SITE SELECTION FOR FLOATING PHOTOVOLTAIC (PV) PANELS ON 8 HEPP RESERVOIRS IN TURKEY BY USING ANALYTICAL HIERARCHICAL PROCESS (AHP)

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

KAAN GÖLLÜ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

SEPTEMBER 2022

Approval of the thesis:

SITE SELECTION FOR FLOATING PHOTOVOLTAIC (PV) PANELS ON 8 HEPP RESERVOIRS IN TURKEY BY USING ANALYTICAL HIERARCHICAL PROCESS (AHP)

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ABSTRACT

SITE SELECTION FOR FLOATING PHOTOVOLTAIC (PV) PANELS ON 8 HEPP RESERVOIRS IN TURKEY BY USING ANALYTICAL HIERARCHICAL PROCESS (AHP)

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Master of Science, Civil Engineering
Supervisor : Assoc. Prof. Dr. Elif Oğuz

September 2022, 120 pages

Energy production from Floating Photo Voltaic (FPV) systems is a promising field of technology that is expected to play an increasingly significant role in worldwide energy demand. FPV is a great alternative to traditional solar energy since it can increase the existing energy yield while supporting the electrical infrastructure and hydropower stations. Encompassing multifaceted criteria, site selection is a critical component in determining the overall success of FPVs. The purpose of this study is to present a site selection suitability analysis using Analytical Hierarchy Process (AHP), which is one of the Multi-Criteria Decision Making (MCDM) methods combined with Ordered Weighted Averaging (OWA). 10 site selection criteria related to the technical, economic and social were identified and a questionnaire was conducted among the field experts of solar energy. Then, a consensus analysis was carried out using consistent questionnaire results to reach a definitive decision of experts. This analysis gives relative weights of each site selection criterion. After that, 8 Hydroelectrical Power Plants (HEPPs) having water reservoirs were selected in different locations of Turkey to establish Floating PVs. The solar energy experts filled another questionnaire to evaluate each selected site for each site selection criterion. Then a new consensus analysis is performed for selected sites. According to the result of the study, although every selected site's weight seems close to each other, Kemer HEPP, located in Aydın, Western Turkey, is found as the most feasible site among other alternatives to establish a Floating PV.

Keywords: Site Selection, Analytical Hierarchical Process (AHP), Floating PV, Solar Energy, Multi-Criteria Decision Making (MCDM)

ÖZ

TÜRKİYE'DEKİ 8 HES REZERVUARI ÜZERİNDE YÜZER FOTOVOLTAİK (PV) PANELLER İÇİN ANALİTİK HİYERARŞİK PROSES (AHP) YÖNTEMİYLE YER SEÇİMİ

Göllü, Kaan
Yüksek Lisans, İnşaat Mühendisliği
Tez Yöneticisi: Doç. Dr. Elif Oğuz

Eylül 2022, 120 sayfa

Yüzer Foto Voltaik (FPV) sistemlerden enerji üretimi, dünya çapında enerji talebinde giderek daha önemli bir rol oynaması beklenen, umut verici bir teknoloji alanıdır. FPV, elektrik altyapısını ve hidroelektrik santrallerini desteklerken mevcut enerji verimini artırabileceğinden geleneksel güneş enerjisine harika bir alternatiftir. Çok yönlü kriterleri kapsayan alan seçimi, FPV'lerin genel başarısını belirlemede kritik bir bileşendir. Bu çalışmanın amacı, Çok Ölçütlü Karar Verme yöntemlerinden biri olan Analitik Hiyerarşi Süreci ve Sıralı Ağırlıklı Ortalama yöntemi beraber kullanılarak, uygun alan seçimi analizi sunmaktır. Teknik, ekonomik ve sosyal alanlar ile ilgili 10 alan seçim kriteri belirlenmiş ve güneş enerjisi alanında uzman kişiler arasında anket çalışması yapılmıştır. Ardından, uzmanların kesin bir kararına varmak için, tutarlı anket sonuçları kullanılarak, fikir birliği analizi yapıldı. Bu analiz ile her bir alan seçim kriterinin göreceli ağırlıkları elde edildi. Daha sonra Türkiyenin farklı bölgelerinde, Yüzer Foto Voltaik sistem kurulabilecek rezervuara sahip 8 adet hidroelektrik santrali alternatif alan olarak belirlenmiştir. Ardından güneş enerjisi alanında uzman kişiler tarafından, her alternatif alanın, her bir seçim kriteri için kıyaslanmasının yapıldığı anket doldurulmuştur ve fikir birliği analizi yapılmıştır.

Çalışmanın sonucunda, belirlenen her alanın FPV kurulumu için uygunluğu birbirine yakın görünse de, Aydın ilinde yer alan Kemer Hidroelektrik Santrali diğer alternatifler arasında en uygun alan olarak değerlendirilmiştir.

Anahtar Kelimeler: Alan Seçimi, Analitik Hiyerarşi Prosesi (AHP), Yüzer Foto Voltaik, Güneş Enerjisi, Çok Ölçütlü Karar Verme

To my family,

ACKNOWLEDGMENTS

I would like to express my thankfulness to my supervisor, Assoc. Prof. Dr. Elif OĞUZ for her guidance, advices, criticism and encouragement throughout my research.

I would like to thank Serkan GÖKMENER for his suggestions, comments and encouragement.

