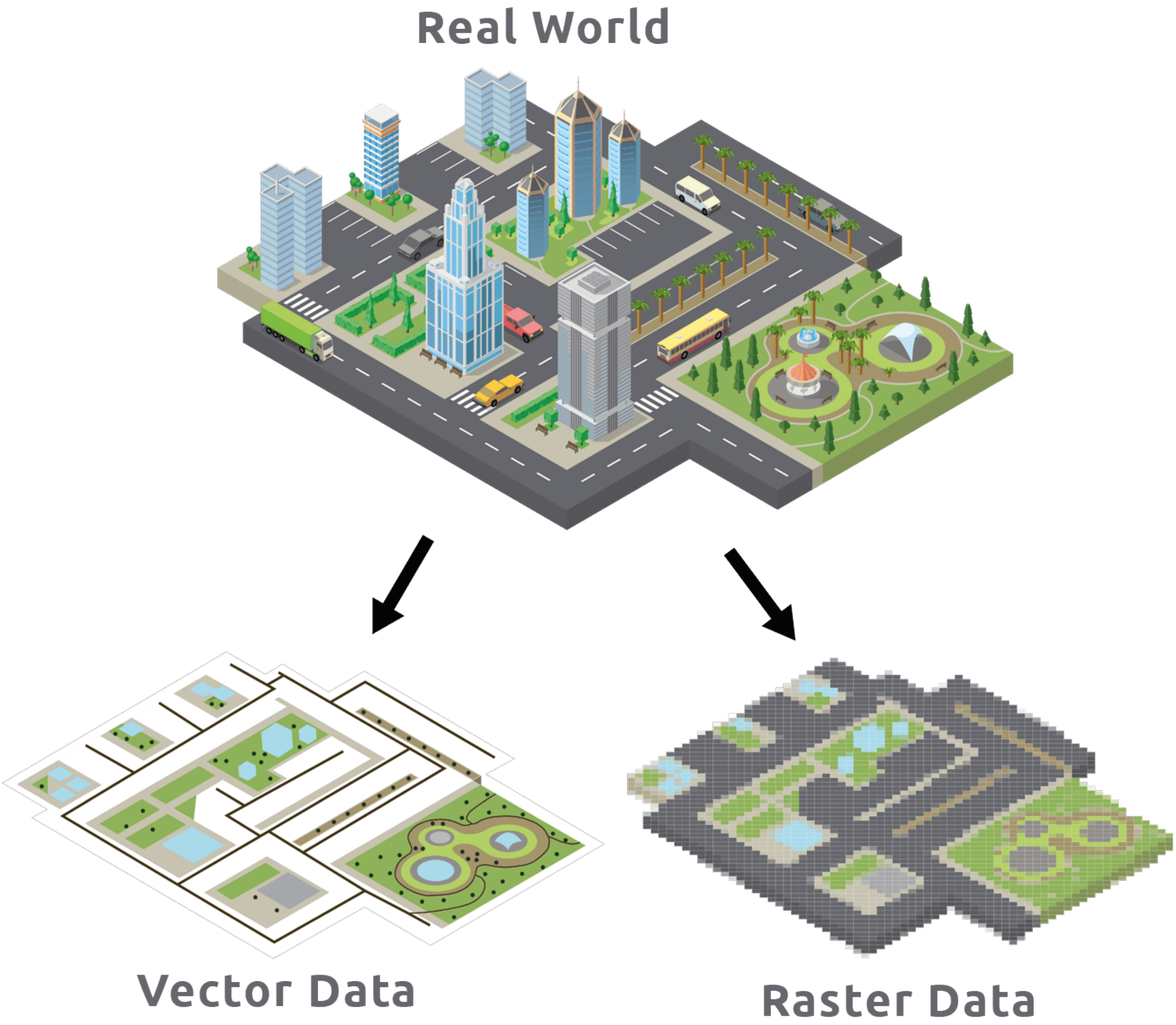

Figure 4.4 Data Representation

4.2 Decision Analysis and Multi-Criteria Decision Making Methods

The process of decision-making can be defined as the examination of the methods employed by decision-makers in order to determine the most appropriate solution. Decision analysis, on the other hand, is the examination of the potential outcomes of different decisions related to a specific problem, with the objective of modelling the problem in order to reach a conclusion through scientific methods. As illustrated in Figure 4.5, decision analysis can be divided into three categories: Single-Criteria Decision Making, Decision Support Systems, and Decision Making with Multi-Criteria [106].

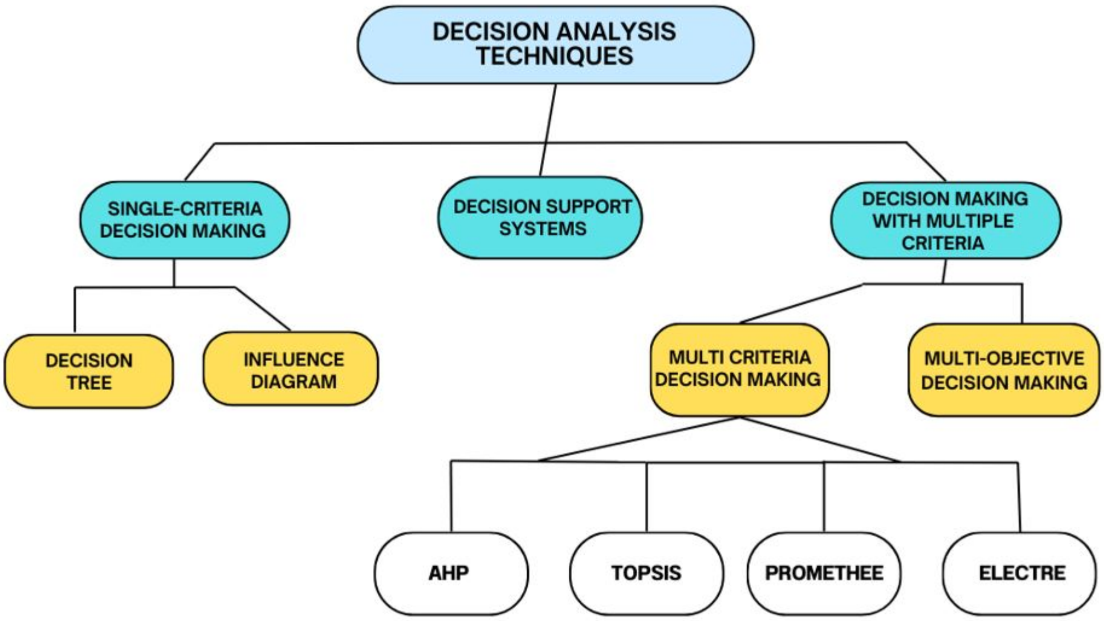

Figure 4.5 Decision Analysis Techniques

The steps to be applied in decision analysis are as follows:

- Define the problem,
- Set objectives,
- Define criteria,
- Analyze the criteria,
- Select the best solution,
- Implement.
- [107].

The most crucial step in executing these steps is determining the appropriate decision-making method. The optimal method can only be selected by choosing a decision-making approach that not only meets the requirements of the problem but also encompasses it. Therefore, it is necessary to conduct a thorough analysis of MCDM methods and determine which one is suitable. MCDM is extensively used as a subset of Decision Analysis among criteria. MCDM is a method that enables the selection of the optimal alternative among multiple and simultaneous criteria. MCDM techniques are tools that present a series of possible alternatives to decision-makers in highly complex scenarios and allow for the simultaneous evaluation and ranking of many conflicting criteria.

The utilization of MCDM methods has significantly increased in recent years. In various fields, these methods have found their place with the support and enhancement of new technologies.

Multi-Criteria Decision Making encompasses many methods, some of which include:

1- AHP
2- Fuzzy Set Theory,
3- Multi Attribute Utility Theory,
4- ELECTRE,
5- PROMETHEE,
6- TOPSIS,
7- Simple Additive Weighting Method

There are many more MCDM methods beyond the ones listed above. However, a survey of studies conducted up to 2015 evaluated the usage rates and frequency of these methods by conducting a survey. As a result, it was revealed that AHP, PROMETHEE, ELECTRE and TOPSIS are the most commonly used methods [108]. Therefore, only these methods are shown in Figure 4.5.

The AHP method has been identified as a highly effective and powerful approach to solving complex problems [15]. In recent years, AHP has been employed with particular frequency in the planning, allocation, and management of renewable and non-renewable energy resources [9]. Consequently, the AHP method has been selected for use in our study.

4.2.1 The Analytic Hierarchy Process (AHP)

AHP is a general theory of measurement. The AHP is employed to generate a scale by means of a comparison of both continuous and discrete variables. The comparison pairs within the analysis can be derived from either actual measurements or abstract measurements reflecting the relative strength of feelings and preferences. AHP is a method that considers the interdependence and consistency between variable groups in order to generate solutions. Its general form allows for the simultaneous consideration of numerous factors, the calculation of consistency and feedback, and the derivation of conclusions through the use of numerical values [109].

In other words, AHP is a decision-making method that provides percentage values at decision points concerning the criteria and factors influencing the decision. This enables the prediction and reaching of a conclusion based on the degree of importance of the factors. It is a method that allows for the comparison of numerical and verbal values based on a decision scale defined before the AHP analysis. This takes into account both the factors influencing the decision and their importance scale, and analyses them through direct comparisons.

The advantages of using AHP include:

- Utilizes hierarchical and proportional scales,
- Provides the opportunity to compare rational factors involving logical thinking, reasoning, and cause-and-effect relationships, qualitative factors based on specific attributes, quantitative factors containing definite values such as cost, quantity, time, and intuitive observations,
- Solves decision problems by including all information containing both objective and subjective criteria in the process,
- Evaluates and compares alternatives as well as criteria,
- Presents decision problems formally, allowing complex and difficult problems to be reduced to a simpler structure,
- Can calculate the accuracy of the comparison made with consistency criteria,
- Can be applied to a single problem or a specific group. [110, 15].

4.2.2 AHP Usage Areas and Application Stages

AHP's success in providing solutions to complex MCDM problems by integrating qualitative and quantitative data has led to its frequent use in energy planning. Its effectiveness in CBS applications has further established AHP as a strong and effective MCDM technique, recognised by international scientific communities [9].

AHP has found its place in various domains. Some of these include determining railway routes [19], airport site selection [8], renewable energy site selection [111,10], sustainable urban planning [33], designing ammunition distribution networks [38], evaluating the suitability of agricultural areas [110], mall location selection [6], assessing structural components for emergency situations during disasters [112] and its use in engineering, education, social, production, industrial, and policy fields [26].

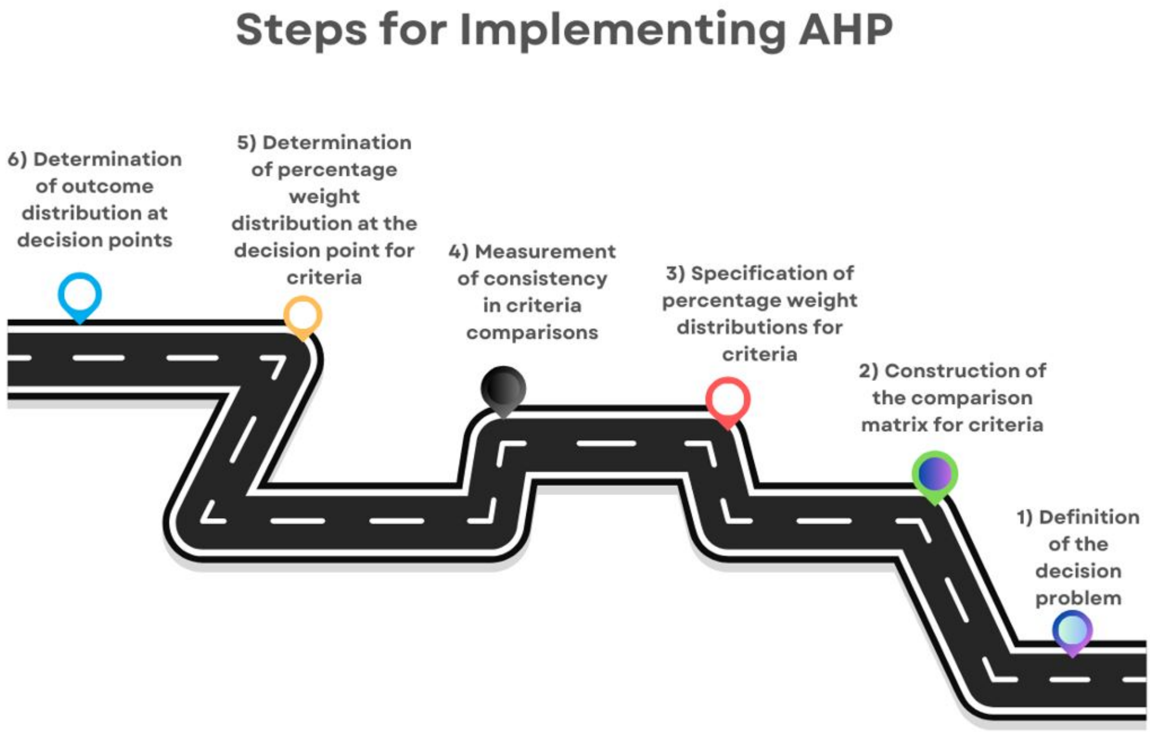

Figure 4.6 Steps for Implementing AHP

The importance levels of factors to be used in AHP are determined through pairwise comparisons using the importance scale developed by Thomas L. Saaty [113].

4.2.3 Usage of AHP in Site Selection

The process of site selection involves the identification of a suitable area based on specific criteria. While these criteria may vary depending on the facility for which the site selection is being conducted, they generally encompass environmental, economic, socio-cultural, political, and technical criteria. Evaluating all these criteria together complicates the site selection process. Site selection is a decision-making problem aimed at selecting the most economical, environmentally friendly, and sustainable location. AHP is widely used in various fields in the literature.

The site selection process commences with the identification of the optimal site within the specified area. Subsequent to this, the criteria that are suitable for the identified area are determined. The potential sites are then ranked according to the importance levels of the identified criteria. The consistency of the comparisons made between the criteria is calculated, and recommendations are made for the most suitable site to complete the process.

5. STUDY AREA

5.1 History of Ankara Province

Although the ancient writers of the first age do not provide precise information regarding the establishment of Ankara province, they do mention legends. The earliest information about the origin of the name Ankara is found in the book Geography Dictionary by the ancient writer Stephanos Byzantinos. The author notes that the city was established by the Galatians and that its original name was in Greek, "Ankypa," and in Latin, "Ancyra." The name "Ankypa" is believed to mean "ship anchor," and it is thought that this name was bestowed upon the Galatians as a victory insignia following a conflict with the Egyptians. The Galatians subsequently named their city after this insignia. The presence of coins minted during that period bearing the figure of a ship anchor serves to corroborate the naming of the city Ankara. Subsequently, the Galatians donated the ship anchor, which had been bestowed upon them as a symbol of victory, to a temple.

Ankara province was the capital of the Tectosages in the Hellenistic period, then the capital of provincial organisations in the Roman period, and in the Ottoman period, it became a kind of centre for Anatolian provinces. The precise date of its foundation is uncertain. Nevertheless, it is postulated that the city was established contemporaneously with the establishment of its settled order, based on the archaeological evidence uncovered in the vicinity. Ankara province has been the site of numerous civilisations, including the Hittites, Phrygians, Lydians, Galatians, Eastern Roman Empire, Anatolian Seljuks, and the Ottoman Empire [114].

Among these, the first known civilization is that of the Hittites. Following the decline of the Hittites in the late 13th century B.C, the Phrygian state began to emerge in Anatolia. Although the precise date is uncertain, it is believed that the Phrygians began to settle around Gordion, which is located in the area around Ankara, in the 9th century BCE. It is also believed that the Phrygian King Midas founded the city of Ankara. Nevertheless, around 690 B.C, Midas was vanquished by the Cimmerians, resulting in a period of decline for the Phrygian state.

Following a brief period of Persian rule, Ankara was definitively captured by the Byzantine Emperor Augustus, who revitalised the city by constructing temples, marketplaces, aqueducts, and roads. Ankara remained under Byzantine rule from 334 to 1071, during which time it served as a significant centre of Christianity for approximately 700 years. Following the Battle of Manzikert in 1071, in which the Byzantines were defeated by Sultan Alp Arslan, the region came under Turkish control.

Ankara experienced its most prosperous period during the reign of Alaeddin Keykubad, the ruler of the Anatolian Seljuk Empire. The city flourished both militarily and economically, with the construction of numerous structures such as mosques and madrasas contributing to its development.

In 1354, the Ottoman Emperor Orhan Bey captured Ankara due to its strategic location on the trade routes from Iran to the Eastern Roman Empire and its position as a strong fortress against the Anatolian Beyliks. Nevertheless, the definitive capture of Ankara occurred during the reign of Sultan Murad I, as a result of a peaceful agreement with the Ahi Brotherhood, without the necessity for warfare [115].

Following the Battle of Ankara in 1402 during the reign of Yıldırım Beyazıd, Ankara was subjected to Mongol invasion. However, the Ottoman Empire demonstrated remarkable resilience and recovered rapidly, reclaiming Ankara within a relatively short period. On 13 October 1923, Ankara was officially designated as the capital of the Republic of Turkey, which was established 16 days later. Prior to its designation as the capital, Ankara, despite its hosting of various civilisations, was a relatively small city. Nevertheless, following the proclamation of the Republic, the city underwent a process of gradual development and transformation, becoming a modern metropolis.

Figure 5.1 Ankara Türkiye-1928 [117]

5.2 General Characteristics of Ankara

The province of Ankara is located in the Central Anatolia Region of Turkey, bordered by Kırşehir and Kırıkkale to the east, Eskişehir to the west, Bolu and Çankırı to the north, and Konya and Aksaray to the south. The area of the province is 26,897 square kilometers, and it is situated at an average elevation of 890 meters above sea level. Ankara is characterized by plains formed by the branches of the Kızılırmak and Sakarya rivers in the northwestern part of Central Anatolia. Positioned between 39° 57' north latitude and 32° 53' east longitude, the northern boundary of Ankara province is delineated by the North Anatolian Mountains, while its southern part features plains such as Tuz Lake, Kepez Plains, and Hacıbekirözü.
Ankara is the second most populous city in Turkey after Istanbul with a population of 5 million 782 thousand 285 people [118].

Ankara province has many lakes and dams. Kesikköprü Dam and Sarıyar Dam are the dams that generate electricity. Apart from these, Çubuk 1 and Çubuk 2 dams, Bayındır dam, Çamlıdere dam are dams used for irrigation. There are also Mogan and Eymir Lakes in Gölbaşı district.

Ankara province has a special place as a location. Located in the middle of Turkey, Ankara is at the center of the transit routes. Ankara, which is a large city with a well-developed transportation network, has opportunities such as highway, airline, railway and high-speed train, which has been developing and spreading rapidly recently.

Ankara's status as the capital makes it a politically, economically and diplomatically important city.

Figure 5.2 Study Area (Ankara, Türkiye)

5.3 Site Selection Criterias for Solar Power Plants According to Previous Studies

In conducting the site selection study, a comprehensive literature review was performed, examining studies conducted both domestically and internationally. As a result of these investigations, it was observed that, as previously mentioned in section 4.2.2, AHP and GIS are frequently utilized in the selection of photovoltaic power plant locations, just as they are in many other fields.

The investigations revealed that different criteria are included in studies conducted in various countries and even in different regions within a single country. Despite these differences, the studies share common criteria.

The differences in criteria and methods among the studies are illustrated in Table 5.1. This table compares 30 different criteria across 20 different studies conducted in various countries and regions around the world.

As a result of this comparison, it was found that the selection criteria for Malatya province in eastern Turkey, as presented in [15], differ from those preferred for Murcia, a city in southern Spain. However, the criteria for Malatya show similarities to those used in the study for Karabük province in [111].

In the study conducted in Andalusia, Spain, cattle paths were included as a restrictive factor [119], whereas this factor is not necessary in many other parts of the world.

For another example, the glacier criterion included in the site selection study in Peru is rarely observed and was not included in any of the other 19 analyzed publications.

Additionally, some investors seeking to invest in solar photovoltaic power plants receive assistance from private companies. These companies utilize criteria related to the usage and marketing of electricity post-production, alongside scientific criteria, for SPPs site selection.

For example, some prominent criteria highlighted in the feasibility report prepared by the Northern Anatolia Development Agency include:

- Incentives related to the sector,
- Supply and demand conditions,
- Market structure and competitive conditions,
- Trends in the sector,
- Sales conditions,

- Sales prices,
- Facility installation capacity,
- Installation costs,
- Operational costs for commissioning the facility [120].

Criterias	References																			
	21	22	24	10	9	122	123	124	119	28	121	125	126	23	127	128	111	129	32	130
Solar Energy Potential	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sunshine Duration		X	X	X		X			X		X					X				
Air Temperature		X	X	X	X				X	X	X			X	X					
Humidity			X	X		X					X									
Elevation			X	X		X					X									X
Slope	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Aspect	X		X	X	X	X			X	X	X	X	X	X	X	X	X			X
Roads	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Major Water Resources	X	X	X		X	X	X	X				X	X		X	X		X	X	X
Land Cover	X	X	X	X	X	X	X			X	X	X			X	X	X	X	X	X
Settlements	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Energy Transmission Line	X		X	X		X	X	X			X	X	X	X	X	X		X	X	X
Transformer Center	X			X	X	X					X			X	X	X	X			
Natural Gas Line	X											X								
Stream							X	X	X		X				X		X			
Fault Line	X	X									X					X	X			
Landslide Sides																				
Mine																X		X		
Precipitation		X		X		X														
World Heritage Sites			X	X	X	X	X	X	X		X	X			X			X		X
Airport			X					X			X	X								
Dust		X		X	X	X					X								X	
Infrastructure				X	X										X					
Military Zones				X	X		X				X				X					
Railway												X			X					
Protected Area			X	X	X	X	X	X				X		X	X			X	X	X
Oil Fields											X									
Cattle trails					X				X						X					
Glaciers and glacial lagoons												X								
Coast					X			X	X						X					X

Table 5.1 Criteria Table from Reviewed Publications

5.4 Criteria to Be Considered in the Site Selection Process

In previous sections, it was mentioned that a set of criteria is necessary for the selection of SPP sites. It was noted that the relevance of certain criteria varies by region, and some criteria are not required in specific countries or areas. In our study, the criteria to be used in the site selection process were determined through surveys and oral interviews with experts, as well as a comprehensive literature review. These criteria:

- Solar Energy Potential
- Air Temperature
- Slope
- Land Cover
- Aspect
- Elevation
- Annual Precipitation
- Proximity to Fault Lines
- Proximity to Settlements
- Proximity to Transformer Centers
- Proximity to Natural Gas Lines
- Proximity to Road
- Proximity to Streams
- Proximity to Railways
- Proximity to Lakes and Dams
- Proximity to Landslide Sites
- Proximity to Energy Transmission Lines

It is possible to add more criteria to the selected 17 criteria; however, some data could not be obtained due to limited data accessibility. For instance, data on military areas were not available. Additionally, the humidity data was not included in the study because it closely overlaps with the annual precipitation criterion.