I would also like to thank to Emre HASPOLAT, Berhan MELEK, Selim HIZAL and Burak ÇOLAK for their technical support, advices, helpfulness and friendship during my study period.

Finally I would like to thank to my family for their support during my study period.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	
AHP	Analytical Hierarchical Process
CI	Consistency Index
CR	Consistency Ratio
EIA	The US Energy Information Administration
ELECTRE	Elimination and Choice Expressing Reality Enrichment Evaluations
EU	The European Union
FPV	Floating Photovoltaic
GHI	Global Horizontal Irradiation
GIS	Geographic Information Systems
HEPP	Hydro-Electrical Power Plant
IEO	The International Energy Outlook
IPCC	The Intergovernmental Panel on Climate Change
MCDM	Multi-Criteria Decision Making
OWA	Ordered Weighted Averaging
PROMETHEE	The Preference Ranking Organization Method for Enrichment Evaluation
PSP	Pumped Storage Power System
PV	Photovoltaic

RI	Random Consistency Index
TODIM	Tomada de Decisao Interativa Multicriterio
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TIFNS	Triangular Intuitionistic Fuzzy Numbers
UN	The United Nations
VIKOR	ViseKriterijumsa Kompromisno Resenje

LIST OF SYMBOLS

SYMBOLS

a_{ij}	Element in i^{th} row and j^{th} column in pairwise comparison matrix
$\bar{a}_{ij}$	Element in i^{th} row and j^{th} column in normalized pairwise comparison matrix
a_{ij}^*	Element in i^{th} row and j^{th} column in modified pairwise comparison matrix
$a_{ij,r}$	Element a_{ij} in pairwise comparison matrix for r^{th} participant
A_i, A_j	Pairs of alternatives
GCI	Group Comparison Index
GCI_r	Group Comparison Index for r^{th} participant
g_{ij}	Element in i^{th} row and j^{th} column in group pairwise comparison matrix
m	Number of alternatives
n	Number of decision criteria
λ_{max}	Maximum eigenvalue of the matrix
W_i	Relative weight of i^{th} decision criteria

CHAPTER 1

INTRODUCTION

Energy is one of the concrete blocks of human civilization to be able to maintain and develop humankind's life. Therefore, it can be considered a driving force of change and development. As the human population grows, an increase in energy demand is inevitable (Rybár et al., 2015). Despite being defined as the "ability to do work" (U.S Energy Information Administration, 2021), the social, political, and environmental aspects of energy remain a more complex concept than its scientific definition. In fact, whether energy is the cause, effect or the core of social and institutional change has been a topic of conversation in the academic world (Shove and Walker, 2014).

As of 2021, population of the world is 7.8 billion. According to United Nations' projections, by the year 2100, the world population will increase 10.9 billion (UUNN, 2019), which will bring an increase in energy demand by 49% in the next 25 years (Uyan, 2013). Even in 2020, the global energy demand saw only a 4,5% decrease despite facing lockdowns worldwide due to the Covid-19 pandemic, which was the most significant decline since 1945 (BP Energy, 2021).

As the energy demand increases, the world still substantially meets this demand with traditional energy sources, such as coal, oil, and natural gas (BP Energy, 2021). Traditional energy sources are limited by definition and, therefore, not an option to feed the ever-growing energy demand of the world. However, other energy sources such as nuclear, hydropower, wind, solar, and biofuels are yet to rank among the main participants, as shown in Figure 1.1.

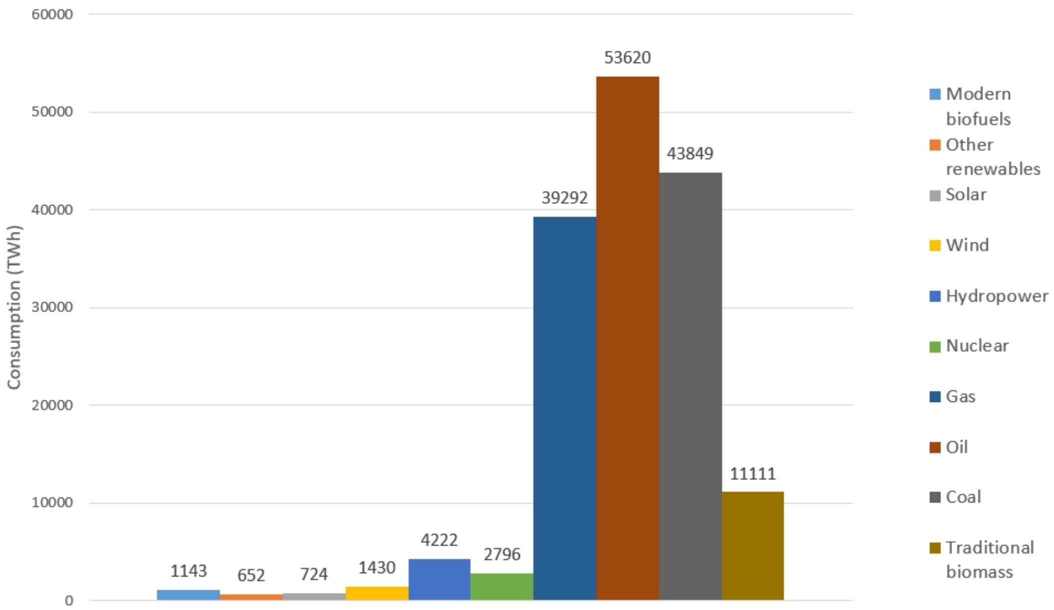

Figure 1.1. Global primary energy consumption by source retrieved from BP Statistical Review of World Energy, 2021

In addition to their unsustainability, traditional energy sources have been a prominent concern from an environmental perspective. The Intergovernmental Panel on Climate Change (IPCC) has stated that the current status will bring about a 3 °C increase in global warming by 2100. IPCC suggests that 70–85% of the world's electricity has to come from renewable sources by 2050 (Vanegas Cantarero, 2020). Hence, low-carbon energy systems have started to become critical solutions for both economic and environmental aspects.