5.5 Selection of Ankara Province

The primary factor in selecting the province of Ankara as the study area is its significant energy demand due to its industrial, population, and production capacity. As Türkiye's second-largest city and capital, Ankara continually attracts migration, which further increases its energy demand. Obtaining this demanded energy from natural gas, coal, oil, or other non-renewable energy sources poses a risk not only to Ankara but also to our country.

Moreover, the installation of SPPs and the local production of electricity are beneficial for energy supply security. Considering that some amount of electricity is lost during transmission, regional production becomes even more advantageous. For all these reasons, and because despite the establishment of hundreds of SPPs in various districts and regions, a comprehensive study encompassing the entire city has not yet been conducted, Ankara has been selected as the study area.

5.6 Solar Power Plants Located in Ankara Province

Within the province of Ankara, there are numerous SPPs established to meet local energy needs and to market the produced energy. SPPs are generally distributed across the entire province of Ankara rather than being concentrated in specific rural areas.

Through searches conducted using updated satellite images from Google Earth, 103 Solar Power Plants were identified within the province of Ankara. These identified SPPs were marked and recorded on Google Earth. Subsequently, the SPP areas were delineated and digitized. These delineated areas were then converted into .shapefile format using the KML to Shape feature in ArcMAP for use in our study. In the future, these converted areas will be compared with suitable and unsuitable locations on our decision map to verify the accuracy of the existing plants' locations.

The map shown in Figure 5.3 illustrates the SPPs in Ankara. Due to the large area of Ankara and the small scale of the map, the converted areas were not visible. Therefore, each SPPs were made visible in the ArcGIS program by applying a 250-meter buffer around them. As seen in the map, the SPPs are distributed throughout Ankara rather than being clustered in a specific area.

SOLAR POWER PLANTS IN ANKARA

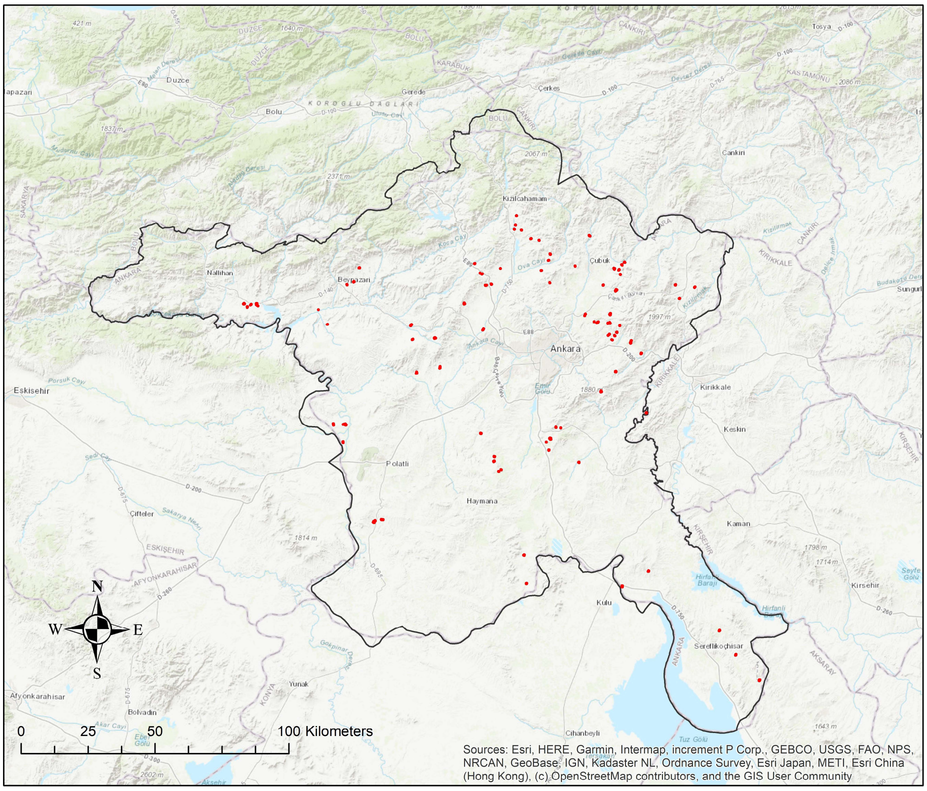

Figure 5.3 Existing Solar Power Plants in Ankara

The 103 SPPs obtained from Google Earth are shown on the Solar Power Plants Map in Figure 5.3. To list the geographical coordinates of the plants on the map, the Netcad program was used. Each plant's coordinates were recorded into an Excel file through the Point Editor and tabulated, as provided in Appendix 2.

6. EVALUATION OF ANKARA PROVINCE IN TERMS OF SITE SELECTION USING GEOGRAPHIC INFORMATION SYSTEMS

In the study conducted to identify suitable areas for the installation of SPPs in the province of Ankara, 17 criteria were considered. Initially, expert opinions were gathered, and publications from around the world and Turkey were analyzed, taking into account the geographical characteristics of the region. Subsequently, to determine the importance of these criteria, surveys were conducted with experts, engineers working in relevant units of the Ministry of Energy, and academics.

The weight values of the criteria identified from the surveys were determined using AHP and weights were assigned to each criterion. Using these weights, maps were created to identify suitable areas for each criterion. This method provides a scientific basis for determining the most suitable areas for SPPs installation in the province of Ankara.

6.1 Analysis with AHP in the Study Area

Site selection can be considered a complex problem influenced by multiple criteria that affect the outcome of preferences. Such multi-criteria decision analysis problems aim to determine the most suitable option by evaluating the relationships and priorities among the specified criteria. Various methods are available to solve these problems; however, in this study, an analysis was conducted specifically using the AHP.

AHP generally revolves around the comparison of criteria. Through these comparisons, the importance levels of the criteria are determined and weighted [24]. Each criterion is evaluated concerning its relationship with the others, resulting in a ranking of importance. These weighted criteria allow for more accurate application of factors affecting the site selection decision. AHP relies on pairwise comparisons, enabling the measurement of each criterion's impact and assisting in objective evaluation for important decisions like site selection.

Surveys used in decision analyses conducted with the AHP must contain consistent and reliable responses for the evaluation of criteria. This consistency means that the responses given by the survey participants should be coherent within themselves. Therefore, the consistency ratio (CR) of surveys prepared in accordance with AHP should be checked. CR is a method introduced by Thomas Saaty to calculate the consistency of judgments in pairwise comparisons [131].

To calculate the consistency ratio of the surveys conducted to determine the weights of the criteria, the open-source AHP Calculator program was used [132]. According to Saaty, the consistency ratio should be less than 10%. If the CR exceeds 10%, the comparison matrix should either be reconstructed or excluded from the study [111]. Therefore, only the surveys with a CR below 10% were included in our study. Two surveys that did not meet this criterion were excluded from the evaluation. Subsequently, the merging process was carried out to combine the 10 surveys that passed the consistency check into a single survey for use in AHP.

When calculating the decision matrices for the surveys that passed the CR, the averages of the pairwise comparisons from all surveys should be taken to reach a single result. However, when using the AHP method, using the arithmetic mean can lead to inaccurate results. Therefore, the geometric mean of the pairwise comparisons should be taken to reach a single result. The elements in the comparison matrices are reciprocals of each other, which is why the geometric mean is preferred over the arithmetic mean. [133].

The geometric means of the 10 surveys that passed the CR check and were included in our study were calculated to combine them into a single survey. This process was performed using Excel (Figure 6.1).

	Geometric Mean	Rounded Value	
Proximity to Settlements	0,316	3,2	Proximity to Streams
Proximity to Settlements	0,319	3,1	Proximity to Railway
Proximity to Settlements	0,23	4,4	Proximity to Lakes and Dams
Proximity to Settlements	4,229	4,2	Proximity to Landslide Sites
Proximity to Settlements	6,236	6,2	Proximity to Energy Transmission Line
Proximity to Transformer Center	0,19	5,3	Proximity to Natural Gas Line
Proximity to Transformer Center	0,229	4,4	Proximity to Road
Proximity to Transformer Center	0,171	5,8	Proximity to Streams
Proximity to Transformer Center	0,2	5	Proximity to Railway
Proximity to Transformer Center	0,165	6,1	Proximity to Lakes and Dams
Proximity to Transformer Center	1	1	Proximity to Landslide Sites
Proximity to Transformer Center	2,783	2,8	Proximity to Energy Transmission Line
Proximity to Natural Gas Line	2,34	2,3	Proximity to Road
Proximity to Natural Gas Line	1	1	Proximity to Streams
Proximity to Natural Gas Line	1,565	1,6	Proximity to Railway
Proximity to Natural Gas Line	1,414	1,4	Proximity to Lakes and Dams
Proximity to Natural Gas Line	5,566	5,6	Proximity to Landslide Sites

Figure 6.1 Geometric Mean Calculation Result

As seen in Figure 6.1, the geometric means of the survey results used in our study were calculated, resulting in values ranging between 0-1 and 2-9. The values between 0-1 obtained from the geometric mean calculation need to be converted to values between 2-9. This conversion was performed using the transformation (1/geometric mean result), and the resulting values were shown on the left side of the table along with the values that fall between 2-9. The survey values combined by geometric averaging were entered into the AHP Calculator program to calculate the weights of the criteria based on their importance levels. From the 136 pairwise comparisons made by the program, the comparison matrix shown below was obtained (Figure 6.2).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	4.00	3.00	7.00	3.00	6.00	5.00	5.00	6.00	4.00	8.00	6.00	8.00	8.00	8.00	4.00	3.00
2	0.25	1	1.00	2.00	0.50	2.00	3.00	2.00	5.00	1.00	4.00	3.00	2.00	6.00	7.00	1.00	0.50
3	0.33	1.00	1	3.00	0.50	2.00	4.00	4.00	6.00	4.00	7.00	5.00	7.00	7.00	7.00	2.00	1.00
4	0.14	0.50	0.33	1	0.25	1.00	1.00	1.00	3.00	0.50	4.00	4.00	5.00	7.00	6.00	0.50	1.00
5	0.33	2.00	2.00	4.00	1	4.00	5.00	3.00	4.00	2.00	2.00	6.00	6.00	6.00	7.00	1.00	0.50
6	0.17	0.50	0.50	1.00	0.25	1	1.00	1.00	2.00	0.50	4.00	2.00	4.00	4.00	4.00	0.50	0.50
7	0.20	0.33	0.25	1.00	0.20	1.00	1	1.00	2.00	0.50	4.00	3.00	5.00	5.00	6.00	0.50	0.50
8	0.20	0.50	0.25	1.00	0.33	1.00	1.00	1	2.00	1.00	6.00	3.00	5.00	7.00	7.00	1.00	0.50
9	0.17	0.20	0.17	0.33	0.25	0.50	0.50	0.50	1	0.33	2.00	1.00	3.00	3.00	4.00	0.25	0.17
10	0.25	1.00	0.25	2.00	0.50	2.00	2.00	1.00	3.00	1	5.00	4.00	6.00	5.00	6.00	1.00	0.33
11	0.12	0.25	0.14	0.25	0.50	0.25	0.25	0.17	0.50	0.20	1	0.50	1.00	0.50	1.00	0.17	0.14
12	0.17	0.33	0.20	0.25	0.17	0.50	0.33	0.33	1.00	0.25	2.00	1	3.00	3.00	4.00	0.33	0.25
13	0.12	0.50	0.14	0.20	0.17	0.25	0.20	0.20	0.33	0.17	1.00	0.33	1	1.00	1.00	0.17	0.12
14	0.12	0.17	0.14	0.14	0.17	0.25	0.20	0.14	0.33	0.20	2.00	0.33	1.00	1	1.00	0.17	0.14
15	0.12	0.14	0.14	0.17	0.14	0.25	0.17	0.14	0.25	0.17	1.00	0.25	1.00	1.00	1	0.17	0.12
16	0.25	1.00	0.50	2.00	1.00	2.00	2.00	1.00	4.00	1.00	6.00	3.00	6.00	6.00	6.00	1	0.50
17	0.33	2.00	1.00	1.00	2.00	2.00	2.00	2.00	6.00	3.00	7.00	4.00	8.00	7.00	8.00	2.00	1

Number of comparisons = 136

Consistency Ratio CR = 4.9%

Principal eigen value = 18.251

Eigenvector solution: 6 iterations, delta = 6.7E-9

Figure 6.2 The Pairwise Comparisons Matrix and Consistency Ratio of AHP

The comparison matrix was found to meet the CR requirement, and the weights determining the importance of the criteria were calculated (Figure 6.3).

Cat		Priority	Rank	(+)	(-)
1	Solar Energy Potential	20.2%	1	8.3%	8.3%
2	Air Temperature	7.0%	5	2.5%	2.5%
3	Slope	10.9%	2	4.8%	4.8%
4	Land Cover	5.0%	9	2.1%	2.1%
5	Aspect	10.9%	3	5.4%	5.4%
6	Elevation	4.1%	11	0.8%	0.8%
7	Annual Precipitation	4.2%	10	1.4%	1.4%
8	Proximity to Fault Line	5.1%	8	1.6%	1.6%
9	Proximity to Settlements	2.3%	12	0.8%	0.8%
10	Proximity to Transformer Center	6.1%	7	1.8%	1.8%
11	Proximity to Natural Gas Line	1.4%	14	1.0%	1.0%
12	Proximity to Road	2.3%	13	0.8%	0.8%
13	Proximity to Stream	1.3%	15	0.7%	0.7%
14	Proximity to Railway	1.2%	16	0.6%	0.6%
15	Proximity to Lakes and Dams	1.1%	17	0.4%	0.4%
16	Proximity to Landslide Sides	6.8%	6	1.6%	1.6%
17	Proximity to Energy Transmission Line	10.3%	4	3.9%	3.9%

Figure 6.3 The weight of criteria according to AHP

6.2 Data

6.2.1 Solar Energy Potential

Solar energy potential is a crucial factor as it directly affects the amount and efficiency of energy that can be obtained from SPPs. Therefore, before considering any other criteria, the solar energy potential of the areas where SPPs will be established is calculated. If the solar energy potential is low, the expected return on investment will also be proportionally low, and thus, that region will not be preferred [24].

Despite Türkiye's advantageous position in terms of solar energy potential, a realistic and detailed study must be conducted to accurately assess the solar energy potential in the region. This is important because there is a significant difference in solar energy potential between the northern and southern borders of our country. To obtain the solar energy potential map for Ankara province used in our study, Digital Elevation Model (DEM) data with a resolution of 30 meters was utilized. These data were downloaded from open sources, and accuracy checks were performed before they were subjected to analyses to create our solar energy potential map [134].

The solar radiation tool in ArcGIS software was used to obtain the solar energy potential map within the boundaries of Ankara province [135], and the map shown in Figure 6.4 was produced. As indicated in the map, the northern parts of Ankara province have low solar potential, while the southern tip has a high potential.

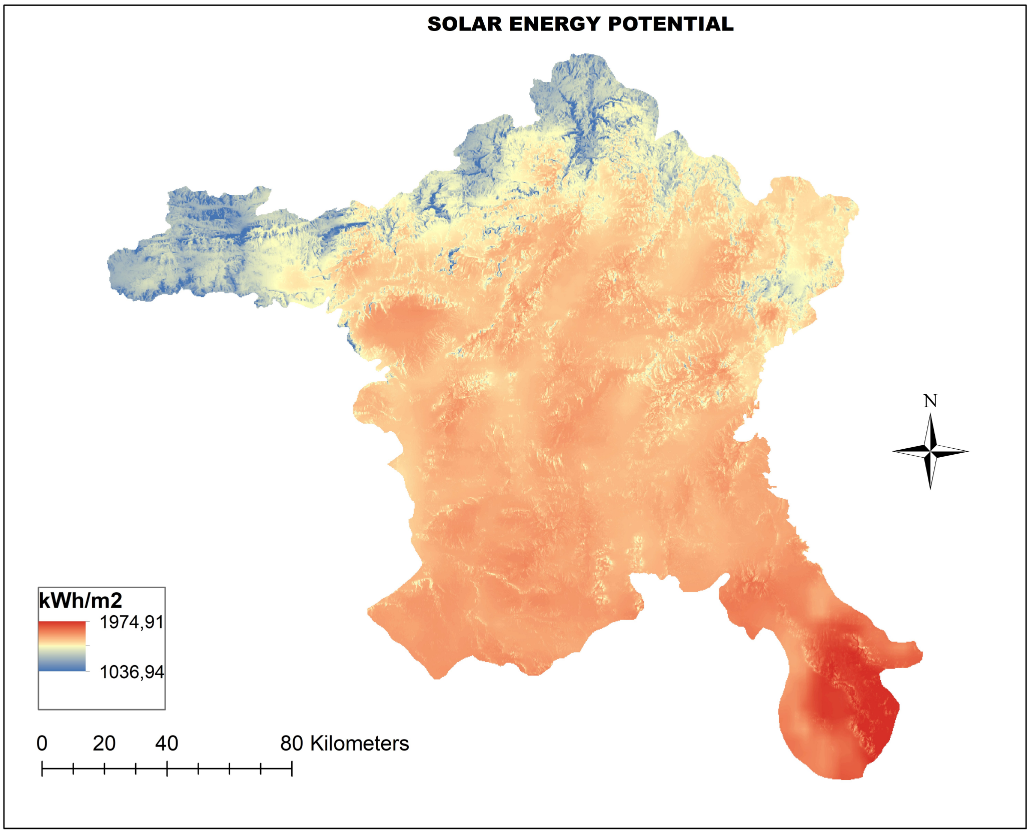

Figure 6.4 Solar Energy Potential Map of Ankara Province

6.2.2 Transformer Centres

The distance of the area where a SPP will be established to the transformer station is another crucial factor to consider. The transmission of electricity generated at an SPP becomes more challenging and costly as the distance to the transformer station increases. Moreover, the energy loss during transmission to a distant location can be a disadvantage for the SPP [21].

For these reasons, the SPP to be constructed should be close to a transformer station. There are 43 transformer stations within the province of Ankara. These stations were downloaded from open-source data, and after accuracy verification, they were included in our study and shown in Figure 6.5 [140].

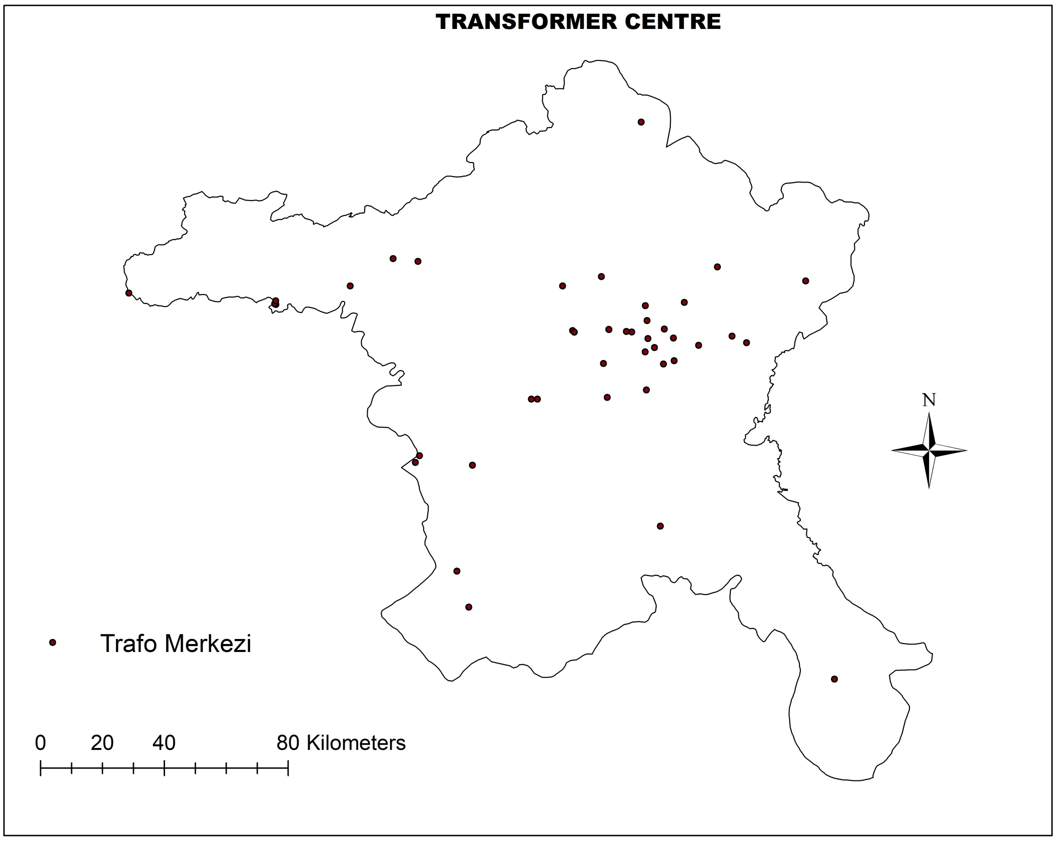

Figure 6.5 Transformer Center Map of Ankara Province

6.2.3 Energy Transmission Lines

The electricity generated at a SPP is transmitted to transformer stations via power transmission lines, from where it is distributed to users. Similar to the distance to transformer stations, the distance to power transmission lines is also a disadvantage for the SPP. If the facility is located far from these lines, the number of poles and lines needed to transmit the energy from the solar panels to the transformer stations increases, resulting in additional financial costs.

Moreover, energy loss during transmission is another negative factor if the distance is significant. If the facility is close to energy transmission lines, the environmental impact of the newly constructed transmission lines is minimized. Additionally, the cost of installing new lines is reduced, and power loss during transmission is minimized. Therefore, the distance of the SPP site to power transmission lines is an important factor to consider [9].

The energy transmission lines within the province of Ankara are shown in Figure 6.6.

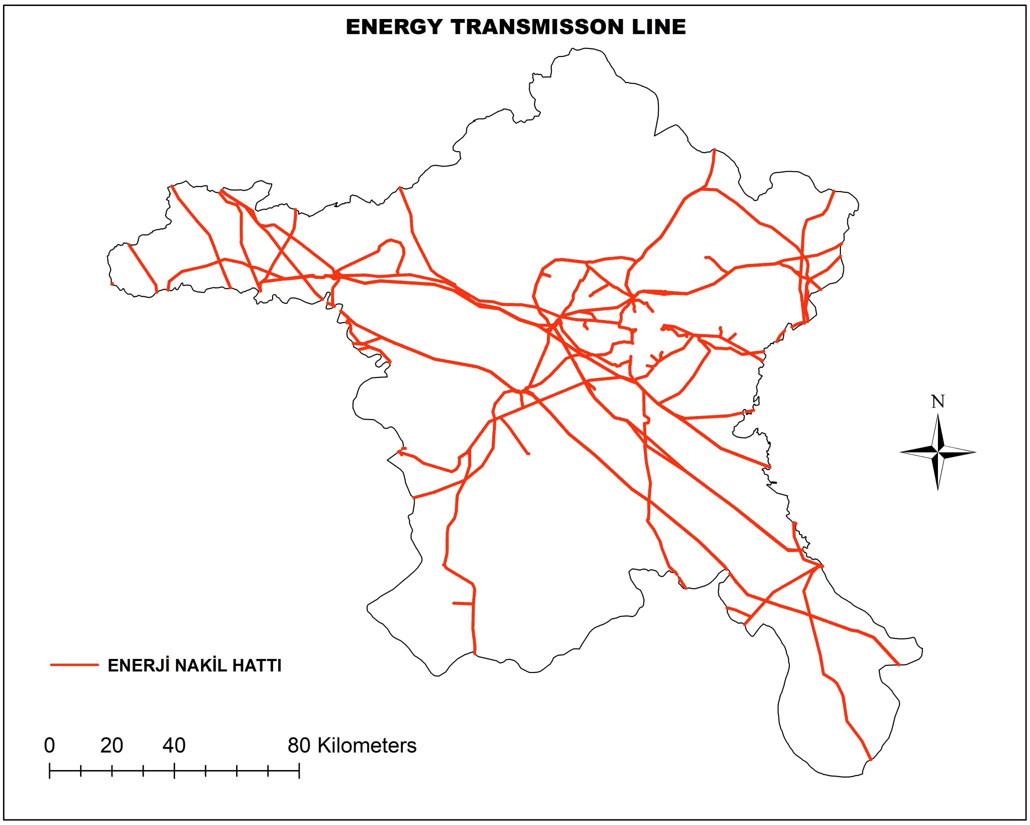

Figure 6.6 Energy Transmission Line Map of Ankara Province

6.2.4 Slope

A steep and rugged terrain increases the cost of establishing a SPP. If the land slope is too steep, the available area for the SPP will be reduced, necessitating excavation and filling operations. Consequently, as the slope increases, so does the cost of installing the SPP. Additionally, high-slope areas will experience shading at different times of the day, which is another factor that reduces efficiency. In summary, an increased land slope results in time, money, and labor losses for the construction of the SPP [121].

To obtain the slope map of the province of Ankara used in our study, DEM data with a resolution of 30 meters were utilized. These data were downloaded from open sources, verified for accuracy, and included in our study [134].

Using the downloaded DEM data, a slope analysis was performed in ArcMap, a module of ArcGIS, to create the Slope Map of Ankara Province (Figure 6.7).

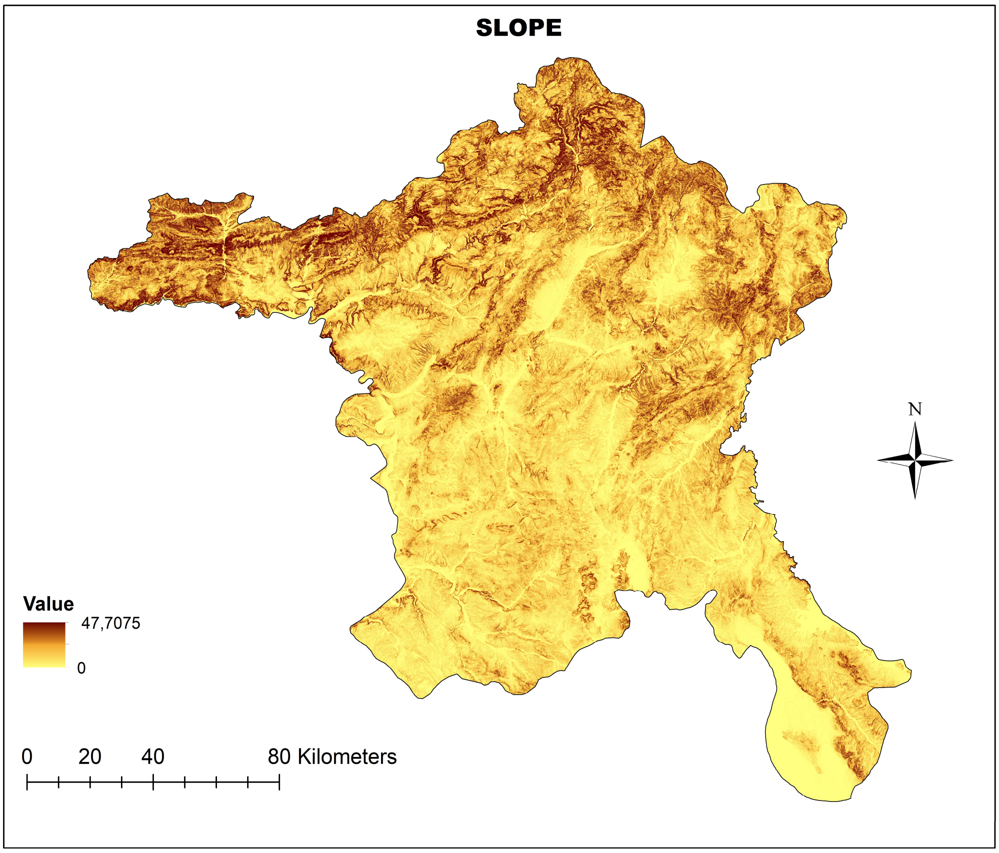

Figure 6.7 Slope Map of Ankara Province

6.2.5 Aspect

The aspect factor is significant due to the rugged terrain of our country. Since Türkiye is located in the northern hemisphere, the solar rays, which are converted into electricity, generally come from the south. Therefore, shadows usually extend towards the north. In areas with significant shading, efficiency will decrease, so considering the aspect factor, it is more appropriate to orient SPP panels towards the south, southeast, and southwest. To obtain the aspect map of Ankara province used in our study, DEM data with a resolution of 30 meters were utilized. These data were downloaded from open sources, verified for accuracy, and included in our study [134].

Using the downloaded DEM data, an aspect analysis was performed in ArcMap, a module of ArcGIS, to create the Aspect Map of Ankara Province (Figure 6.8).

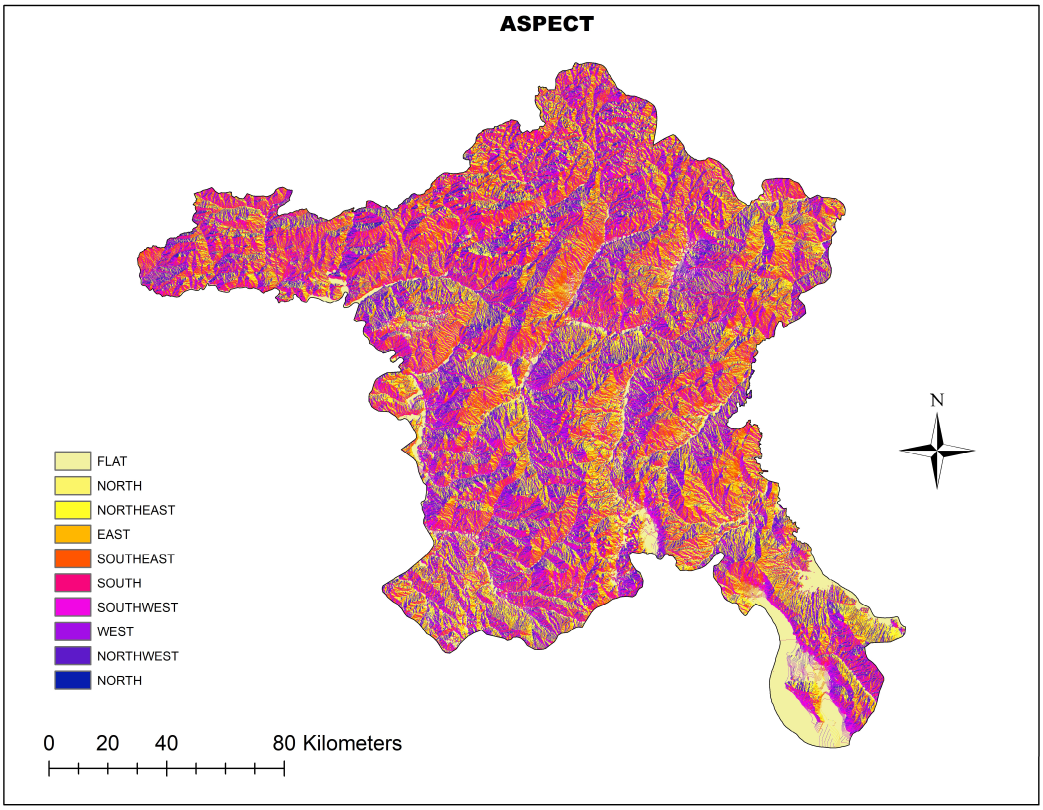

Figure 6.8 Aspect Map of Ankara Province

6.2.6 Roads

The proximity to highways is an economic factor for the establishment of SPPs. During the installation phase, transportation of solar panels, assembly materials, and construction materials for the foundation requires access to a highway. The presence of an existing highway eliminates the need for constructing a new road, thereby reducing infrastructure costs. Moreover, building a new road would cause environmental damage, which can be avoided if the SPP is near an existing road. Therefore, selecting sites close to highways minimizes construction costs. The road data used in our study includes all intercity roads, highways, and city roads within the province of Ankara. This data was downloaded from open sources, verified for accuracy, and included in our study [140].

All the roads within the province of Ankara are shown in Figure 6.9.

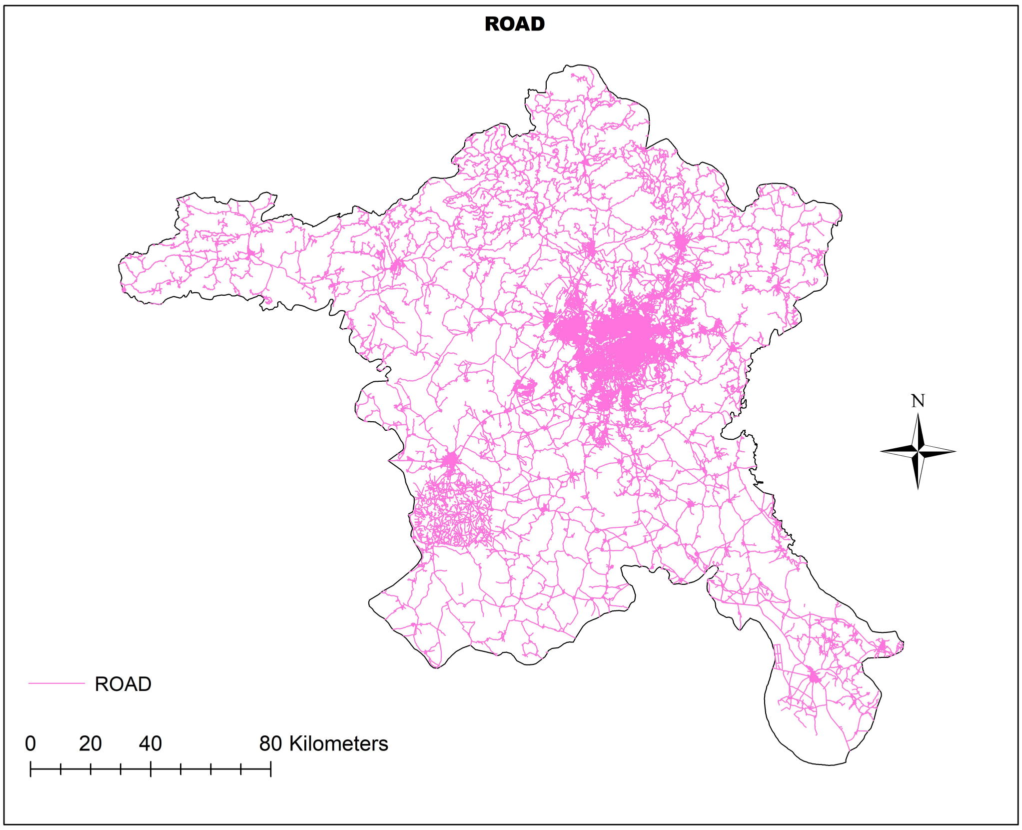

Figure 6.9 Road Map of Ankara Province

6.2.7 Railways

Similar to the highway factor, proximity to railways is also an economic factor. Having a railway near the site of the SPP facilitates the transportation of solar panels, assembly materials, and construction materials needed for the foundation. Additionally, rail transport is much safer and more economical compared to road transport. Therefore, selecting sites for SPPs close to railways is advantageous for minimizing construction costs. The railway data used in our study was downloaded from open sources, verified for accuracy, and included in our study [140].

All the railways within the province of Ankara are shown in Figure 6.10.

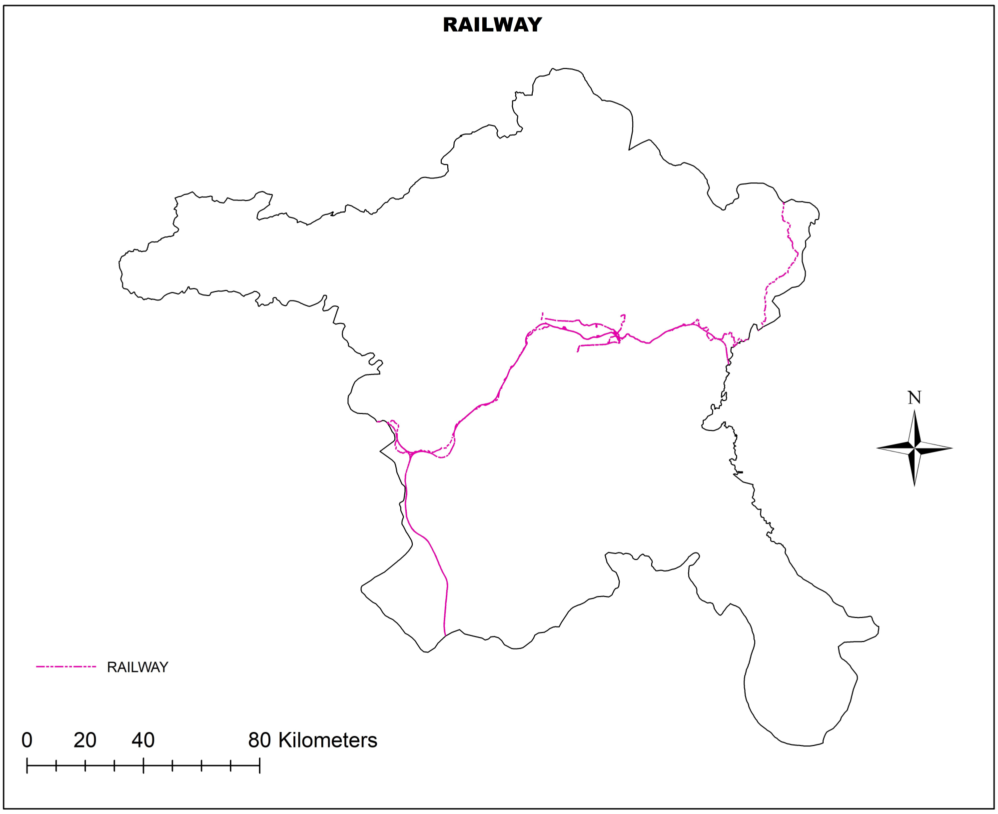

Figure 6.10 Railway Map of Ankara Province

6.2.8 Air Temperature

The temperature criterion and its impact on panels are quite important in SPPs. There is an inverse relationship between the energy produced by solar panels and temperature. Surface temperature and the heating of the panels cause a reduction in the power obtained from the panels. As the ambient temperature increases, the efficiency significantly decreases, for example, by about 5%. Since the main component of solar panels is semiconductor material, lower temperatures directly increase efficiency. A panel that reduces its operating temperature from 353 Kelvin to 273 Kelvin has shown an efficiency increase from 7.34% to 9.78% [136]. Therefore, regions with lower temperatures are more efficient and should be preferred for SPPs.

The annual average air temperature map data included in our study was obtained using satellite images downloaded from NASA's website and processed using the IDW interpolation technique in the ArcGIS program [137].

The annual average air temperature map of the province of Ankara is shown in Figure 6.11.

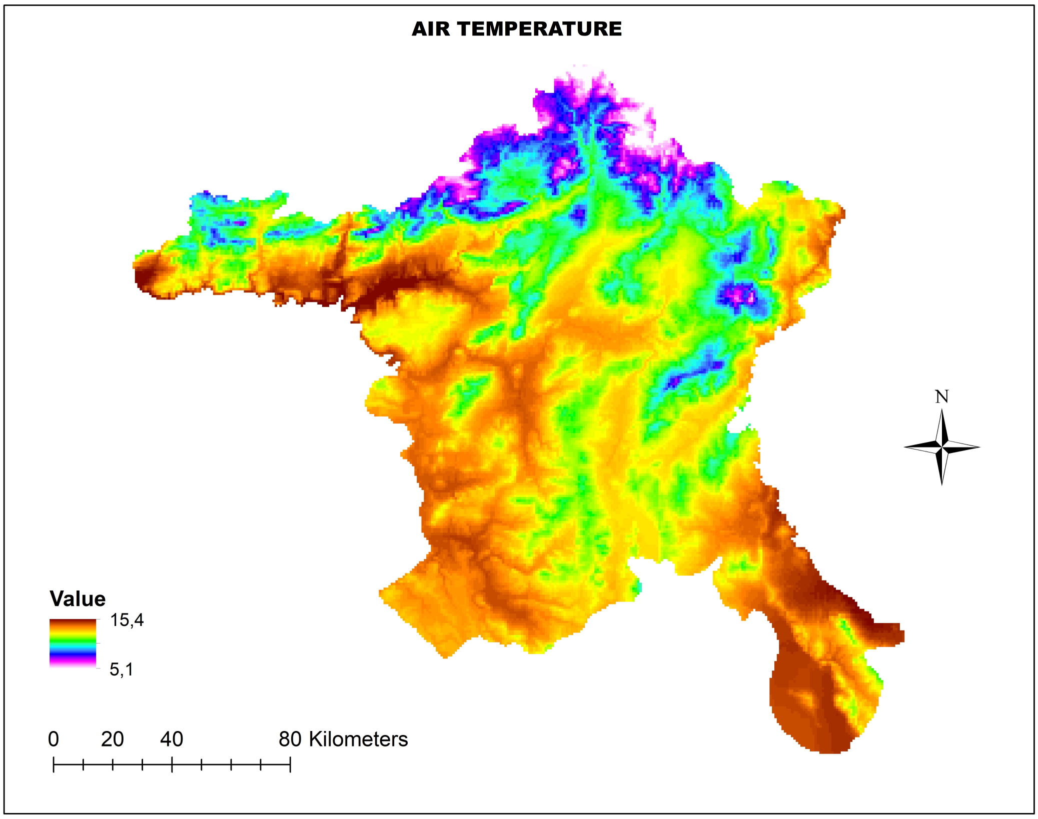

Figure 6.11 Air Temperature Map of Ankara Province

6.2.9 Annual Precipitation

Rain generally does not have a negative impact on solar panels. In fact, rainwater can clean dust and dirt accumulated on the inclined surfaces of solar panels. However, in regions with high humidity, intense rainfall can reduce the solar radiation that we need to capture for energy production.

Water vapor and carbon dioxide are considered significant factors in the atmosphere that absorb solar rays. Therefore, in regions with high relative humidity, the absorption of shortwave solar radiation by water vapor reduces the efficiency of solar energy [22]. Relative humidity is the percentage of water vapor in the air, and rainfall does not occur until relative humidity exceeds 100%. Thus, there is a direct relationship between humidity and rainfall. For this reason, areas with low rainfall should be selected for SPP installations.

The annual average precipitation map data included in our study was obtained using satellite images downloaded from NASA's website and processed using the IDW interpolation technique in the ArcGIS program [137].

The annual average precipitation map of the province of Ankara is shown in Figure 6.12.

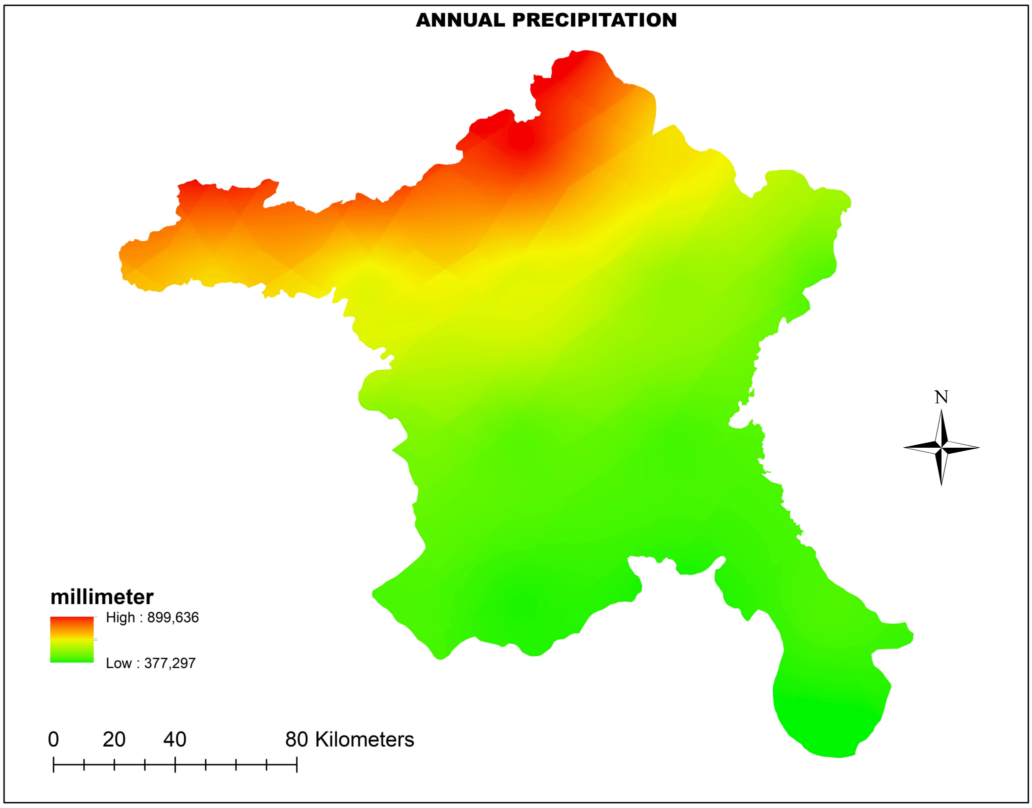

Figure 6.12 Annual Precipitation Map of Ankara Province

6.2.10 Landslide

Landslides, caused by water, slope, and other factors, are significant considerations for site selection due to the risk of soil displacement. Landslides typically occur in mountainous and sloped areas. Therefore, the northern mountainous regions of Ankara are at risk of landslides.