In conclusion renewable energy sources are needed to meet the energy requirements in a sustainable manner. Thus, decision and policy making become increasingly critical for countries. A lasting energy policy should take a range of technical, economic, environmental, and social criteria into account while selecting energy projects, energy alternatives and power plant site selection.

1.1 Renewable Energy

Renewable energies are infinite energy sources that regenerate in nature. The Sun, oceans, rivers, wind, tides, geothermal and biomass can be classified as renewable energy sources (Ellabban et al., 2014).

1.1.1 Global Status and Potential of Renewable Energy

As climate change becomes more apparent, countries and unions are looking for ways to generate sustainable and cleaner energy. Hence, governments have started to take national and international actions to spread the usage of natural energy sources rather than traditional ones.

The 1992 United Nations (UN) Conference on Environment and Development, which resulted in UN Framework on Climate Change, was the first significant action emphasizing the importance of renewable energy. The framework was later followed by the Kyoto Protocol of 1997 and is considered an important milestone in supporting and encouraging renewable energy (Tahri et al., 2015).

After the Kyoto Protocol, different countries and unions started developing policies on renewable energy systems. One of the most successful examples is the European Union, where over one-fifth of the energy is used for heating and cooling from renewable sources. The European Union almost achieved the goal of 20% of the energy generation from renewable energy sources in 2019 with a score of 19.7% (EUROSTAT, 2021).

In 2021 The International Energy Outlook (IEO) highlighted that renewables would be the primary energy source; on the other hand, natural gas, coal, and increasingly batteries should be used to help meet load and support grid reliability. However, the report also pointed out that energy-related carbon dioxide emissions will increase through 2050 due to population and economic growth. Furthermore, oil and gas production is still expected to grow as it is being utilized for developing Asian economies (EIA, 2021).

Despite the situation, renewable energy continues to grow both industrially and technologically. Hydropower takes the lead as the largest source of renewable energy generation with ~4 trillion kWh, followed by wind with ~1.9 trillion kWh, solar with 1 trillion kWh, and other renewables, respectively (EIA, 2021).

Although renewable energy has many advantages, it is also worth noting its possible drawbacks. For example, biomass energy is a widespread energy source and can be used to burn waste products. However, it causes air pollution and is often not cost-effective. Hydropower is also another clean energy source. Yet, it can cause disruption to the ecosystem. Furthermore, energy generation from hydropower requires a suitable water body to work on which limits the implementation. Another effective renewable energy source is wind which does not cause pollution. However, wind farms are dependent on wind and require large lands, which can impact the landscape significantly. The well-implemented solar energy is another type of renewable energy which provides a clean and sustainable solution. Nevertheless, it relies on sunny days and requires storage and backup (Ellabban et al., 2014).

1.2 Energy Situation and Renewable Energy Potential of Turkey

Population plays a critical role in energy demand. Turkey hosts a very young population, with 15.4% of the nation consisting of people between the ages of 15-24 (TUIK, 2022). Such a young population combined with growing industry and urbanization makes Turkey need massive energy (Toksari, 2007).

Turkey continues to generate most of its energy needs from traditional sources, mainly fossil fuels in thermal power plants (TSKB, 2020).

Turkey’s energy generation by traditional energy sources is not favorable due to environmental concerns. Turkey's imported energy dependency ratio remains at

75%, whereas for the neighboring EU, this ratio is at 54% and continues to drop due to long-term and sustainable energy strategies (Uğurlu and Gokcol, 2017).

However, as Turkey has a great potential of renewable energy sources, the government is deploying new policies to encourage clean and sustainable energy (Çapik et al., 2012).

1.3 Solar Energy

The energy industry enters a new phase and reestablishment in the 21st century as more environmentally friendly, renewable, and sustainable options are coming into the scene. The movement gathered support from the public as well as the international policies deployed all over the world (Hardvard Business Review, 2019).

Solar energy is a clean and infinite energy source and can be utilized in many different ways, such as generating electricity, hot water, heating, and cooling (EIA, 2021).

A Harvard Business Review by Katherine White, David J. Hardisty, and Rishad Habib in 2019 suggested that the general public, but especially younger generations such as millennials, promote and encourage brands that have sustainable production. The governments are also introducing new energy policies and emphasizing the importance of global cooperation, such as the Kyoto Protocol. These advancements have created an attraction to solar energy, and a new concept of floating solar power plants was introduced (Hardvard Business Review, 2019).