In Section 6.7, we discussed the slope factor and mentioned that highly sloped terrains are not suitable for SPPs. Since landslide-prone areas are also sloped, they are similarly unsuitable.

Furthermore, large landslides pose a risk of completely destroying the established SPPs, jeopardizing both safety and property. Therefore, landslide areas should be avoided.

The landslide sites in the province of Ankara are shown in Figure 6.13.

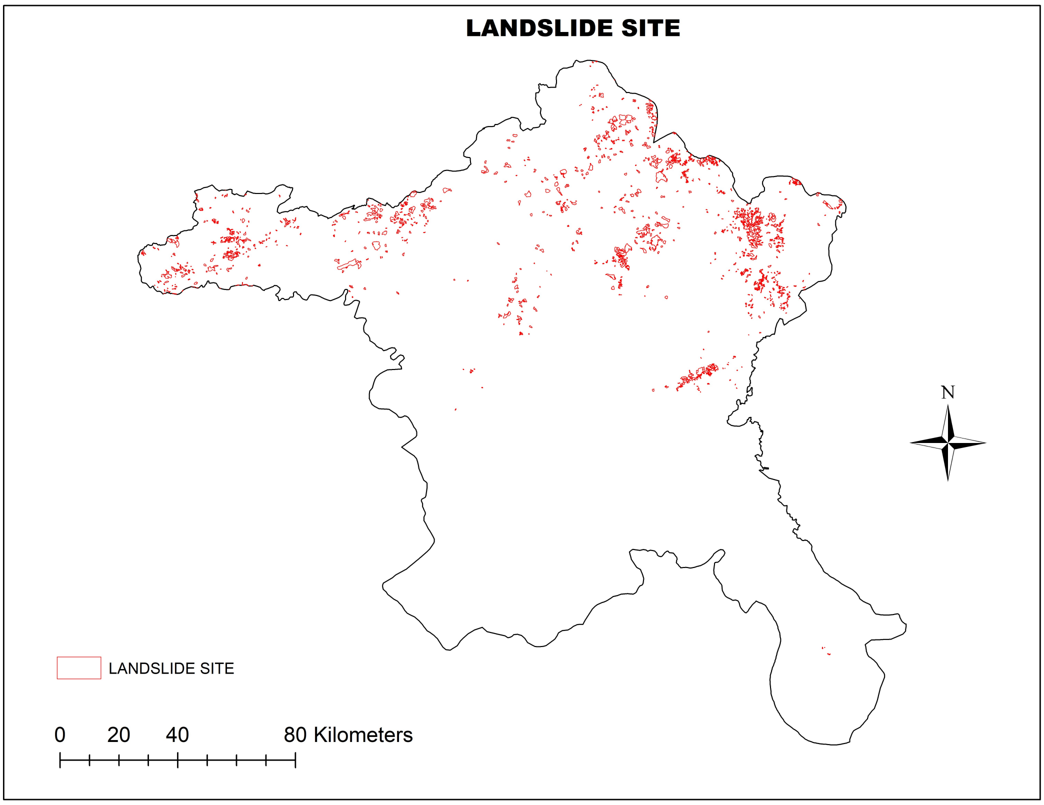

Figure 6.13 Landslide Site Map of Ankara Province

6.2.11 Lakes and Dams

The proximity of a SPP to bodies of water can be advantageous, provided a buffer zone is established. Over time, solar panels accumulate dust and dirt, which negatively impacts their efficiency.

In this context, being near a body of water is beneficial for the maintenance of the SPP, as it facilitates the cleaning of the solar panels. It is more convenient to obtain cleaning water from a nearby source rather than from a distant location. The water bodies data used in our study were downloaded from open sources, verified for accuracy, and included in our study [140].

The lakes and dams within the province of Ankara are shown in Figure 6.14.

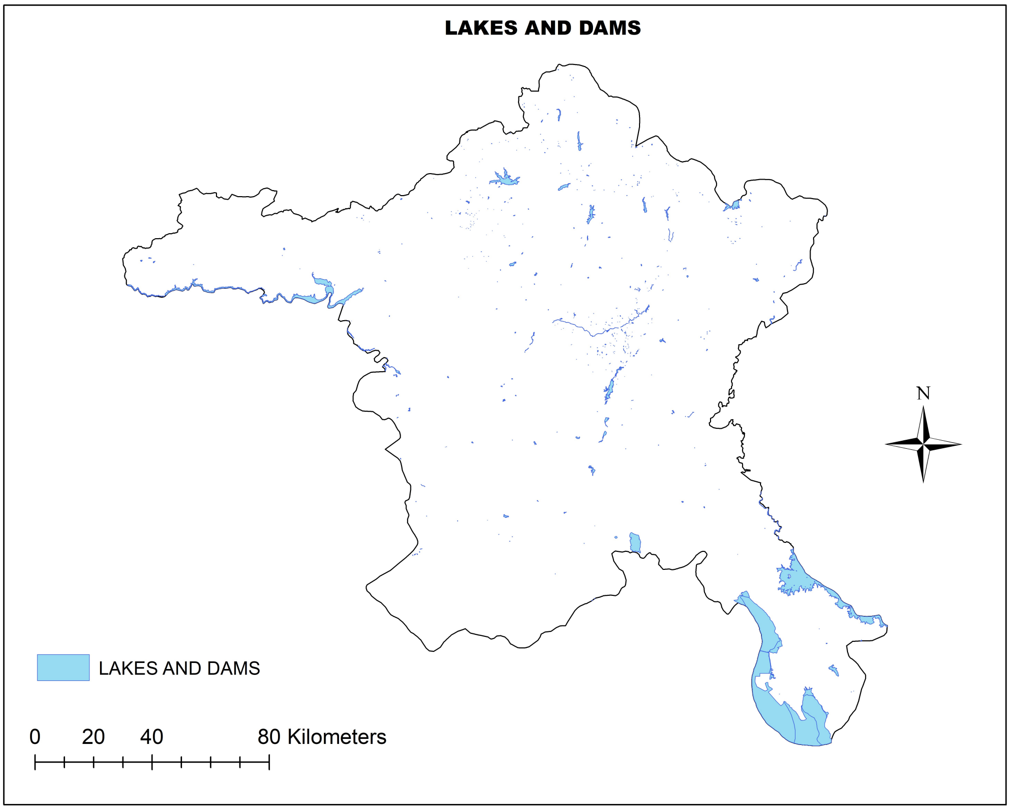

Figure 6.14 Lakes and Dams Map of Ankara Province

6.2.12 Streams

Similar to the importance of proximity to bodies of water, proximity to streams is also crucial for the cleaning of solar panels. Additionally, regions with bodies of water and streams are often suitable for agriculture. Agricultural areas, which vary from region to region, significantly depend on agricultural irrigation.

From this perspective, the energy produced by SPPs located near agricultural and wetland areas can meet the energy needs required for irrigation in agriculture. For all these reasons, after establishing a buffer zone as a precaution against natural disasters such as floods, SPP installation sites should be chosen near streams. The stream data used in our study were downloaded from open sources, verified for accuracy, and included in our study [140].

The streams within the province of Ankara are shown in Figure 6.15.

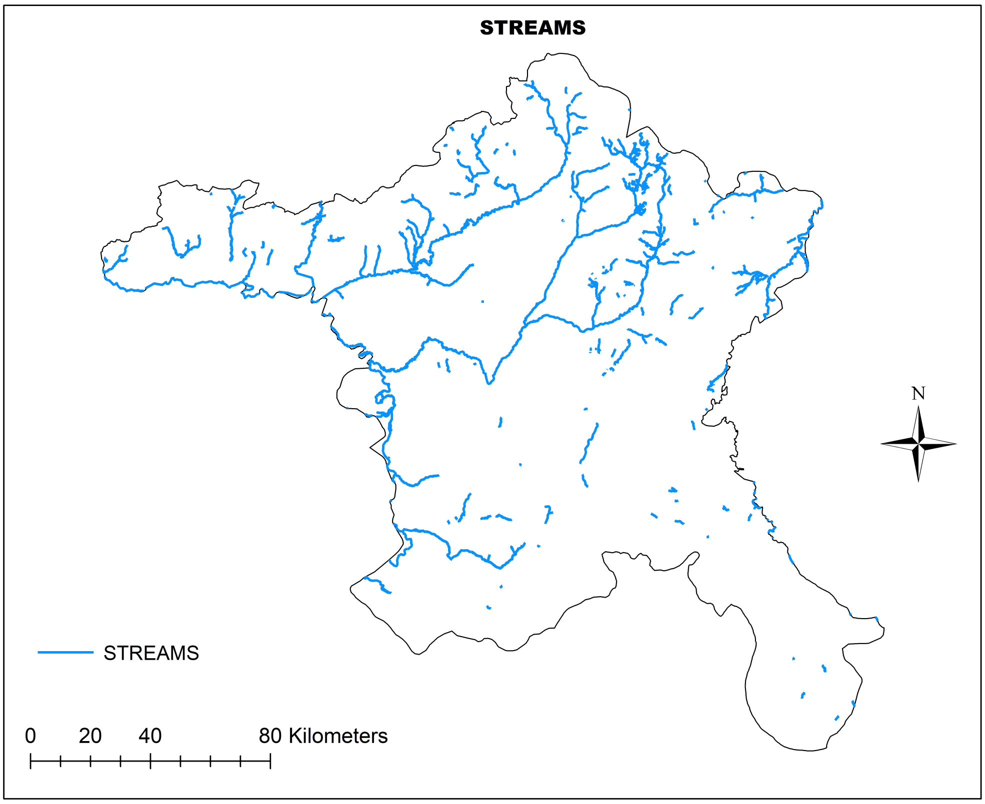

Figure 6.15 Streams Map of Ankara Province

6.2.13 Land Cover

The land use map includes various areas such as agricultural lands, pasturelands, forests, mining sites, meadows, and shrublands, among others. Some of these areas are entirely prohibited for SPP installation, while others depend on the land's characteristics. For example, if the SPP site coincides with a forest parcel, it is strictly forbidden to install unlicensed SPPs, and for licensed SPPs, there are criteria such as the land being an unproductive forest area without trees and shrubs.

SPP installation is entirely prohibited in active mining sites. The situation is similar for agricultural lands. If the area is used for special crop farming, or if it is classified as planted agricultural land, absolute or special crop land, marginal agricultural suitability permits are not granted for SPP installation. Due to these and similar reasons, the land use factor is an important criterion. The land use map data included in our study were obtained by downloading the 2018 CORINE data in vector format from the Copernicus site [138].

The land cover map of Ankara province is shown in Figure 6.16.

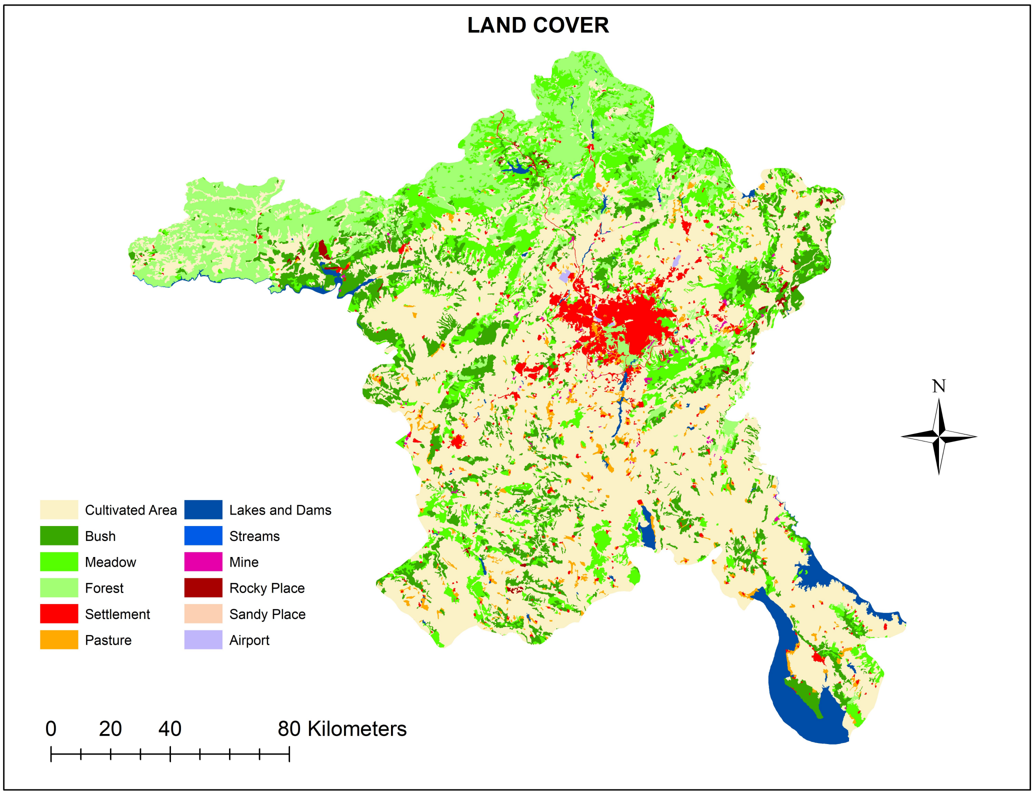

Figure 6.16 Land Cover Map of Ankara Province

6.2.14 Elevation

The energy obtained from solar panels is primarily dependent on the presence of solar radiation. The more solar radiation available, the more energy can be produced. The elevation criterion is significant in this context because the amount of solar radiation reaching the Earth's surface increases proportionally with elevation above sea level.

Solar radiation is absorbed by certain gases in our atmosphere before reaching the surface. As elevation increases, the effect of these absorbing parameters decreases, resulting in an increase in the amount of solar radiation. A study by the Meteorology General Directorate found that for every 1000 meters increase in elevation, there is an average increase of about 10% in solar radiation. To obtain the elevation map of the province of Ankara used in our study, Digital

Elevation Model (DEM) data with a resolution of 30 meters was utilized. These data were downloaded from open sources, verified for accuracy, and included in our study [134].

The elevation map of the province of Ankara is shown in Figure 6.17.

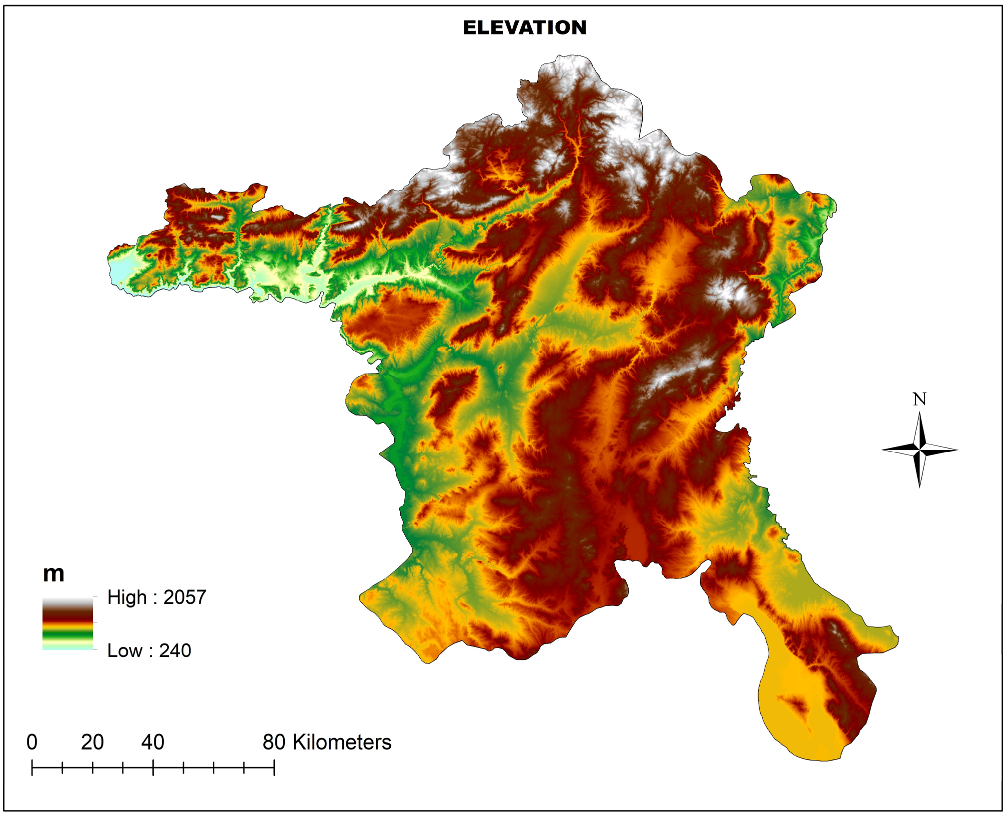

Figure 6.17 Elevation Map of Ankara Province

6.2.15 Fault Lines

Turkey is located on the Alp-Himalaya earthquake belt and has faced numerous earthquake disasters throughout history. Approximately 96% of Turkey's land area and nearly the entire population are at risk of earthquakes [139].

Although soil surveys are conducted to test the durability of the surface where an SPP will be installed, the planned area should be far from active fault lines, in regions not affected by potential disasters, and with low earthquake risk. An SPP built on a fault line faces the risk of collapse during an earthquake. While the North Anatolian Fault, Turkey's largest active fault, passes through the northern part of Ankara, there are no significant active faults within the boundaries of Ankara province. Nonetheless, areas with lower earthquake risk should be preferred.

The fault line data used in our study were downloaded from open sources, verified for accuracy, and included in our study [140]. The fault lines within the province of Ankara are shown in Figure 6.18.

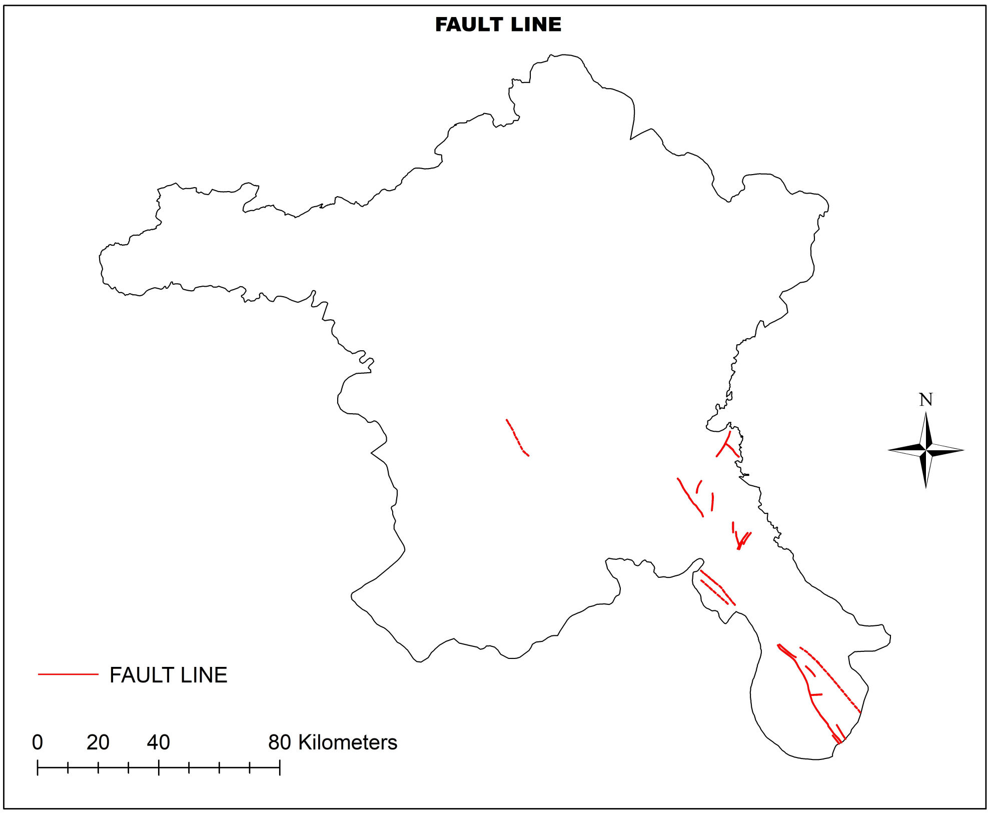

Figure 6.18 Fault Line Map of Ankara Province

6.2.16 Settlements

Another critical factor to consider when determining optimal locations for SPPs is the proximity to residential areas. To prevent an established SPP from being enveloped by urban expansion in the future, it is crucial to consider the city's growth potential and avoid locations too close to residential zones. However, constructing SPPs in undeveloped and non-urbanized areas can be costly due to issues such as the lack of roads and the transportation of materials.

Moreover, the proximity of SPPs to consumption areas is advantageous as it facilitates the distribution of generated energy to those regions. Therefore, it is advisable to select SPP sites within a buffer zone that is not too distant from residential areas. In our study, the data on residential areas were sourced from open-access databases and included after thorough accuracy verification [140].

The settlements within the Ankara province are illustrated in Figure 6.19.

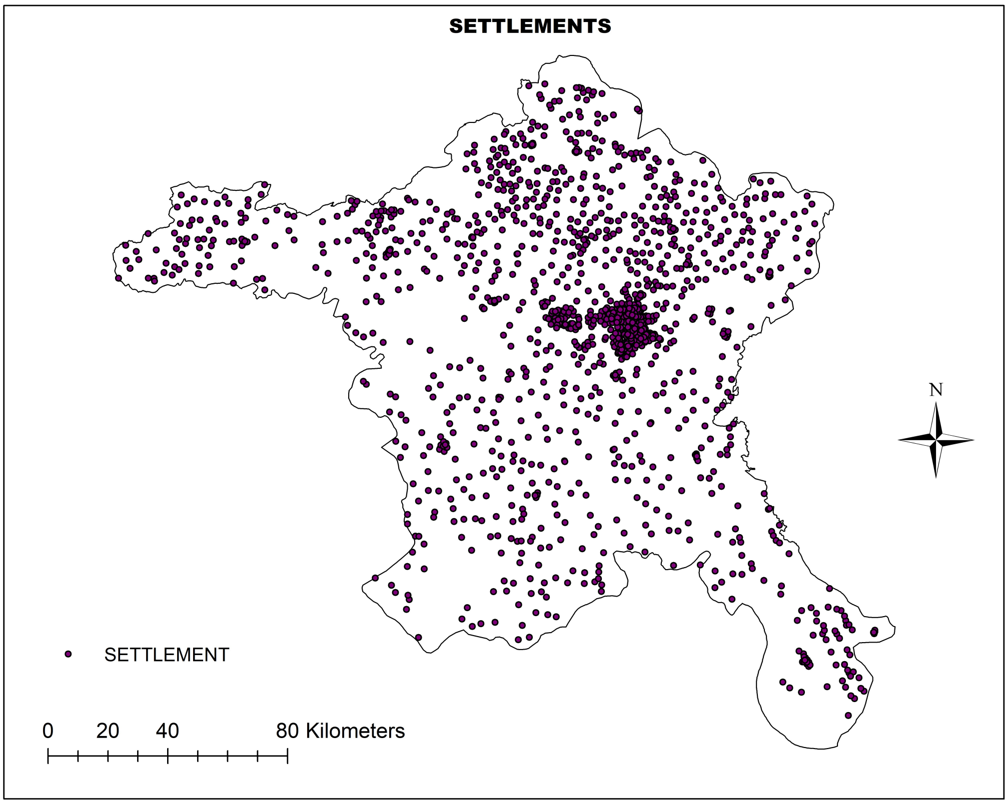

Figure 6.19 Settlements Map of Ankara Province

6.2.17 Natural Gas Lines

The infrastructure factor is another criterion that must be considered in the site selection of SPPs. Specifically, infrastructures such as pipelines, which pose hazards such as explosions, leaks, and fires, are risky for the safety of SPPs. Therefore, SPP sites should be chosen with a certain safety distance from pipelines.

The natural gas pipelines within the Ankara province are shown in Figure 6.20.

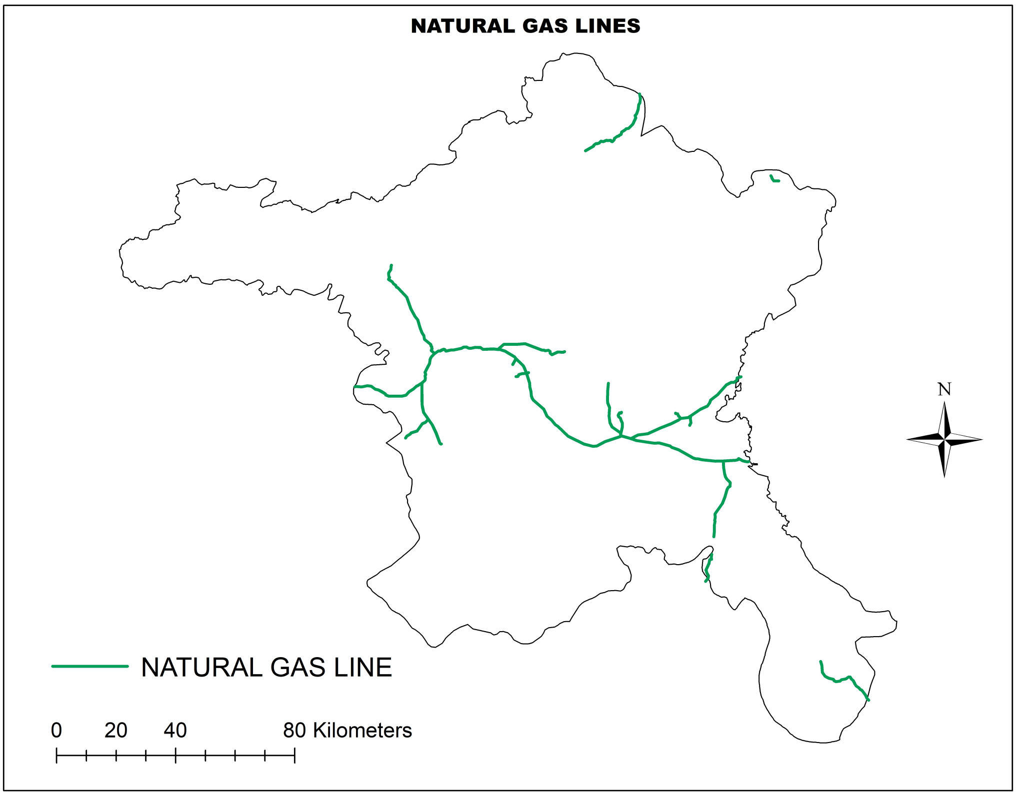

Figure 6.20 Natural Gas Lines Map of Ankara Province

6.3 Examination of the Region According to Established Criteria

As in other studies, the fundamental requirement during the site selection of SPPs is the acquisition of data to be used in the analysis. Consequently, the most effort and time in the analysis are devoted to obtaining the necessary data. The next stage involves analyzing the acquired data using GIS. After determining the weights of the criteria using the AHP, the application of the data to the study area begins. The ArcGIS program, along with GIS, was utilized to determine the most suitable locations for SPPs based on weighted criteria. Most of the data included in our site selection study were obtained as open-source, verified for accuracy, and then included, while some were digitized using Google Earth.

In this section of our study, specific distance intervals were established for each criterion previously determined, and these intervals were expressed in tables. According to these defined distances, maps were produced in the ArcGIS program using the Euclidean distance method for each criterion. In forming and scoring the distances, the geographical characteristics of the

Ankara province, as well as previous surveys and literature reviews, were utilized. A scoring scale ranging from 1 to 5 was used, with a score of 5 indicating the most suitable locations and a score of 1 indicating the least suitable locations. The values and their corresponding meanings are provided in Table 6.1.

Suitability	Score
Very Low	1
Low	2
Moderate	3
High	4
Very High	5

Table 6.1 Suitability Table

6.3.1 Examination of the Region According to Solar Energy Potential

The amount of solar radiation is the most critical component for the establishment of SPPs as solar panels convert solar radiation into electrical energy. Compared to all other factors, solar radiation is paramount. The geographical location of the study area is the primary factor affecting solar radiation. In Türkiye, it is observed that solar radiation increases as one moves southward due to its geographical position. The solar energy potential map for the Ankara province is shown in Figure 6.4. The solar radiation values depicted on the map created from the analyses are measured in kilowatt hours per square meter (kWh/m^2). The scoring for solar potential was derived by dividing the lowest to the highest values approximately equally on a scale from 1 to 5.

Since solar energy potential is entirely dependent on geographical location, the highest solar radiation values in the southern regions, considered the most suitable, were given a score of 5, while the lowest values in the northern regions were assigned a score of 1. The classification intervals and scores for solar energy potential data are presented in Table 6.2. The solar energy potential suitability map for the Ankara province is shown in Figure 6.21.

Sub-Criteria(kWh/m²)	Score
1036 - 1526	**1**
1526- 1640	**2**
1640- 1732	**3**
1732 - 1820	**4**
1820 -1974	**5**

Table 6.2 Sub-Criteria Intervals and Scores for Solar Energy Potential

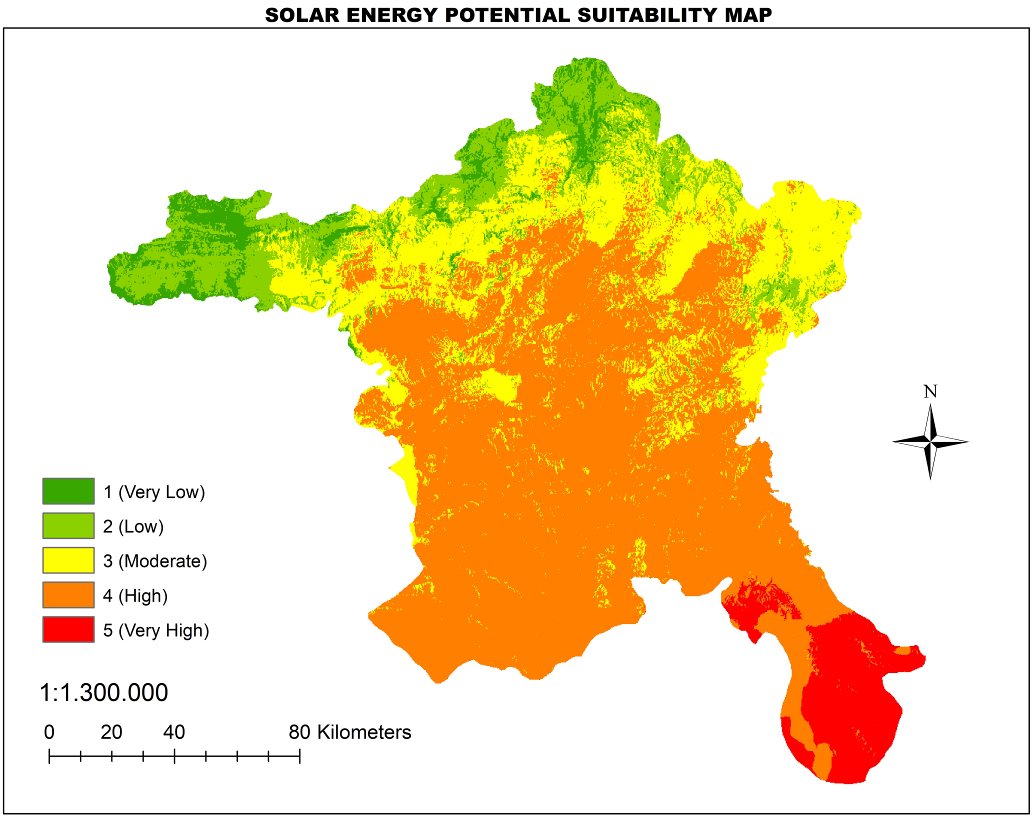

Figure 6.21 Solar Energy Potential Suitability Map of Ankara Province

6.3.2 Examination of the Region According to Transformer Centres

The transformer center criterion is one of the most crucial factors in terms of proximity. The vector-format data containing transformer substations, as shown in Figure 6.2.2, were converted to raster format using the Euclidean Distance method, and the resulting raster data with a 30x30 meter resolution were scored. The essential distances for scoring were set in meters, with areas closest to the transformer centers being rated 5 points and the furthest distances being rated 1 point.

The distance classification intervals and scores for transformer substations are presented in Table 6.3, and the Transformer Center Proximity Suitability Map for the Ankara province is shown in Figure 6.22.

Sub-Criteria (m)	Score
> 40000	**1**
3000 - 40000	**2**
15000 - 30000	**3**
5000 - 15000	**4**
0 - 5000	**5**

Table 6.3 Sub-Criteria Intervals and Scores for Transformer Centre

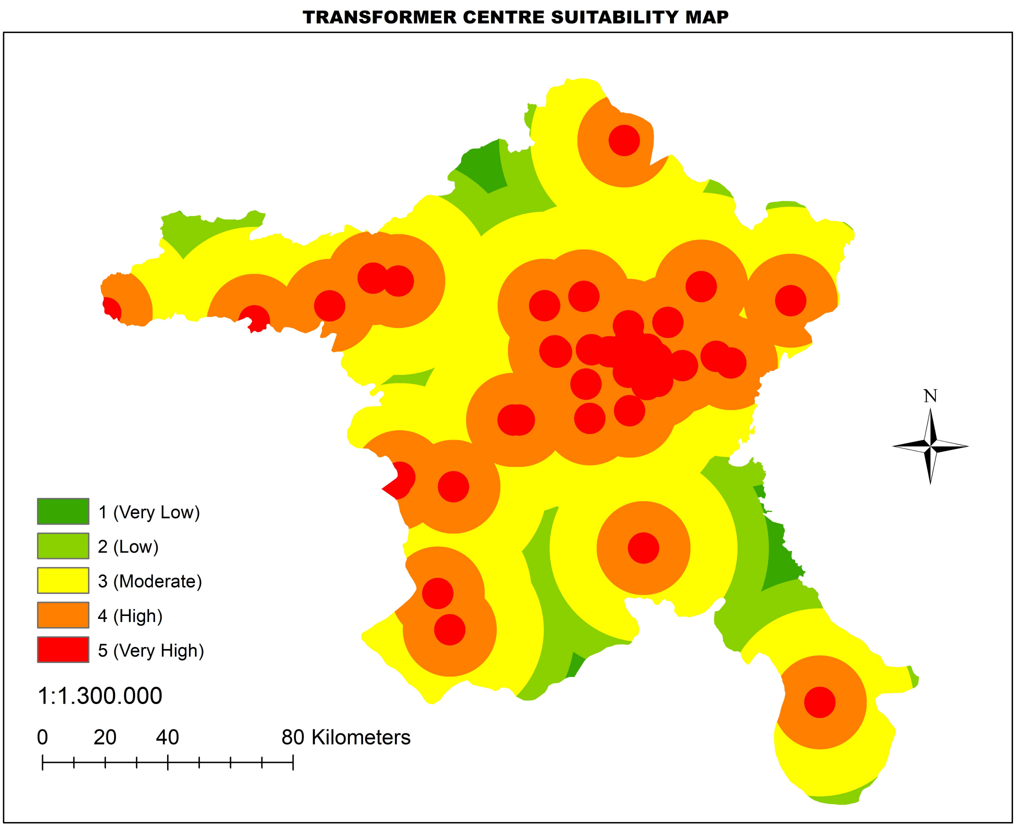

Figure 6.22 Transformer Centre Suitability Map of Ankara Province

6.3.3 Examination of the Region According to Energy Transmission Lines

The distance of the energy transmission line from the area where the SPP will be established is a disadvantage due to the potential energy loss during transmission, the environmental impact, and the increased cost of constructing a new transmission line. The vector-format data of the energy transmission lines, shown in Figure 6.23, were converted to raster format with a resolution of 30x30 meters. Using the Euclidean Distance method, the areas closest to the transmission lines were given the highest score of 5, while the furthest distances were given a score of 1.

The distance classification intervals and scores for the energy transmission lines are presented in Table 6.4.

Sub-Criteria (m)	Score
> 20000	**1**
15000 - 20000	**2**
10000 - 15000	**3**
5000 - 10000	**4**
0 - 5000	**5**

Table 6.4 Sub-Criteria Intervals and Scores for Energy Transmission Lines

ENERGY TRANSMISSION LINE SUITABILITY MAP

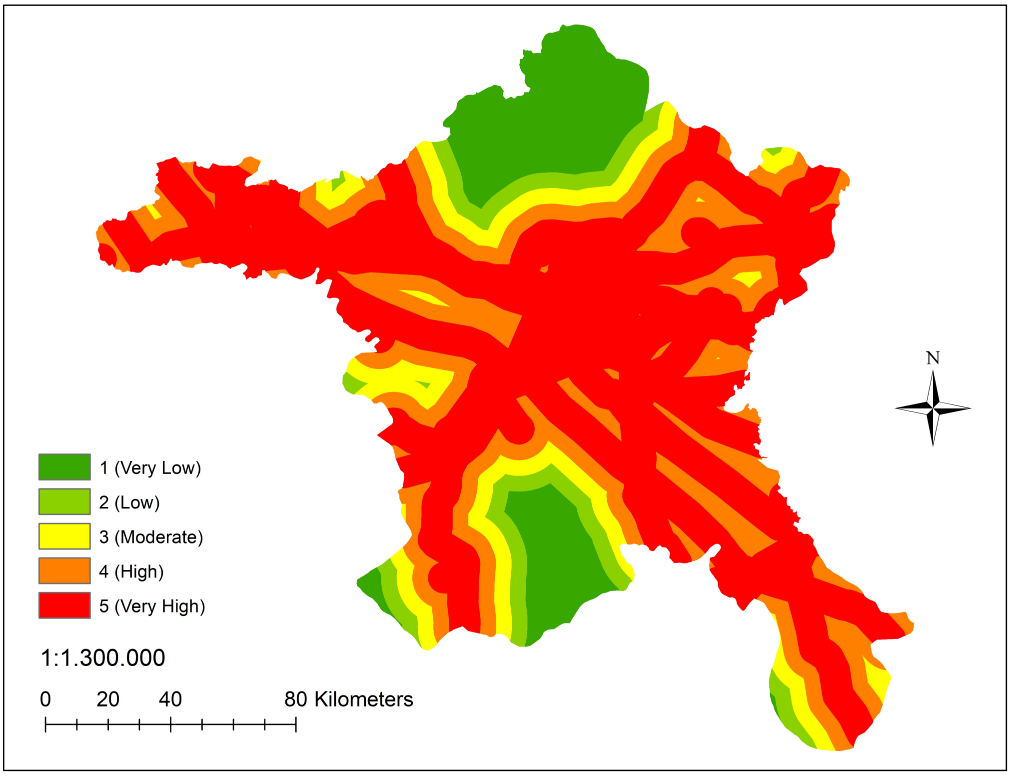

Figure 6.23 Energy Transmission Lines Suitability Map of Ankara Province

6.3.4 Examination of the Region According to Slope

The slope map derived from the Digital Elevation Model was shown in Figure 6.2.4. This raster-format map was classified using the Euclidean Distance method, and the slope values were calculated in degrees and included in our study. As previously mentioned, sloped terrains are not suitable for the installation of SPPs. The most suitable areas are flat regions with a slope of 0 degrees. Therefore, as shown in Table 6.5, the suitability score decreases as the slope degree increases.

The Slope Suitability Map, classified according to slope degrees, is shown in Figure 6.24..

Sub-Criteria (degree)	Score
> 10	**1**
6 - 10	**2**
4 - 6	**3**
2 - 4	**4**
0 - 2	**5**

Table 6.5 Sub-Criteria Intervals and Scores for Slope

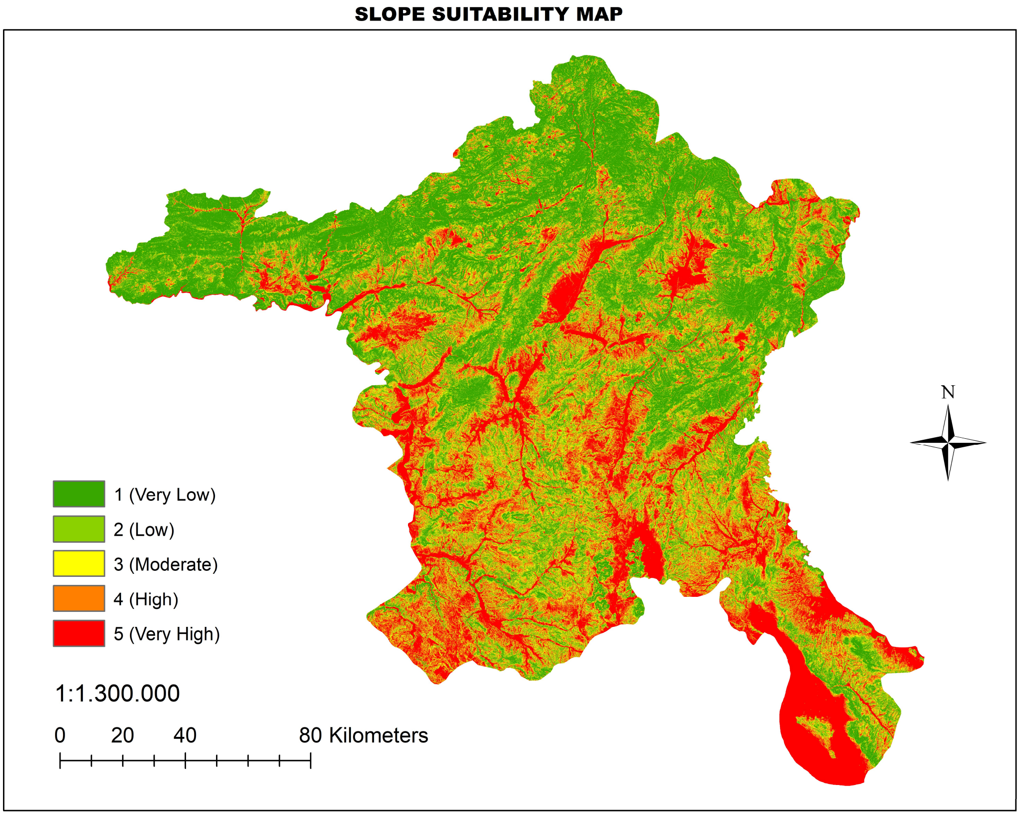

Figure 6.24 Slope Suitability Map of Ankara Province

6.3.5 Examination of the Region According to Aspect

The aspect criterion is a crucial factor for the efficiency of SPPs. As previously mentioned, since Türkiye is located in the northern hemisphere, shadows extend northward, and south-facing slopes have a high potential for solar radiation.

According to the aspect map we obtained, scores were assigned as follows: south, southeast, and southwest aspects received 5 points each; flat areas that receive solar radiation from all directions also received 5 points each; and north, northwest, and northeast aspects were given 1 point each, as shown in Table 6.6.

The Aspect Suitability Map, classified according to the assigned scores, is shown in Figure 6.25.

Sub-Criteria (aspect)	Score
Northwest	**1**
North	**1**
Northeast	**1**
West	**2**
East	**3**
Southwest	**4**
Southeast	**4**
South	**5**
Flat	**5**

Table 6.6 Sub-Criteria Intervals and Scores for Aspect

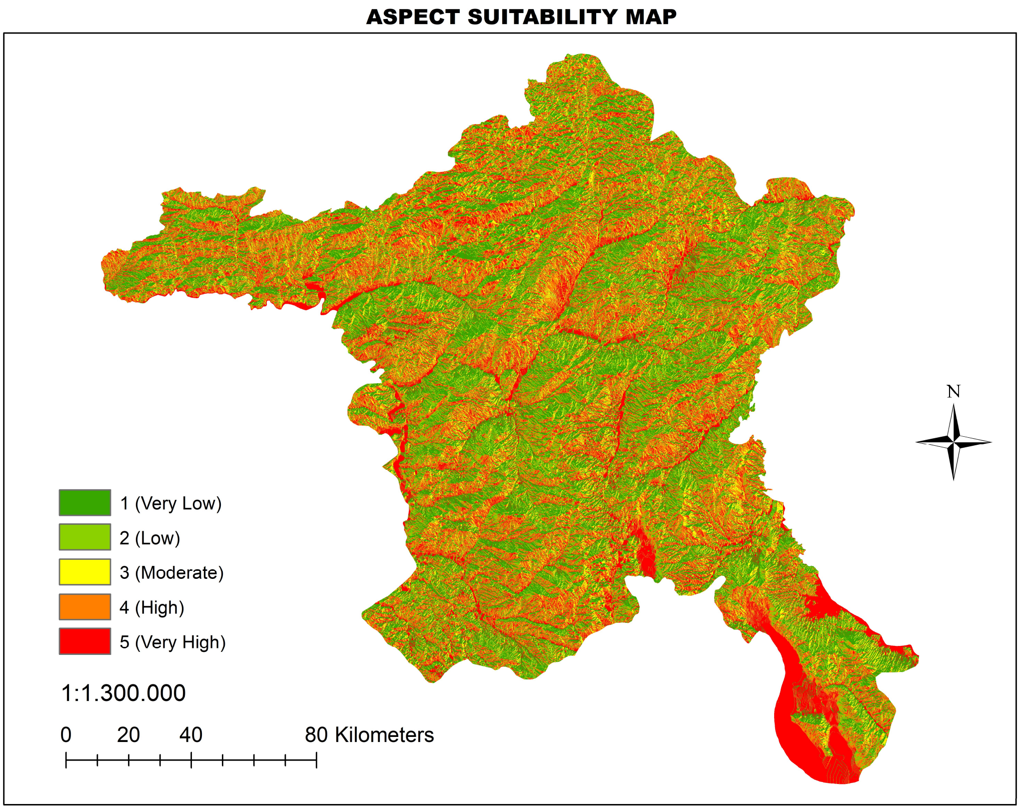

Figure 6.25 Aspect Suitability Map of Ankara Province

6.3.6 Examination of the Region According to Roads

Transportation is an economically significant factor for areas where SPPs will be established and investments will be made. The most commonly used mode of transportation in our country is by road. The Road Map, previously shown in vector format, was converted to a distance map in raster format with a resolution of 30x30 meters using the Euclidean Distance method.