1.3.1 Solar Energy in Global

World's energy demand is growing rapidly owing to the expanding population as well as technological advancements for which fossil fuels such as natural gas, petroleum and coal are among the most used and preferred energy sources. However these limited resources are used unplanned without much regard to environmental concerns and future considerations. Inexhaustible, clean and cost-effective renewable energy sources such as solar energy is a freely available natural resource that could potentially replace fossil fuels. Additionally, solar energy can provide more economic gain compared to fossil resources and it is superior to traditional energy sources in terms of accessibility, capacity and efficiency (Kannan and Vakeesan, 2016). While solar energy is exponentially and globally increasing to respond to energy crises and climate change, economic barriers to its deployment are decreasing (Hernandez et al., 2019). Therefore, the next century seems to be important in using the sun and its derivatives and other inexhaustible and clean energy resources (Soydan, 2021). Currently, China has the largest installed PV power in Asia with 175 GW alongside Japan with an installed power of 56 GW. Excluding Turkey, Europe follows Asia with 115 GW of installed power. The USA has the largest capacity of solar PV with 62 GW, contributing to 74 GW in the American continent (Celik and Özgür, 2020). Accordingly, the advantages of the use of renewable energy are recognized thanks to the large-scale investments made by countries such as China, Japan, USA, India and Germany. The cumulative capacity of PV is expected to hit 1 TW level between 2025 and 2030 (Y. Chen et al., 2018). In terms of the developments in the EU, the target is to reach renewable energy set at 32% for 2030 (Celik and Özgür, 2020). In 2020, the global share of energy consumption based on solar energy is 12% in the world (Soydan, 2021).

1.3.2 Solar Energy in Turkey

Turkey has a great solar energy potential measured to be equivalent to 1.3 billions ton of oil (Toklu, 2013). Turkey has 2993 sunshine hours with 1460 kWh/m^2 per year generation potential in the South East Anatolia region. The Black Sea Region has the rainiest days and has 1971 sunshine hours amounting to 1460 kWh/m^2 per year (Toklu, 2013). This is no surprise as Turkey is located between 36°C and 42°N latitudes, which is considered a sunny belt with a good margin for solar energy

(Sözen and Arcaklioğlu, 2005). Figure 1.2 shows the solar energy potential of Turkey.

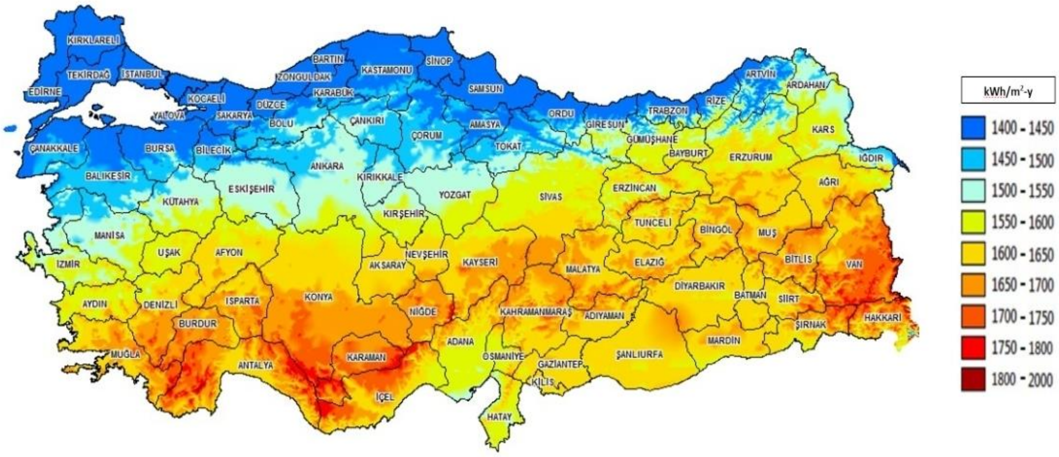

Figure 1.2 Turkey Solar Energy Potential Map (retrieved from Republic of Turkey Ministry of Energy and Natural Resources)

Since Turkey has an average sunshine duration of 7.5 hours and solar energy intensity of 12.96 MJ/m^2 a day, the solar potential of the country is measured at 1015 kWh which is estimated to be 5700 times its current electric use (Kaygusuz and Avci, 2018).

Turkey is a very densely populated country; therefore, the most suitable area for solar power plants is the wastelands in which urban development and agriculture cannot be utilized. Estimations showed that Turkey has 243.000 km^2 of wasteland and most of the wastelands are located in the Southeastern part of Turkey (Kaygusuz, 2011).

Solar energy is mainly used for water heating in Turkey. PV systems, on the other hand, are still in development. Observation towers of the Ministry of Agriculture and Forestry, lighthouses of Turktelekom, and other lighthouses and highways make up most of the PV effort in Turkey. Other applications include small R&D facilities in university programs such as METU GÜNAM or Renewable Energy Research Center in Gebze Technical University (Karataş, 2009).

1.4 Scope of the Thesis

This study aims to find the most suitable site among pre-selected HEPP reservoirs in Turkey using Analytical Hierarchy Process (AHP) and Ordered Weighted Averaging (OWA) methods.

In Chapter 2, previous studies on site selection of solar PV systems using MCDM methods are summarized and the ones similar to this study are listed. The site selection criteria in the literature are also determined to be used in this study. Then floating PV, a relatively new technology compared to existing renewable energy generation systems, is explained in detail. Also, comparison of land-based solar PVs and floating PVs are given.

Chapter 3 explains Analytical Hierarchy Process and Ordered Weighted Averaging methods. The questionnaire for the site selection criteria used in this study is explained. Then, properties of the alternative sites for this study are presented. Afterwards, a second set of questionnaires are conducted to rate the alternative sites per site selection criteria with the experts.