Before classifying the created distance map based on distance values, a buffer zone of 100 meters around the roads was established and excluded from the classification. Areas close to the roads were given a score of 5, while the distant areas were given a score of 1, as shown in Table 6.7.

The Road Suitability Map, classified according to the assigned scores, is shown in Figure 6.26.

Sub-Criteria (m)	Score
> 5000	**1**
3000 - 5000	**2**
2000 - 3000	**3**
1000 - 2000	**4**
100 - 1000	**5**

Table 6.7 Sub-Criteria Intervals and Scores for Road

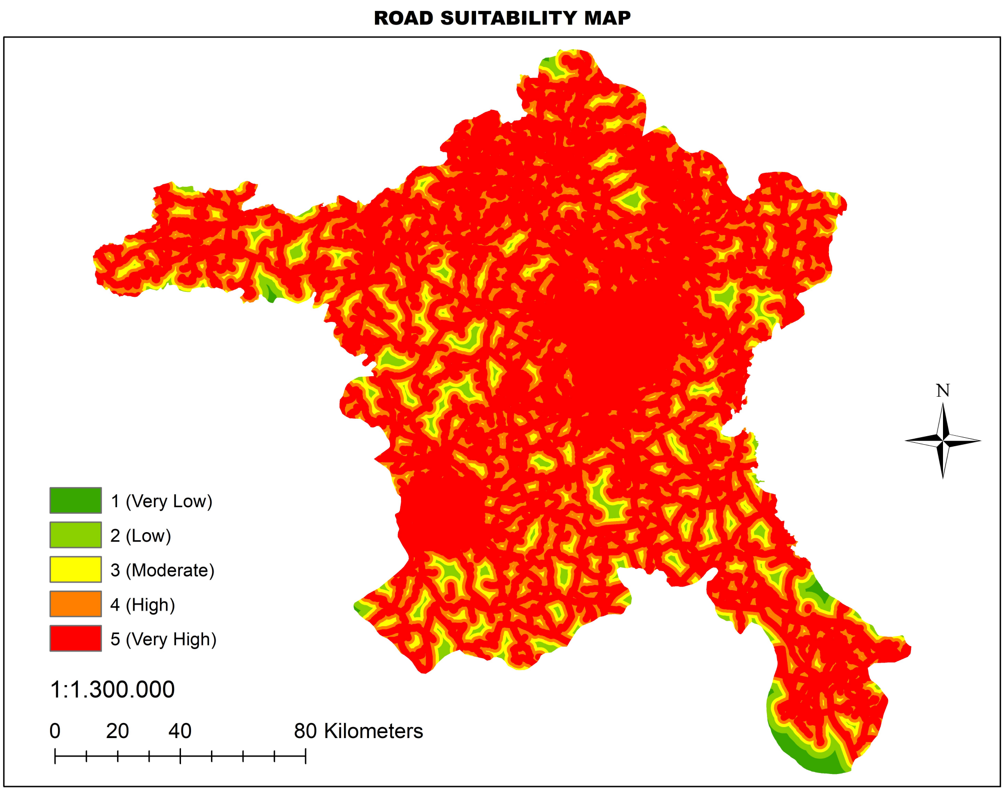

Figure 6.26 Road Suitability Map of Ankara Province

6.3.7 Examination of the Region According to Railways

In Figure 6.2.7, the Railway Map was shown in vector format, and it was stated that railways are a more economical means of transportation compared to roads. SPPs near railways are considered to be in a more advantageous position than those that are not. Before converting the Ankara Railway Map of Ankara province from vector format to raster format with a pixel size of 30x30 meters, a 100-meter buffer zone was established, excluding areas within 100 meters of the railways from the classification.

After this process, the Euclidean Distance method was used to score the areas, with 1 point assigned to areas far from the railways and 5 points assigned to areas close to the railways. These intervals are shown in Table 6.8, and the Railway Suitability Map is shown in Figure 6.27.

Sub-Criteria (m)	Score
> 50000	**1**
25000 - 50000	**2**
10000 - 25000	**3**
5000 - 10000	**4**
100 - 5000	**5**

Table 6.8 Sub-Criteria Intervals and Scores for Railway

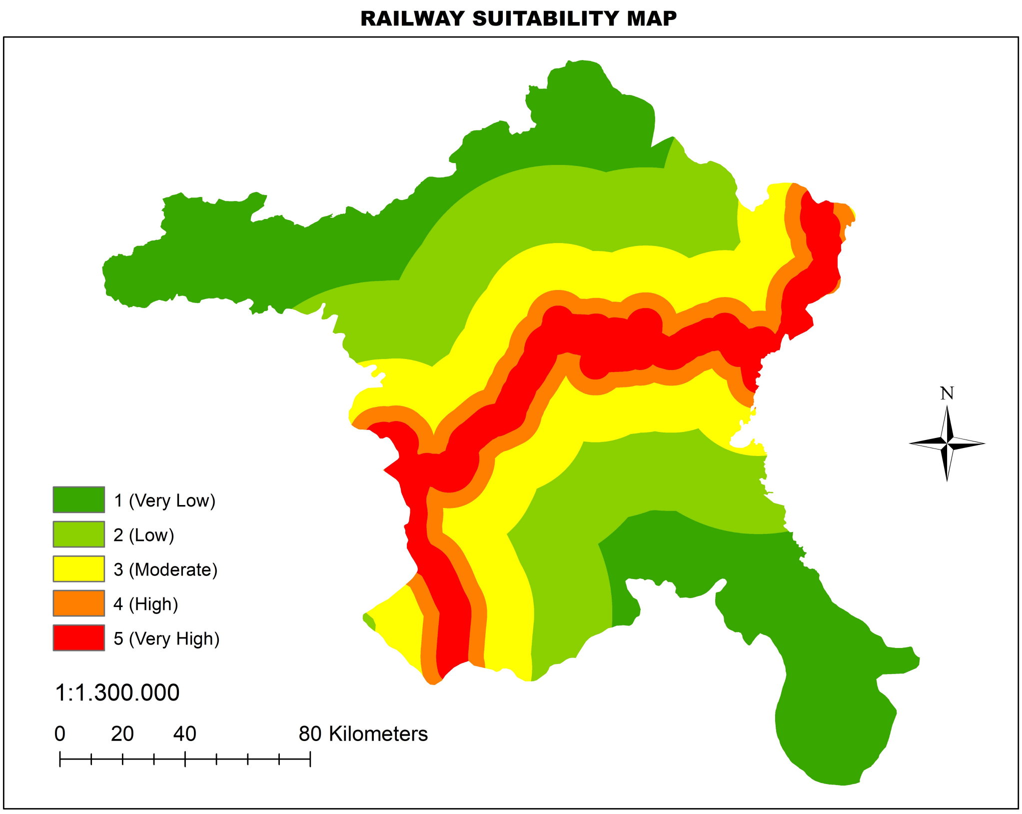

Figure 6.27 Railways Suitability Map of Ankara Province

6.3.8 Examination of the Region According to Air Temperature

The province of Ankara, due to its location, is situated in a region with a continental climate, and air temperatures generally range between 5 and 15 degrees Celsius. The raster-format Air Temperature Map shown in the previous section has been reclassified into categories in this section. As stated, high temperatures decrease the efficiency of SPP panels. Therefore, in the scoring of the temperature intervals created, areas with high temperatures were given 1 point, while areas with lower temperatures were given 5 points, as shown in Table 6.9.

The Ankara Province Temperature Suitability Map, classified according to these table values, is shown in Figure 6.28.

Sub-Criteria (celsius degree)	Score
13 - 15	**1**
11 - 13	**2**
9 - 11	**3**
7 - 9	**4**
5 - 7	**5**

Table 6.9 Sub-Criteria Intervals and Scores for Air Temperature

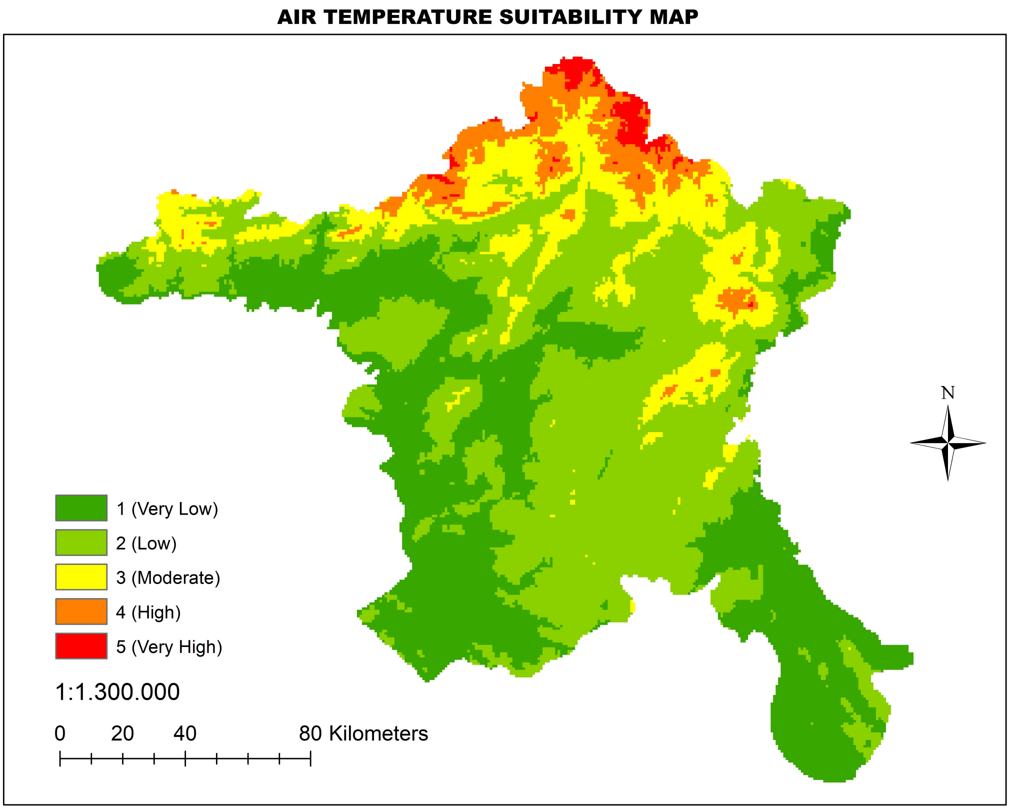

Figure 6.28 Air Temperature Suitability Map of Ankara Province

6.3.9 Examination of the Region According to Annual Precipitation

Establishing SPPs in regions with high rainfall is disadvantageous compared to areas with less rainfall. Due to the obstruction of solar radiation, regions with high rainfall negatively affect the efficiency of SPPs. Therefore, areas in the southern regions with less rainfall were given 5 points, while the mountainous northern regions with heavy rainfall were given 1 point, as shown in Table 6.10.

Annual Precipitation Suitability Map of Ankara Province, classified according to these table values, is shown in Figure 6.29.

Sub-Criteria (kg/m²)	Score
> 750	1
750 - 650	2
550 - 650	3
450 - 550	4
377 - 450	5

Table 6.10 Sub-Criteria Intervals and Scores for Annual Precipitation

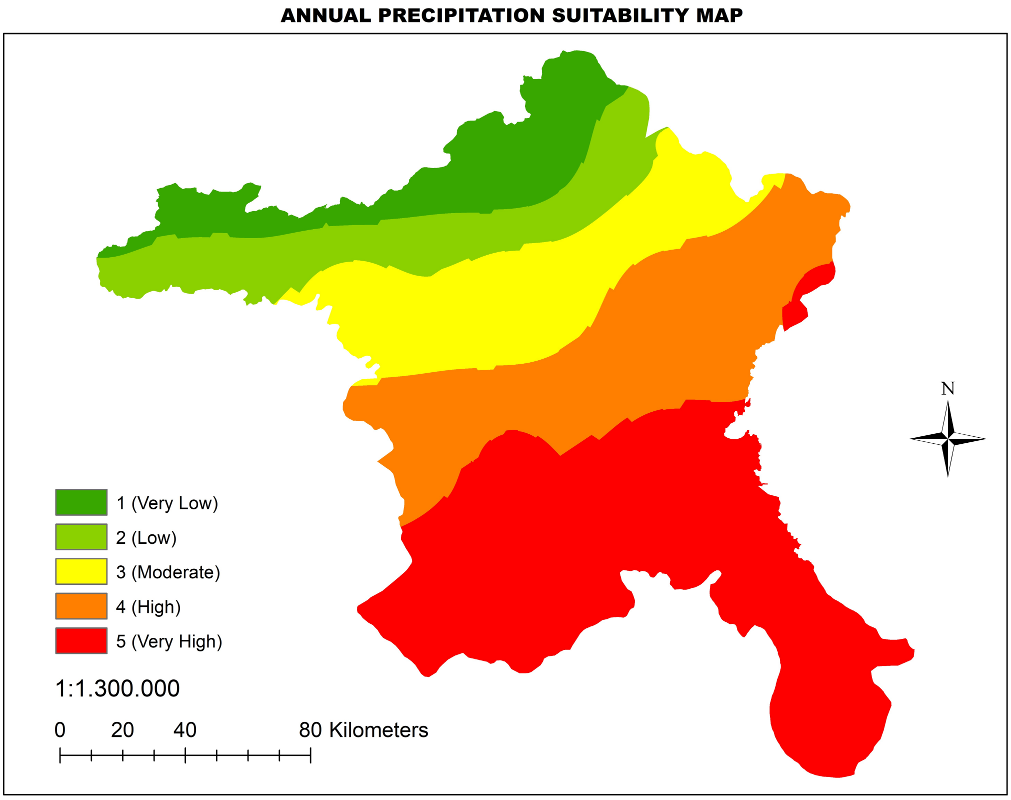

Figure 6.29 Annual Precipitation Suitability Map of Ankara Province

6.3.10 Examination of the Region According to Landslide

The northern regions of Ankara are mountainous and prone to landslides. Establishing a SPP in a landslide-prone area could result in the total loss of investment in the event of a soil displacement. Therefore, areas close to landslide-prone regions were given 1 point, while the furthest areas were given 5 points, as shown in Table 6.11.

Landslide Sides Suitability Map of Ankara Province, classified according to these table values, is shown in Figure 6.30.

Sub-Criteria (m)	Score
0 - 2000	1
2000 - 4000	2
4000 - 6000	3
6000 - 8000	4
> 8000	5

Table 6.11 Sub-Criteria Intervals and Scores for Landslide Site

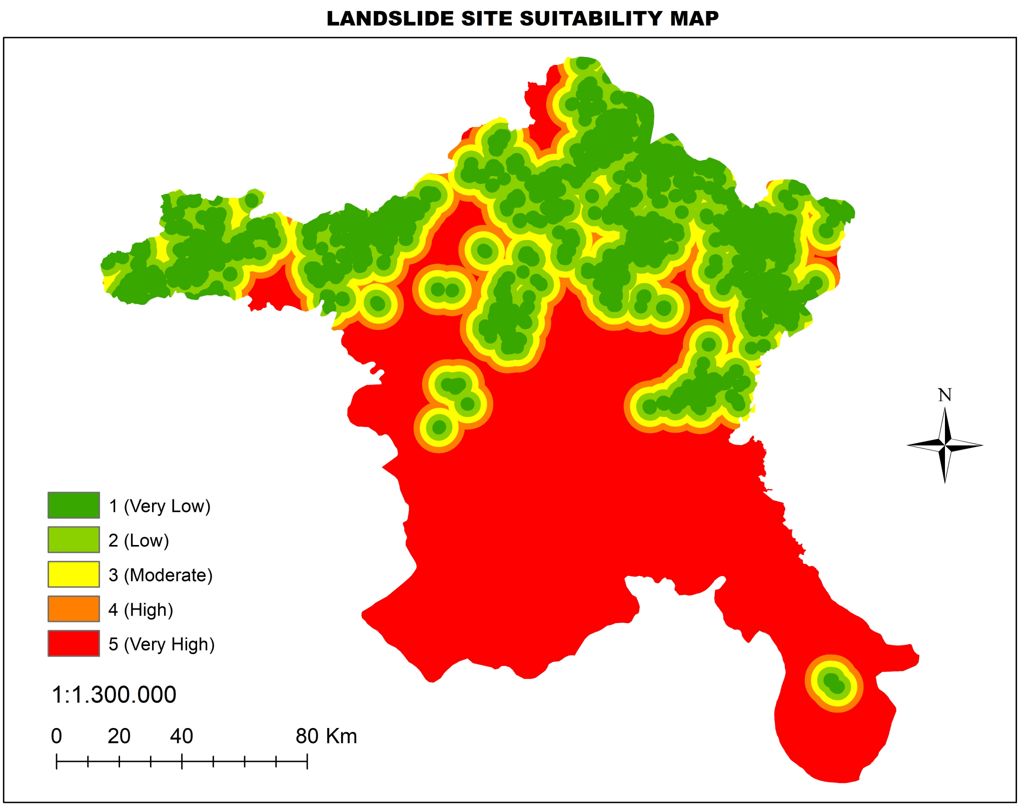

Figure 6.30 Landslide Site Suitability Map of Ankara Province

6.3.11 Examination of the Region According to Lakes and Dams

The map of lakes and dams within Ankara province was previously shown in vector format. Before classifying this data in meters using the Euclidean Distance method, a 500-meter buffer zone was created around the water bodies to exclude these areas from the classification for the safety of SPPs against flood risks. Subsequently, points were assigned to the areas according to the specified intervals, with areas close to the lakes and dams receiving 5 points and distant areas receiving 1 point, as shown in Table 6.12.

The Ankara Province Water Bodies Proximity Suitability Map, classified according to these table values, is shown in Figure 6.31.

Sub-Criteria (m)	Score
> 15000	**1**
10000 - 15000	**2**
5000 - 10000	**3**
3000 - 5000	**4**
500 - 3000	**5**

Table 6.12 Sub-Criteria Intervals and Scores for Lakes and Dams

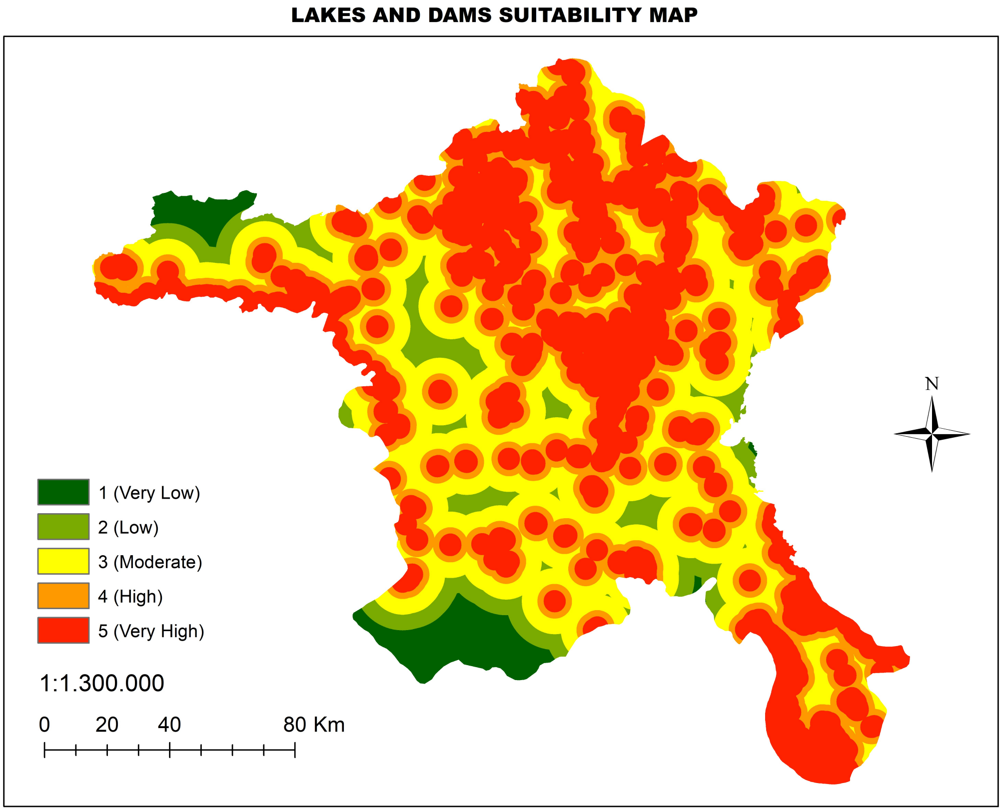

Figure 6.31 Lakes and Dams Suitability Map of Ankara Province

6.3.12 Examination of the Region According to Streams

The map of rivers within Ankara province was previously shown in vector format. Before classifying this data in meters using the Euclidean Distance method, a 500-meter buffer zone was created around the rivers to exclude these areas from the classification for the safety of SPPs against flood risks. Subsequently, points were assigned to the areas according to the specified intervals, with areas close to the rivers receiving 5 points and distant areas receiving 1 point, as shown in Table 6.13.

Stream Suitability Map of Ankara Province, classified according to these table values, is shown in Figure 6.32.

Sub-Criteria (m)	Score
> 15000	**1**
10000 - 15000	**2**
6000 - 10000	**3**
3000 - 6000	**4**
500 - 3000	**5**

Table 6.13 Sub-Criteria Intervals and Scores for Streams

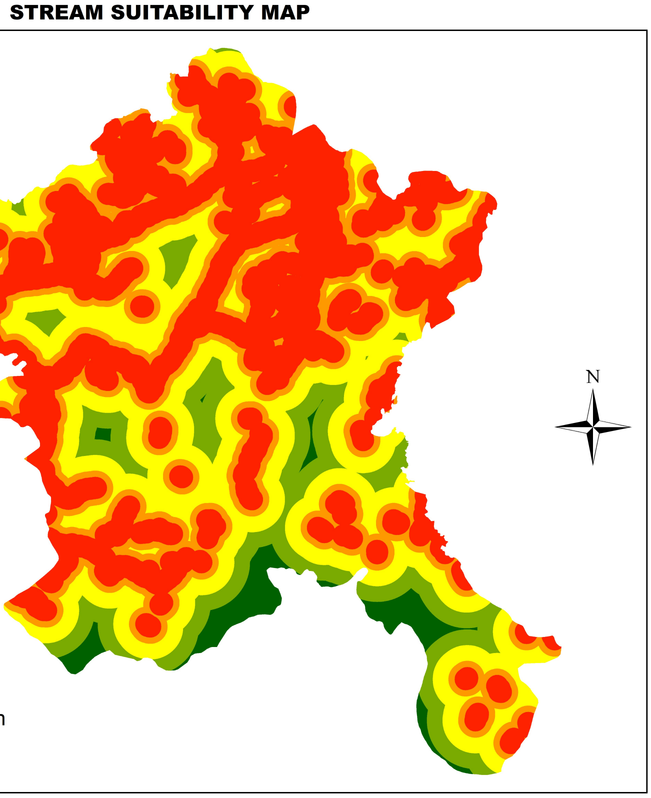

Figure 6.32 Stream Suitability Map of Ankara Province

6.3.13 Examination of the Region According to Land Cover

Land use is one of the fundamental factors in determining areas for the establishment of SPPs. It includes areas where installation is prohibited and where certain permits and land-use changes are required. Therefore, as explained in previous sections, areas where SPP installation is prohibited were given 1 point, while areas where installation is difficult and costly were rated between 2 and 3 points. Pasture, meadow, and similar areas were considered the most suitable and given the highest points (Table 6.14).

The Land Cover Map, initially in vector format, was converted to raster format with a pixel size of 30x30 meters and included in our study. The raster-format map was then classified according to the table values and presented as Land Cover Suitability Map of Ankara Province in Figure 6.33.

Sub-Criteria	Score
Settlement	**1**
Forest	**1**
Lakes and Dams	**1**
Streams	**1**
Airport	**1**
Sandy Place	**2**
Rocky Place	**3**
Bush	**3**
Cultivated Area	**3**
Mine	**4**
Meadow	**4**
Pasture	**5**

Table 6.14 Sub-Criteria and Scores for Land Cover

LAND COVER SUITABILITY MAP

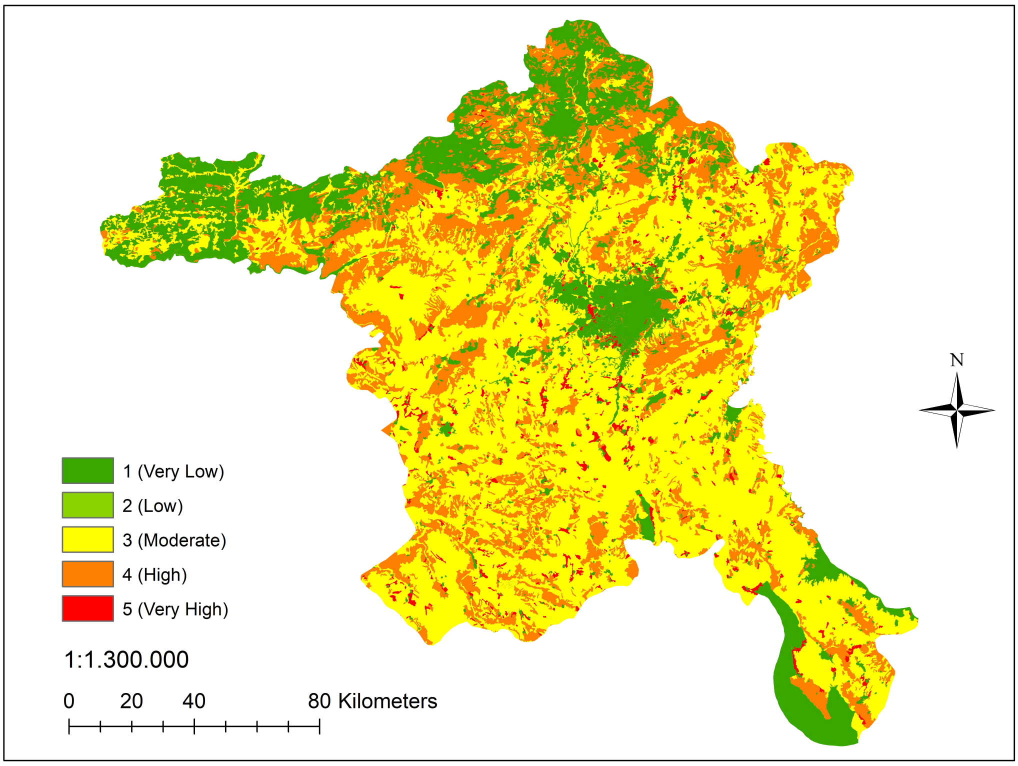

Figure 6.33 Land Cover Suitability Map of Ankara Province

6.3.14 Examination of the Region According to Elevation

The elevation factor directly affects the efficiency of SPPs. Higher areas receive more sunlight compared to lower areas because certain gases in the atmosphere cause solar radiation to be absorbed. Therefore, the higher northern mountainous regions within Ankara province were given 5 points, while the lower plains, generally clustered in the western part of Ankara, were given 1 point, as shown in Table 6.15.

The Ankara Province Elevation Suitability Map, classified according to these table values, is shown in Figure 6.34.

Sub-Criteria (m)	Score
240 - 500	**1**
500 - 900	**2**
900 - 1300	**3**
1300 - 1700	**4**
> 1700	**5**

Table 6.15 Sub-Criteria Intervals and Scores for Elevation

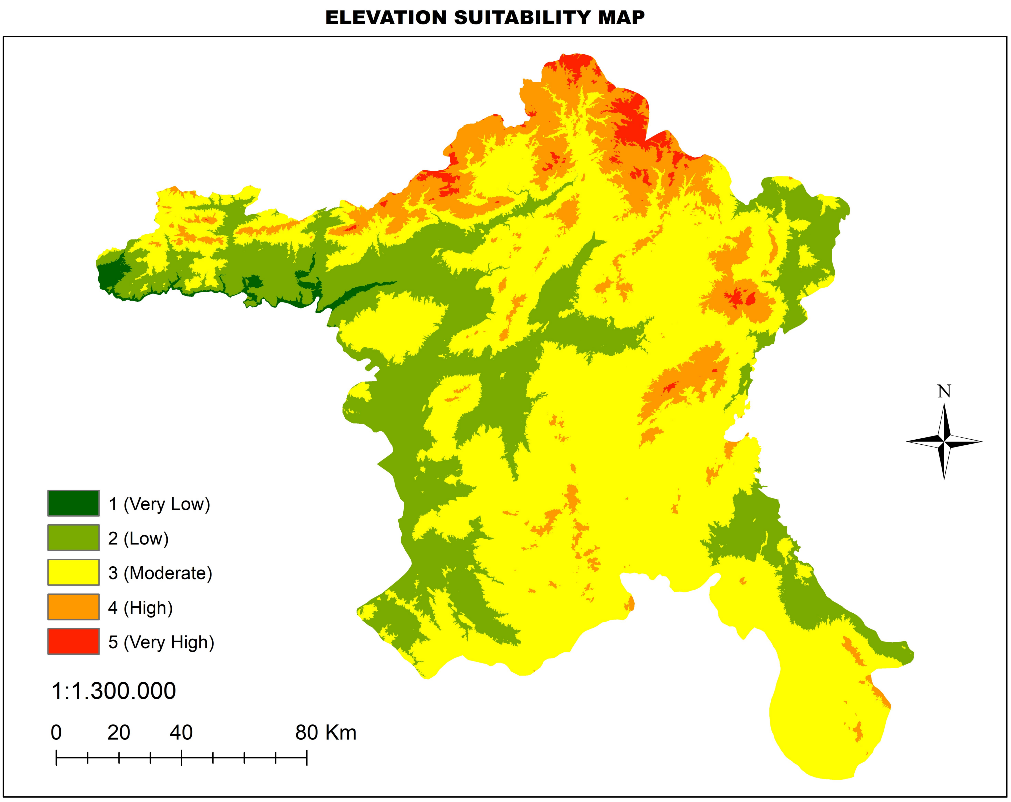

Figure 6.34 Elevation Suitability Map of Ankara Province

6.3.15 Examination of the Region According to Fault Lines

The earthquake risk of the area where the SPP will be established poses a risk both for the investment and for the safety of the facility. Therefore, ensuring that the SPP is distant from fault lines will minimize potential damage in the event of an earthquake. These factors were considered when creating the fault line distance table, with distant areas receiving 5 points and nearby areas receiving 1 point, as shown in Table 6.16.

Fault Line Suitability Map of Ankara Province, classified according to these table values, is shown in Figure 6.35.

Sub-Criteria (m)	Score
0 - 5000	**1**
5000 - 10000	**2**
10000 - 15000	**3**
15000 - 20000	**4**
< 20000	**5**

Table 6.16 Sub-Criteria Intervals and Scores for Fault Line

FAULT LINE SUITABILITY MAP

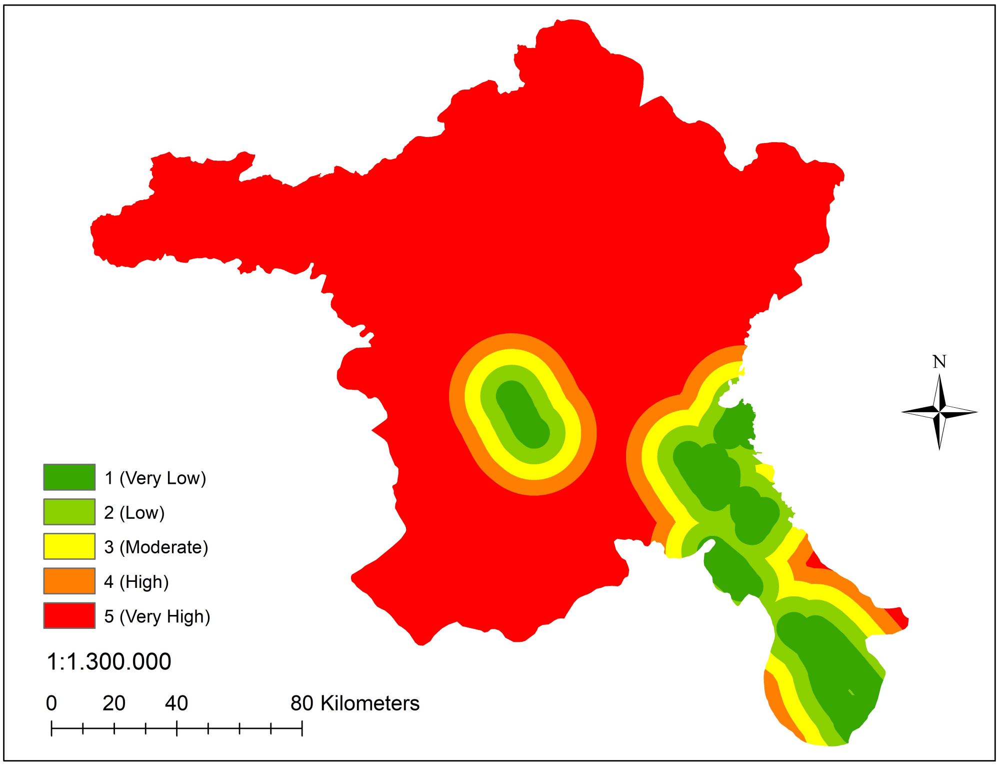

Figure 6.35 Fault Line Suitability Map of Ankara Province

6.3.16 Examination of the Region According to Settlements

Care should be taken to avoid establishing SPPs in residential areas. Considering that the parcel prices in residential areas are higher compared to vacant lots and lands, the area covered by the SPP will increase costs and expose the facility to potential risks within the city. Additionally, being too far from residential areas can lead to energy loss during transmission, making it less desirable.

Therefore, a 500-meter buffer zone was created around the Settlements Map previously shown in vector format, excluding the 500-meter surrounding areas from the classification. The resulting map was then converted to raster format with a pixel size of 30x30 meters using the Euclidean Distance method. Following the creation of the 500-meter buffer zone, the scoring was done with areas closest to the residential areas receiving 5 points and the furthest areas receiving 1 point, as shown in Table 6.17.

Settlements Suitability Map of Ankara Province, classified according to these table values, is shown in Figure 6.36.

Sub-Criteria (m)	Score
500 - 2000	**5**
2000 - 4000	**4**
4000 - 6000	**3**
6000 - 8000	**2**
> 8000	**1**

Table 6.17 Sub-Criteria Intervals and Scores for Settlements

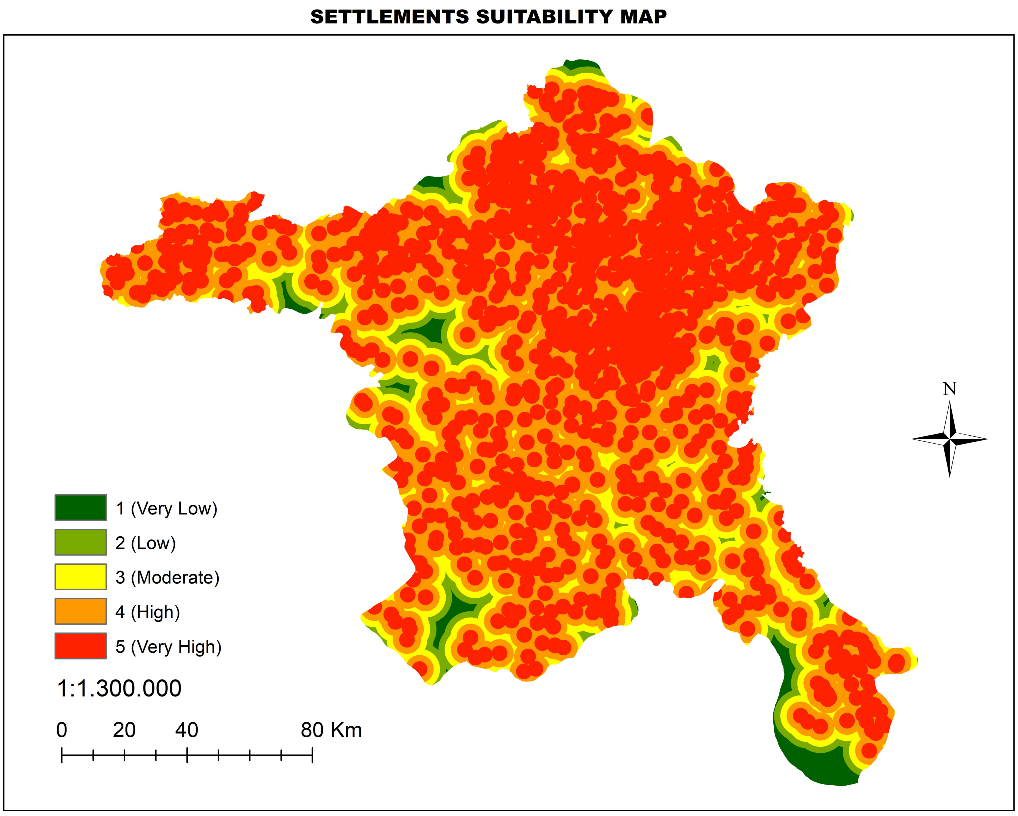

Figure 6.36 Settlements Suitability Map of Ankara Province

6.3.17 Examination of the Region According to Natural Gas Lines

Establishing a SPP over or near a pipeline is not advisable due to the potential hazards and the possibility of damaging the solar panels during maintenance or repair work. Therefore, SPPs should not be constructed along pipeline routes.

To address this, a 70-meter buffer zone was created around the Natural Gas Pipeline Map, obtained in vector format, before converting it to raster data with a pixel size of 30x30 meters. These buffer areas were excluded from the classification. For the reasons mentioned, areas close to the pipelines were given 1 point, while distant areas were given 5 points, as shown in Table 6.18.
Natural Gas Lines Suitability Map of Ankara Province, classified according to these table values, is shown in Figure 6.37.

Sub-Criteria (m)	Score
70 - 5000	**1**
5000 - 10000	**2**
10000 - 15000	**3**
15000 - 20000	**4**
< 20000	**5**

Table 6.18 Sub-Criteria Intervals and Scores for Natural Gas Lines

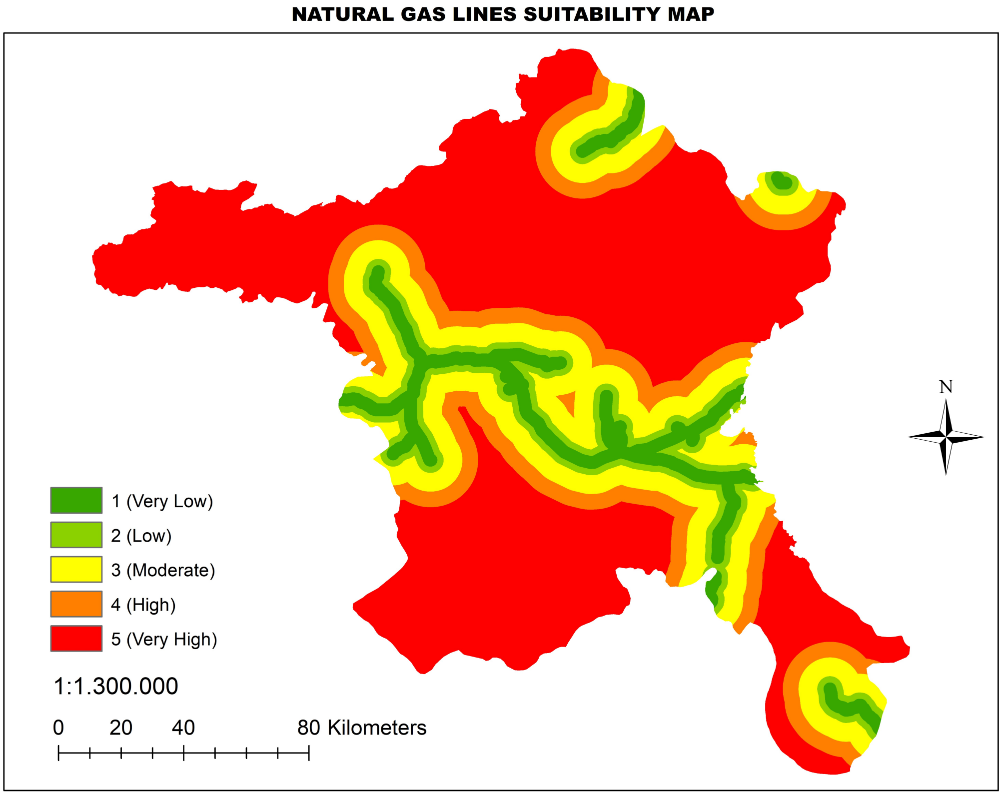

Figure 6.37 Natural Gas Lines Suitability Map of Ankara Province

7. RESULT AND EVALUATION

This study focuses on identifying suitable locations for new SPPs. To this end, an evaluation was conducted that considered both information from existing research and regional characteristics. As a result of this evaluation, it was concluded that sufficient and appropriate criteria must be determined for SPP site selection. In this context, a literature review was conducted, and surveys were administered to establish suitable and sufficient criteria.

In addition to the existing surveys, another survey compliant with the AHP was conducted to determine the importance levels of the obtained criteria. Based on the results of this survey, the criteria were subjected to pairwise comparisons, and their importance levels were determined and weighted.

Vector and raster data were collected for each criterion to visualize suitable areas for SPPs using the ArcMap program. Data not in digital format were digitized and included in the study. As a result of this process, raster maps were obtained for each criterion using ArcMap.

In determining suitable areas for SPPs, the proximity and distance values of the criteria were evaluated, and tables were created based on these evaluations. For example, areas close to highways were prioritized, while areas near landslide zones were given lower priority.

In addition to proximity and distance evaluations, factors such as aspect, land use, and solar radiation amount were examined to create suitability maps. The impact of all criteria on SPP site selection was investigated, and after obtaining the maps, weights were determined using the survey results.

Using the Weighted Overlay Analysis, the suitability of areas within the province of Ankara for SPP installation was determined. The Reclassify tool was used to classify the maps, and suitability analysis was conducted based on the classified maps and the determined weights.

As a result of the Weighted Overlay Analysis, incorporating the weights of 17 criteria, the Suitability Map for Solar Power Plants in Ankara Province was obtained (Figure 7.1).

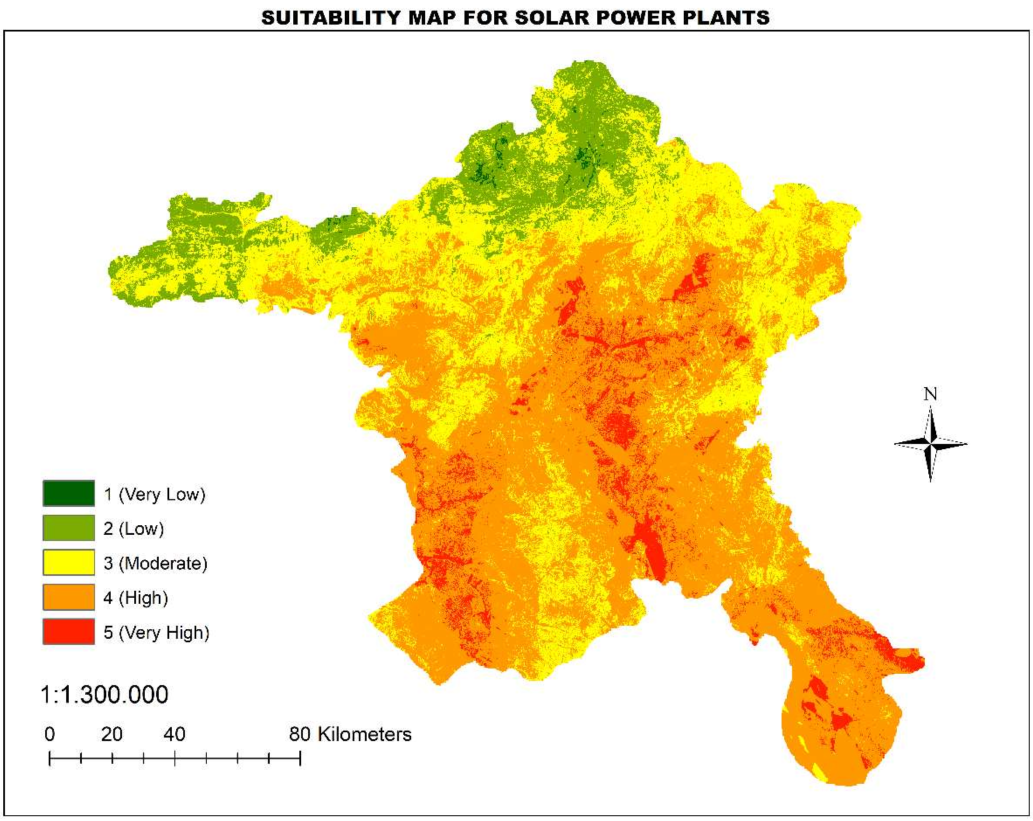

Figure 7.1 Suitability Map for Solar Power Plants in Ankara Province

When examining the suitability map, the most suitable locations are ranked from red to green. Red and orange colors depict the most suitable areas, while dark and light green colors represent unsuitable areas.

Additionally, the areas subjected to the suitability analysis were calculated using the Field Calculator tool in ArcMAP, and these areas were tabulated as percentages (Table 7.1).