In Chapter 4, results of the questionnaires are analyzed by using AHP and OWA techniques and the results are combined in order to get the most suitable site for a Floating PV installation. Afterwards, the results of both site selection criteria questionnaire and alternative site questionnaire are discussed.

Finally, Chapter 5 includes the conclusions and recommendations for the future studies.

The contribution of this study is that:

- An extensive literature review is carried out and the methodology of this study is formed according to the previous studies.
- A great number of site selection criteria such as solar irradiation, annual sunshine hours, average temperature, topographic elevation, water depth, distance to settlements, distance to grid connections, local average wind

speed, impacts on regional development and local economies and social acceptance are explained (see details in Chapter 4).

- The spatial data existing on the General Directorate of State Hydraulic Works (DSİ) is considered. Annual Sunshine values are taken from the Turkish State Meteorological Service and scaled from “very low” to “very high”. The data concerning Global Horizontal Irradiation (GHI) and Average Temperature are taken from Global Solar Atlas. After deciding on 8 alternative sites, the rest of the information concerning the water reservoirs is mainly acquired from Global Wind Atlas, Google Earth and Open Infrastructure Map, which are utilized for data necessary to determine the criteria; local average wind speed, distance to settlements and distance to grid connections.
- Since there is already a limited number of research on FPV systems, this study can be considered among the few research conducted on master’s level.
- Site selection is one of the most integral components in determining the success of FPVs. Turkey is still at the early stages of FPV technology. This study is an extensive site selection study covering 10 site selection criteria and 8 alternative sites all around the country by using MCDM methodology AHP combined with OWA.

CHAPTER 2

LITERATURE REVIEW

In this chapter, MCDM methods are explained and previous site selection studies on both land based and floating PVs are mentioned. Then, the site selection criteria in this study are determined and explained in detail. Afterwards, the chronological development and the details of floating PV systems are explained briefly. Following this, benefits and challenges of FPV are given. Then, a comparison of land based PVs and floating PVs are presented. Finally, the current situation of the world and Turkey on FPV systems are explained.The Geographic Information System (GIS) is an effective tool for preparing, analyzing and editing data, maps, or other spatial information. So, the usage of GIS for site selection studies has been increasing day by day. Developing a decision support model that combines a GIS with several criteria will make it easier to choose the best location for a solar energy facility. Several criteria related to the location of a solar PV plant impact the feasibility of solar PV investment. Therefore, evaluation of different criteria to select an optimal site for a solar PV plant is critical. In this manner, multi-criteria decision-making (MCDM) methods are frequently used to consider different criteria and select the optimal site for solar PV installation. Although there are several MCDM methods such as AHP, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIseKriterijumsa Kompromisno Resenje (VIKOR), Elimination and Choice Expressing Reality Enrichment Evaluations (ELECTRE), The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) and fuzzy decision-making methods, the most frequently applied method for site selection studies is AHP and the combination of AHP with other decision techniques. AHP, which was developed by Saaty in the 1970s, organizes and evaluates complex decisions based on mathematics and human judgment. Also, AHP provides decision-makers to handle complex decision-making processes and choose the optimal solution (Jankowski, 1995). With a potential to speed up multi-objective programming analyses, AHP offers a practical method for establishing an initial linear approximation of such an unexpressed utility function. Another advantage is using the consistency ratio to improve decision-maker evaluation (Olson, 1988). Pairwise comparisons, used by AHP to handle both the subjective and objective aspects of a decision, help to simplify the case. The AHP method can also be integrated with other MCDM techniques in addition to being used alone (Al Garni and Awasthi, 2017).

As it can be seen in Table 2.1, most of the studies in the literature have been conducted for site selection studies by applying the AHP-based approaches. Also, a considerable number of studies have been performed using fuzzy methods. Fuzzy set theory is often used to analyze situations that MCDM techniques cannot solve by strenghening the decision theory.

Table 2.1 Some of the Previous Studies Related to Solar Photovoltaic (PV) Site Selection

No	*Reference*	*Applied Methodology*	*Renewable Energy Sources*	*Location*
1	(Charabi and Gastli, 2011)	GIS based spatial fuzzy	Solar PV	Oman
2	(Aydin et al., 2013)	GIS-based spatial fuzzy multi-criteria evaluation	Wind-Solar PV	Turkey
3	(Sánchez-Lozano et al., 2013)	GIS and MCDM	Solar PV	Murcia, Spain
4	(Uyan, 2013)	GIS and AHP	Solar PV	Konya, Turkey
5	(Yun-Na et al., 2013)	Ideal Matter-Element Extension method	Wind-Solar PV	China
6	(Jun et al., 2014)	ELECTRE-II	Wind-Solar PV	China
7	(Tahri et al., 2015)	GIS and AHP	Solar PV	Morocco
8	(Georgiou and Skarlatos, 2016)	GIS and AHP	Solar PV	Cyprus
9	(Lee and Lee, 2016)	GIS+AHP	Floating PV	South Korea

Table 2.1 Some of the Previous Studies Related to Solar Photovoltaic (PV) Site Selection (continued)