The percentages indicate that the areas rated with 1 point and 5 points are lower compared to other areas, which is natural. The reason for the lower percentage of areas rated as "Very Suitable" (5 points) is that the likelihood of all criteria being at optimal levels and all conditions being ideally met is relatively low. On the other hand, it is also unlikely that many criteria are not met. Therefore, "Moderately Suitable" and "Suitable" areas cover nearly 80% of the total area.

Suitability	Area (Hectare)	Percentage (%)
1 (Very Low)	110423,2	4,40
2 (Low)	379084,6	15
3 (Moderate)	930051,8	36,60
4 (High)	1065952	42
5 (Very High)	50763,24	2
Total	2536274,84	100,00

Table 7.1 Suitable Areas and Their Percentages

7.1 Assesment of Existing Solar Power Plants According to Suitibility Map

To test the validity of the SPP suitability map developed through the analysis, 103 existing SPPs within Ankara province were identified and digitized using Google Earth, as previously mentioned. These digitized SPPs were overlaid onto our result map, and the outcomes were evaluated. Several examples of the overlay results are shown in Figures 7.2, 7.3, 7.4, 7.5, 7.6, and 7.7.

When examining the cumulative results of the existing 103 SPPs, the following findings were observed:

- 9 were classified as Very Suitable
- 60 were classified as Suitable
- 33 were classified as Moderately Suitable
- 1 was classified as Not Suitable

The study largely aligns with the locations of currently operational SPPs. This correspondence demonstrates the accuracy and reliability of our study.

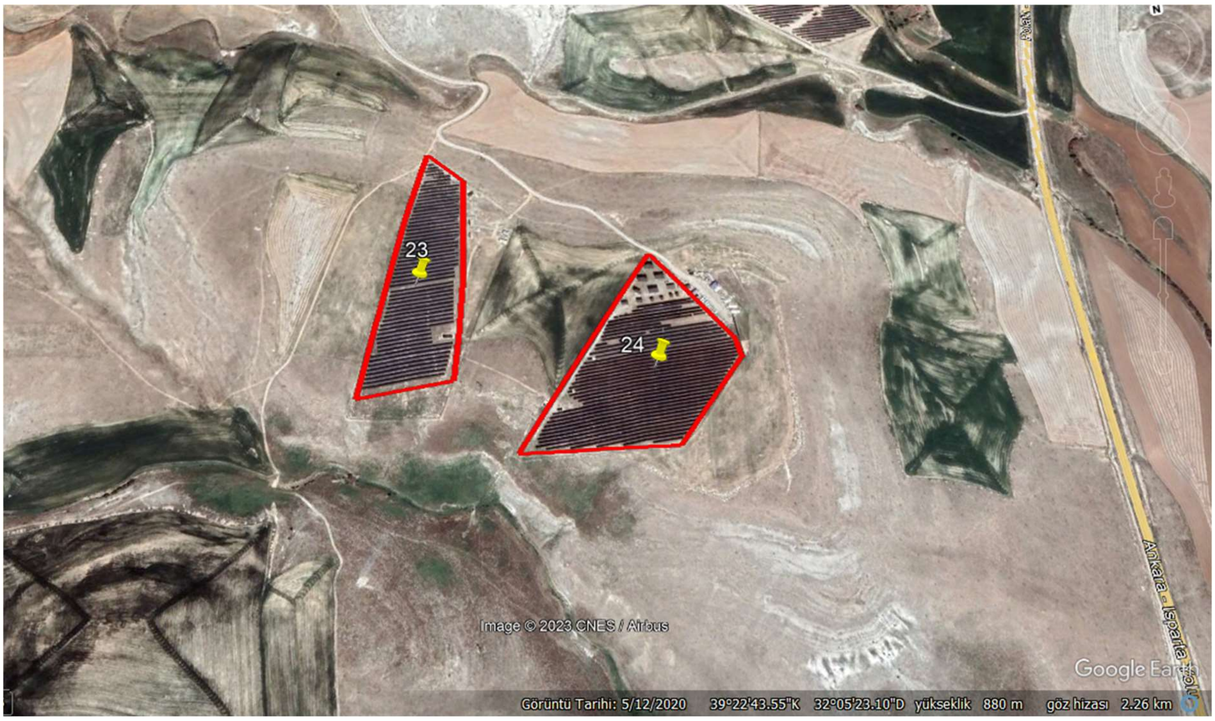

Figure 7.2 Satellite Imagery of Solar Power Plants Numbered 23-24

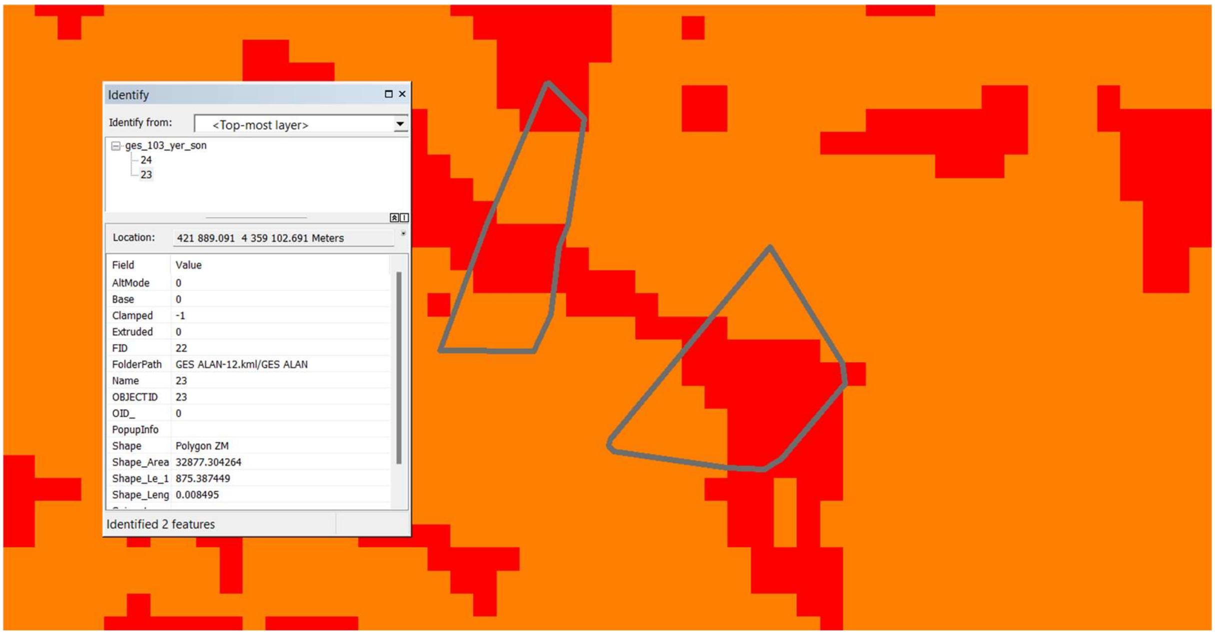

Figure 7.3 Weighted Overlay Analysis Image of Solar Power Plants Numbered 23-24

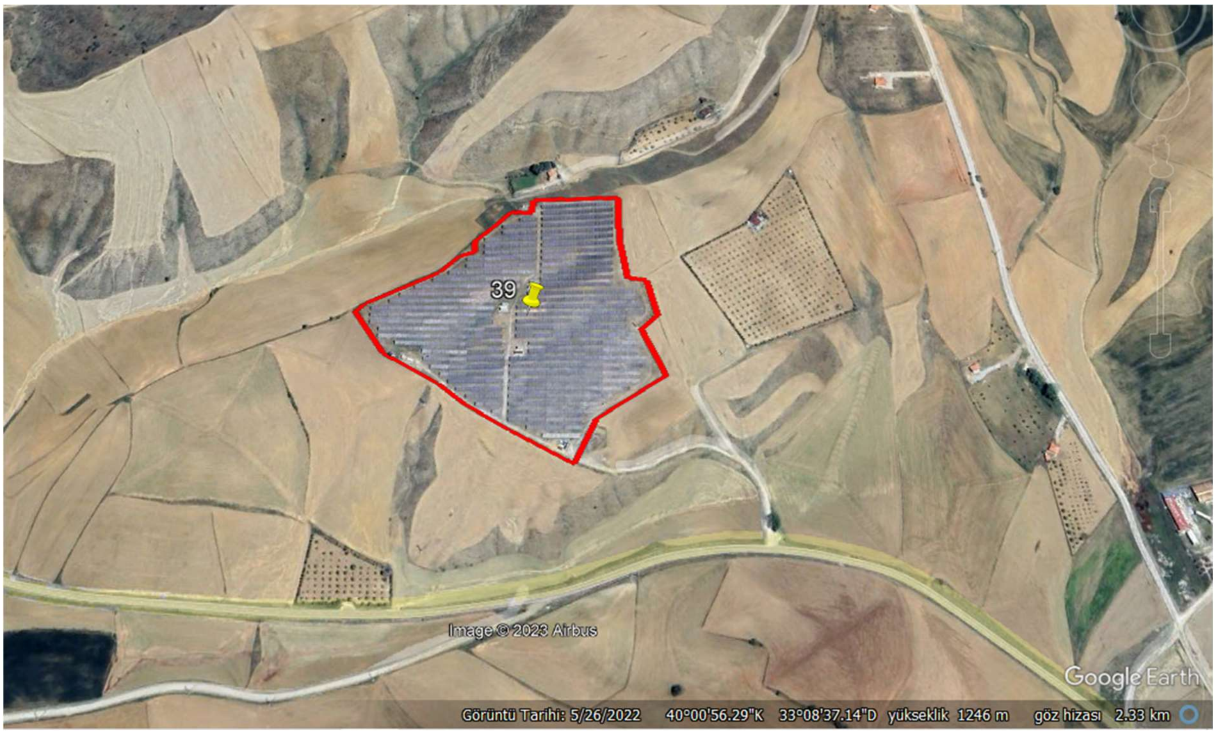

Figure 7.4 Satellite Imagery of Solar Power Plant Numbered 39

Figure 7.5 Weighted Overlay Analysis Image of Solar Power Plant Numbered 39

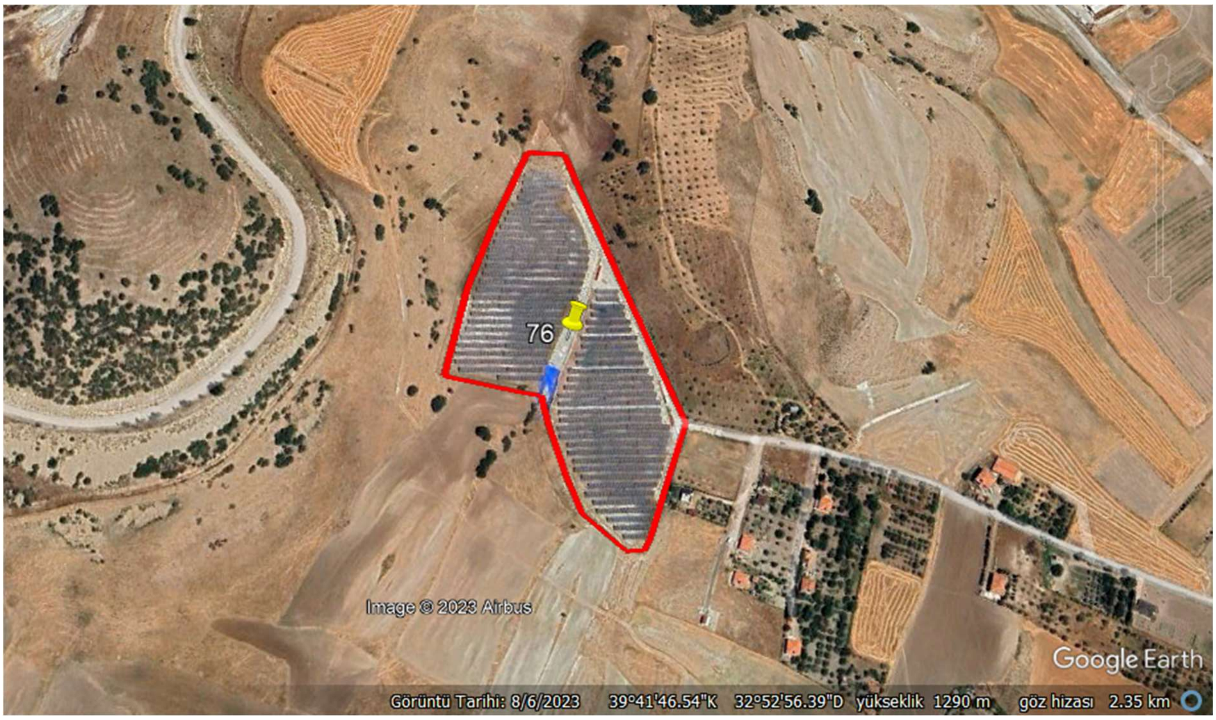

Figure 7.6 Satellite Imagery of Solar Power Plant Numbered 76

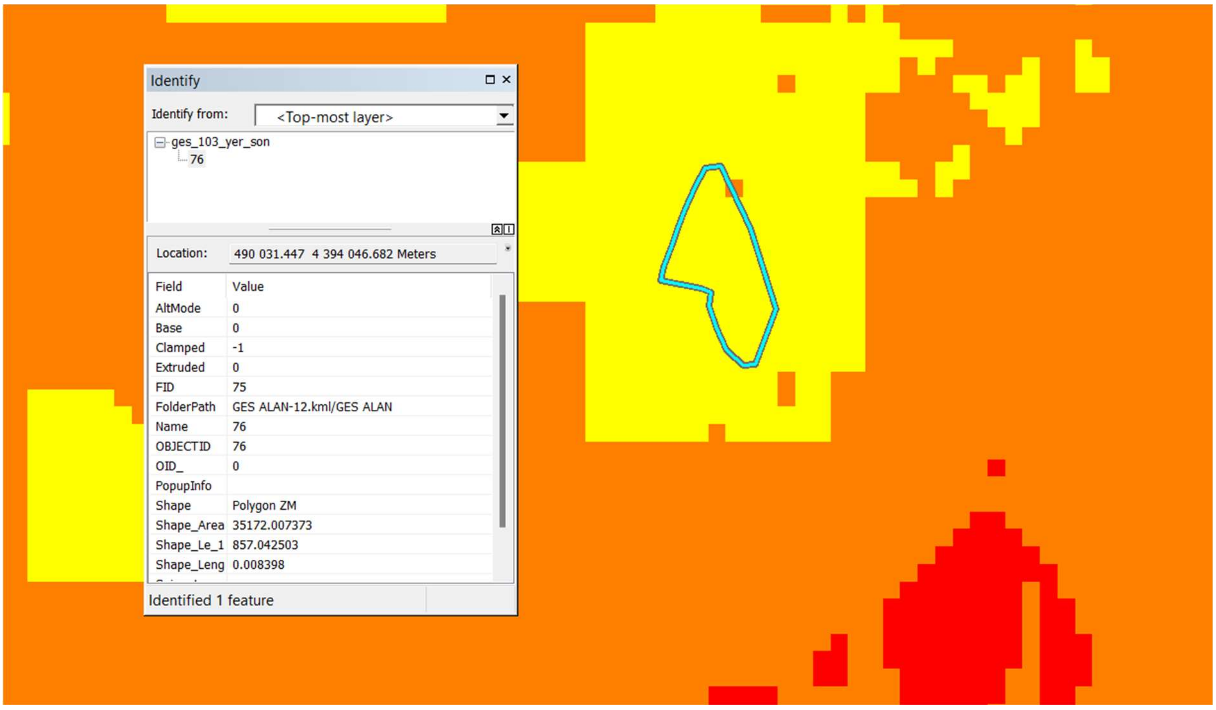

Figure 7.7 Weighted Overlay Analysis Image of Solar Power Plant Numbered 76

8. CONCLUSION

Turkey's significant potential for solar energy has led to a rapid increase in solar energy investments in recent years. Recently, substantial investments have been made in SPPs in Ankara, with ongoing developments. However, it is insufficient to base investments solely on solar energy potential; other factors must also be considered when establishing SPPs.

In this research, various criteria were used to identify suitable and unsuitable areas for SPP site selection in Ankara. In addition to solar energy potential, these criteria include Annual Solar Radiation Value, Air Temperature, Slope, Land Cover, Aspect, Elevation, Annual Precipitation, Proximity to Fault Lines, Proximity to Settlements, Proximity to Transformer Centre, Proximity to Natural Gas Lines, Proximity to Road, Proximity to Streams, Proximity to Railways, Proximity to Lakes and Dams, Proximity to Landslide Site, and Proximity to Energy Transmission Lines. GIS and the AHP were utilized to conduct various analyses, and suitable and unsuitable areas for SPP installation in Ankara were identified, resulting in a final map.

This study demonstrates that analyzing solar radiation alone is insufficient for determining SPP installation sites, as it can lead to errors. Numerous criteria must be considered, such as ensuring the area is not mountainous or rugged, proximity to highways and railways, south-facing aspects, and safe distances from fault lines and landslide areas. Even areas with high solar energy potential may be unsuitable for SPP installation if other factors are unfavorable. For example, regions with slopes over 10 degrees, north-facing aspects, areas within 100 meters of highways and railways, areas within 500 meters of residential zones, and areas within 500 meters of rivers and lakes are identified as unsuitable.

Neglecting these criteria and adopting a one-dimensional approach can result in selecting inappropriate sites, leading to both time and financial losses.

This thesis demonstrates that suitable site selection for SPPs can be conducted anywhere in the world by adjusting criteria and their weights. This approach minimizes environmental damage and maximizes efficiency, allowing us to harness the infinite energy of the sun and leave a cleaner, more livable world for future generations.

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10. ATTACHMENTS

Appendix 1 – Surveys

Within the Framework of a Master Thesis Study at the Departmant of Geomatics Engineering at Hacettepe University, the Impact of Solar Power Plants Criteria on Site Selection is Being Investigated in Ankara Province

Your Affiliated Institution/Department:

1) Do you find criteria listed below acceptable?

Criteria	Yes	No
Solar Energy Potential	☐	☐
Air Temperature	☐	☐
Slope	☐	☐
Land Cover	☐	☐
Aspect	☐	☐
Elevation	☐	☐
Heritage Sites	☐	☐
Annual Precipitation	☐	☐
Fault Lines	☐	☐
Settlements	☐	☐
Transformer Centres	☐	☐
Natural Gas Lines	☐	☐
Military Zones	☐	☐
Roads	☐	☐
Streams	☐	☐
Railways	☐	☐
Lakes and Dams	☐	☐
Landslide	☐	☐
Energy Transmission Lines	☐	☐
Humidity	☐	☐

2) According to importance, what other criteria not mentioned in the first question would you like to add?

a)...

b)...

c)...

d)...

RATING SOLAR POWER PLANTS CRITERIA IN ANKARA PROVINCE

Note: During the survey evaluation, if criteria such as connectivity and walkability are deemed equally important, they are rated as 1. If Solar Energy Potential is considered more important than Air Temperature, the importance level is marked on the side of Solar Energy Potential.Conversely, if Air Temperature is seen as more important than Solar Energy Potential, the importance level is marked on the side of Air Temperature.

Önem Derecesi Artışı	←								Eşit Seviye								→	Önem Derecesi Artışı
Ana Kriterler	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Değerlendirme Kriterleri**
Solar Energy Potential																		Air Temperature
Solar Energy Potential																		Slope
Solar Energy Potential																		Land Cover
Solar Energy Potential																		Aspect
Solar Energy Potential																		Elevation
Solar Energy Potential																		Annual Precipitation
Solar Energy Potential																		Proximity to Fault Line
Solar Energy Potential																		Proximity to Settlement
Solar Energy Potential																		Proximity to Transformer Centre
Solar Energy Potential																		Proximity to Natural Gas Line
Solar Energy Potential																		Proximity to Road
Solar Energy Potential																		Proximity to Stream
Solar Energy Potential																		Proximity to Railway
Solar Energy Potential																		Proximity to Lake and Dam
Solar Energy Potential																		Proximity to Landslide Site
Solar Energy Potential																		Proximity to Energy Transmission Line
Air Temperature																		Slope
Air Temperature																		Land Cover
Air Temperature																		Aspect
Air Temperature																		Elevation

Appendix 2 – Solar Power Plants Coordinates

No.	Y	X
1	32.256	39.987
2	32.984	39.579
3	32.858	39.658
4	31.571	40.098
5	31.515	40.099
6	31.518	40.100
7	31.996	40.178
8	31.967	40.168
9	33.090	40.171
10	33.139	40.226
11	33.160	40.223
12	33.173	40.240
13	33.185	40.248
14	32.747	39.268
15	32.757	39.172
16	33.080	39.815
17	32.616	39.597
18	32.615	39.582
19	32.646	39.554
20	32.635	39.548
21	32.130	39.384
22	32.100	39.380
23	32.093	39.376
24	32.096	39.374
25	33.761	38.845
26	31.531	40.089

No.	Y	X
27	31.547	40.097
28	32.247	40.033
29	32.250	40.036
30	33.166	40.207
31	33.029	40.338
32	33.033	40.335
33	33.012	40.074
34	33.009	40.069
35	33.064	40.045
36	33.111	40.043
37	33.119	40.044
38	33.163	40.035
39	33.150	40.013
40	33.140	40.001
41	33.117	40.006
42	33.111	40.002
43	33.129	39.987
44	33.210	39.977
45	33.213	39.984
46	33.256	39.942
47	32.559	40.208
48	32.526	40.243
49	32.550	40.210
50	33.121	40.073
51	33.121	40.077
52	33.051	40.049

No.	Y	X
53	33.146	40.155
54	33.081	39.813
55	32.354	39.992
56	32.842	39.645
57	32.853	39.619
58	32.809	40.321
59	32.773	40.327
60	32.700	40.358
61	32.709	40.404
62	32.574	40.170
63	32.578	40.169
64	33.144	39.882
65	33.425	40.126
66	33.407	40.171
67	33.492	40.163
68	33.660	38.932
69	33.590	39.013
70	32.600	40.173
71	32.858	40.275
72	32.851	40.255
73	32.819	40.221
74	32.856	40.179
75	32.884	39.695
76	32.905	39.692
77	33.286	39.214
78	33.171	39.162

No.	Y	X
79	31.915	39.699
80	31.959	39.700
81	31.968	39.698
82	31.966	39.701
83	31.957	39.640
84	32.557	39.673
85	31.842	40.083
86	31.883	40.034
87	32.020	40.226
88	33.278	39.743
89	32.275	39.876
90	32.377	39.896
91	32.481	40.109
92	32.967	40.236
93	32.639	40.227
94	32.731	40.355
95	32.273	39.873
96	33.030	40.336
97	33.066	40.047
98	32.376	39.892
99	32.377	39.894
100	32.565	40.022
101	32.481	40.111
102	33.144	39.881
103	33.145	40.152