No	*Reference*	*Applied Methodology*	*Renewable Energy Sources*	*Location*
10	(Merrouni et al., 2016)	GIS	Solar PV	Eastern Morocco
11	(E. Noorollahi et al., 2016)	GIS based spatial fuzzy	Solar PV	Iran
12	(Sabo et al., 2016)	GIS	Solar PV	Malaysia
13	(Sánchez-Lozano et al., 2016)	GIS, AHP, TOPSIS-ELECTRE	Solar PV	Spain
14	(Al Garni and Awasthi, 2017)	GIS and AHP	Solar PV	Saudi Arabia
15	(Asakereh et al., 2017)	GIS based Fuzzy-AHP	Solar PV	Iran
16	(W. Chen et al., 2017)	AHP and Fuzzy PROMETHEE	Wind-Solar PV	-
17	(Doljak and Stanojević, 2017)	GIS and AHP	Solar PV	Serbia
18	(Merrouni et al., 2016)	GIS and AHP	Solar PV	Eastern Morocco
19	(Vasileiou et al., 2017)	GIS and AHP	Floating Wind-Wave	Greece
20	(Loukogeorgaki et al., 2018)	GIS and AHP	Wind-Wave	Greece
21	(Yousefi et al., 2018)	GIS and Boolean Fuzzy Logic Model	Solar PV	Iran
22	(Colak et al., 2020)	GIS and AHP	Solar PV	Turkey
23	(Dhunny et al., 2019)	GIS and Fuzzy	Wind-Solar PV	Mauritius
24	(Dikmeoğlu, 2019)	GIS based MCDM	Solar PV	Beypazarı, Turkey
25	(Doorga et al., 2019)	GIS and AHP	Solar PV	Mauritius
26	(Majumdar and Pasqualetti, 2019)	GIS	Solar PV	Arizona, USA
27	(Solangi et al., 2019)	AHP-Fuzzy VIKOR approach	Solar PV	Pakistan
28	(Spencer et al., 2019)	GIS	Floating PV	USA
29	(Eshra and Amin, 2020)	GIS and AHP	Floating Wind-Floating Solar PV-Wave	Saudi Arabia
30	(N. Lee et al., 2020)	GIS	Floating Solar PV-Hydropower	-
31	(Nebey et al., 2020)	GIS+AHP	Floating PV	Ethiopia

Table 2.1 Some of the Previous Studies Related to Solar Photovoltaic (PV) Site Selection (continued)

No	*Reference*	*Applied Methodology*	*Renewable Energy Sources*	*Location*
32	(Al-Shammari et al., 2021)	GIS based MCDM	Solar PV	Saudi Arabia
33	(Elboshy et al., 2022)	GIS and AHP	Solar PV	Egypt
34	(Guo et al., 2021a)	hesitant fuzzy linguistic DEMATEL-PROMETHEE	Floating PV	China
35	(Günen, 2021)	GIS and AHP	Solar PV	Turkey
36	(Nyoni et al., 2021)	Weighted sum method	Floating Wind-Hydropower-Floating Solar PV	Zambia
37	(Settou et al., 2021)	GIS and AHP	Solar PV	Algeria
38	(Soydan, 2021)	GIS and AHP	Solar PV	Turkey
39	(Spyridonidou et al., 2021)	GIS based MCDM	Wind- Solar PV	Israel
40	(Türk et al., 2021)	GIS-Fuzzy	Solar PV	Turkey
41	(Vagiona, 2021)	GIS-AHP-TOPSIS-VIKOR-PROMETHEE II	Solar PV	Greece
42	(Alhammad et al., 2022)	GIS and AHP	Solar PV	Saudi Arabia
43	(Caceoğlu et al., 2022)	AHP	Floating Wind	Northwest Turkey
44	(Y. Noorollahi et al., 2022)	GIS and Fuzzy-Boolean logic and AHP	Solar PV	Iran
45	(Zhou et al., 2022)	GIS based AHP-Fuzzy OWA	Floating Wind-Wave	Hainan, China

In the literature, most of the studies have been carried out for site selection of land-based PVs. Also, several studies have been found for the site selection of hybrid energy systems that combine solar and wind energy systems. On the other hand, there are a limited number of studies in the literature, with only 4, about FPV site selection. In addition, studies on hybrid energy systems, including FPVs, have been found. Some of the comprehensive studies that are listed in Table 2.1 are mentioned.

2.1 Site Selection Studies on Land-Based Solar PV Systems

One of the earliest studies on solar PV site selection was conducted by Charabi and Gastli in 2011. They used a GIS-based spatial fuzzy multi-criteria evaluation method to determine feasible regions in Oman for installing solar PV plants. By analyzing 3 main criteria and 9 sub-criteria, 0.5% of the study area were classified as highly suitable for solar PV investment (Charabi and Gastli, 2011). By combining the GIS and AHP methods, Sánchez-Lozano et al. (2013) identified potential locations (i.e., alternatives) for the installation of solar PV plants in Cartagena, southeast Spain. The location was determined to be the main factor in choosing a solar PV site based on the analysis's findings. Climate, geomorphology, and environment were the other primary factors that were arranged in declining order of importance (i.e., based on their weights). Additionally, it was said that the solar irradiation and the distance of the solar PV plant from the power lines were the two most crucial sub-criteria for installing solar PV plants. In conclusion, 3.206%, 9.591%, and 0.773% of the Cartagena region were classified as excellent, very good, and good for solar PV installation, respectively. Asakereh et al. (2017) used a multi-staged GIS-based integrated Fuzzy-AHP method to investigate the suitability of the Khuzestan region in Iran for solar PV installation. In the first stage, fuzzy membership functions were created for the distances of agricultural lands, wetlands, urban and rural areas, forests, wildlife, slope and inapplicable regions, e.g., road networks, sand dunes, flood zones to possible solar PV sites. In the second stage, the AHP method was used in order to calculate scores of criteria as the solar energy potential, environmental constraints and availability of transport connections. Based on the results, solar energy potential was obtained as the most important criteria, while the transport connection was at least. Solangi et al. (2019) applied the AHP method to 7 main criteria and 20 sub-criteria for the assessment of solar PV site selection in Pakistan. According to their study, location and distance to on-grid transmission lines are the most significant main criteria and sub-criteria, respectively. Then, in order to rank 14 alternatives in terms of solar PV installation suitability, the Fuzzy-VIKOR method was used. Al-Shammari et al. (2021) stated that the solar irradiation and then the average temperature had the highest weight, whereas the carbon emission reduction and population density had the lowest based on AHP analysis. Obtained criteria weights regarded to AHP analysis were integrated to 17 alternatives to select the best one by using the TOPSIS method.

2.2 Site Selection Studies on Floating PV Systems

Lee and Lee (2016) performed a study in order to determine the suitable waterbodies to install FPV in South Korea. Nine criteria were considered, and unsuitable areas were eliminated based on the limit values of criteria by using GIS. Then, the AHP method was applied to gain weights of the criteria based on experts' opinions. Based on AHP analysis, the most important criteria were stated as solar irradiation and precipitation were less. Finally, combining AHP results and GIS, the suitability map was presented.

Spencer et al. (2019) examined the FPV potential of artificial water reservoirs in the United States. The waterbodies were filtered in GIS software by applying five exclusion criteria as water depth, availability of transmission, the purpose of the reservoir, duplicate waterbodies and surface area of the reservoir. In conclusion, 24419 waterbodies were evaluated as suitable for FPV installation. Moreover, filtered waterbodies' potential electric generation capacity was analyzed using the System Advisor Model (SAM) tool with a capacity density assumption of 10,000 m^2/MW. The evaporation rate reduction and average avoided land purchase costs because of the installation of FPV were also evaluated.

Nebey et al. (2020) analyzed the three irrigation dams in the Amhara region, Ethiopia, by applying the GIS-AHP method to determine the suitable areas of the reservoirs for FPV installation. Four criteria, the distance from land, the reservoir's surface area, forest distance and water depth, were taken into account during the evaluation phase. According to the analysis results, approximately 60% of the water surface area of three reservoirs has been found suitable for FPV installation.

Guo et al. (2021b) prepared a site selection framework for the FPVs. 11 exclusion and 16 evaluation criteria were considered in a two-staged analysis. A weighting model based on the hesitant fuzzy linguistic relative entropy was adopted based on experts' opinions. According to the results, the most critical factor for solar PV investment stated as the economic factor.

2.3 Site Selection Studies on Hybrid Energy Systems

Nyoni et al. (2021) used a ranking multi-criteria-based methodology to determine hydropower reservoirs for integrating hybrid connected onshore wind and floating PV systems in Zambia. In stage one, 14 hydropower reservoirs were filtered based on the reservoir's surface area, capacity factor, distance to grid and distance to the protected zone. In the second stage, FPV potential, energy export, ease of access and demand criteria were weighted to determine ideal alternatives within the 14 hydropower reservoirs.

Wu et al. (2014) used a hybrid MCDM technique to develop a two-stage framework for the offshore hybrid wind-photovoltaic-seawater pumped storage site selection. To ensure that the natural resources of the evaluated site match the minimal requirements of the units of the offshore hybrid wind-PV-SPS system, four exclusion criteria were established. Then, a second selection criterion for the second stage is designed based on natural, environmental, economic, and social issues and considers 19 sub-criteria. The criteria values are determined by triangular intuitionistic fuzzy numbers (TIFNS). The criteria weights are then assessed using the entropy weight approach to consider decision-making process uncertainties. The dominance of the alternative sites is ranked using the TODIM (Tomada de Decisao Interativa Multicriterio) method. Eshra and Amin (2020) applied the GIS-AHP method for site selection of hybrid renewable energy systems in the Red Sea, Saudi Arabia. In their study, solar, wave and wind energies were considered. The power density of the potential areas was determined. These areas were then classified based on the distance to the residential area, spatial location, topography and speed of the wind. In conclusion, the Northwestern of the Red Sea within the borders of Saudi Arabia was determined as the optimal site for building a hybrid energy system. A large-scale group decision-making framework was developed by Guo et al. (2021a) based on a probabilistic linguistic term set and fuzzy Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method for the site selection of an FPV-pumped storage power system (PSP). The two-stage strategy is used to establish the choice criteria. The initial stage of the decision-making process involves identifying the decision-making indicators using a literature analysis of prior site selection studies on FPV and PSP. The second stage involved setting the site selection criteria by experts with various backgrounds. 4 main criteria and 19 sub-criteria were considered during the analysis. The researchers used the PROMETHEE approach to incorporate the idea of the probabilistic linguistic term set and take into account the subjectivity of the weights assigned to the various criteria and the personal behaviors of the decision-makers (Guo, et al., 2021b).

In addition to the studies mentioned above, Aydin et al. (2013), Chen et al. (2017), Dhunny et al. (2019) applied GIS-based Fuzzy methods for site selection of integrated wind-solar PV systems; on the other hand, Yun-Na et al. (2013), Jun et al. (2014), Spyridonidou et al. (2021) applied GIS-based MCDM methods. Moreover, Vasileiou et al. (2017) and Loukogeorgaki et al. (2018) used a combination of GIS and AHP methods to determine feasible locations for hybrid wind-wave energy systems and floating wind-wave energy in Greece, respectively.

2.4 Site Selection Criteria

Proper site selection for a floating solar PV system is required to develop a successful project. This study aims to use all criteria needed to establish floating PV panels in the best possible site. To this end, an extensive literature review conducted to discuss each criterion. Site election criteria used in previous studies are summarized in Table 2.2. They are additionally endorsed by experts' opinions in order to exclude personal bias. However, it must be noted that the literature on FPV is still very new; thus, there was a lack of specific case studies which take into consideration or prioritize water depth and average local wind as their main or subcriteria. In this study, social acceptance and economical impact on locas are taken into account as main criteria.

Table 2.2 Site Selection Criteria used in previous studies

Criteria	*Solar Irradiation*	*Annual Sunshine Hours*	*Average Temperature*	*Topographic Elevation*	*Water Depth*	*Distance to Settlements*	*Distance to Grid Connections*	*Local Average Wind Speed*	*Impacts on Regional Development*	*Social Acceptance*
Reference	- Choi and Munkhbat (2021) - Alhammad et al. (2022) - Taofik et al. (2021) -Kırcalı et al. (2021) -E. Noorallahi et al. (2016) -Suh et al. (2016) -Hassaan et al. (2020) -Dikmeoğlu (2019) -Merrouni et al. (2016) -Lozano et al. (2013)	-Kırcalı et al. (2021) -Suh et al. (2016) -Hassaan et al. (2020) -Habib et al. (2019) -Effat (2013) -Shorabeh et al. (2018)	-Taofik et al. (2021) -Kırcalı et al. (2021) -E. Noorallahi et al. (2016) -Suh et al. (2016) -Hassaan et al. (2020) -Lozano et al. (2013) -Solangi et al. (2019) -Türk et al. (2021) -Effat (2013) -Sindhu et al. (2017)	-Kırcalı et al. (2021) -Solangi et al. (2019) -Yousefi et al. (2018)	-Nebey et al. (2020) -Lopez et al. (2022)	-Choi and Munkhbat (2021) -Alhammad et al. (2022) -Kırcalı et al. (2021) -Nebey et al. (2020) -E. Noorallahi et al. (2016) -Suh et al. (2016) -Hassaan et al. (2020) -Uyan (2013) Dikmeoğlu (2019) -Merrouni et al. (2016)	-Choi and Munkhbat (2021) -Alhammad et al. (2022) -Kırcalı et al. (2021) -E. Noorallahi et al. (2016) -Suh et al. (2016) -Hassaan et al. (2020) -Uyan (2013) -Dikmeoğlu (2019) Merrouni et al. (2016) -Lozano et al. (2013)	-Kırcalı et al. (2021) -Lopez et al. (2022) -Türk et al. (2021) -Habib et al. (2019)	-Solangi et al. (2019) -Sindhu et al. (2017)	-Solangi et al. (2019) -Sindhu et al. (2017)

Table 2.2 Site Selection Criteria used in previous studies (continued)

Criteria	*Solar Irradiation*	*Annual Sunshine Hours*	*Average Temperature*	*Topographic Elevation*	*Water Depth*	*Distance to Settlements*	*Distance to Grid Connections*	*Local Average Wind Speed*	*Impacts on Regional Development*	*Social Acceptance*
Reference	-Solangi et al. (2019) -Lopez et al. (2022) -Castillo et al. (2016) -Yousefi et al. (2018) -Türk et al. (2021) -Settou et al. (2020) -Colak et al. (2019)-Tahri et al. (2015) -Habib et al. (2019) -Effat (2013) -Sindhu et al. (2017) -Shorabeh et al. (2018)					-Lozano et al. (2013) -Solangi et al. (2019) -Castillo et al. (2016) -Yousefi et al. (2018) -Kereush et al. (2017) -Settou et al. (2020) -Colak et al. (2019) -Tahri et al. (2015) -Habib et al. (2019) -Effat (2013) -Sindhu et al. (2017) -Shorabeh et al. (2018)	-Solangi et al. (2019) -Castillo et al. (2016) -Yousefi et al. (2018) -Türk et al. (2021) -Kereush et al. (2017) Settou et al. (2020) Colak et al. (2019) -Tahri et al. (2015) -Effat (2013) -Sindhu et al. (2017) -Shorabeh et al. (2018)			
#	**22**	**6**	**10**	**3**	**2**	**22**	**21**	**4**	**2**	**2**

Site selection criteria used in this thesis are briefly explained in the following subsections.

2.4.1 Solar Irradiation

Solar irradiation is the most fundamental factor in finding the potential site for solar power plants. It can be defined as the solar energy (light) arriving at the surface of the Earth on a yearly basis (Perpiña-Castillo et al., 2016). In other words, it is the incident shortwave energy per unit area. It is essential to identify areas where solar radiation will be sufficient throughout the year because it can affect the average annual power performance. Generally, PV systems' efficiency is higher in sunnier regions. E. Noorollahi et al. (2016) carried out a study on solar energy potential of Iran where he suggested that due to the geographical location and climatic conditions, Iran had considerable solar irradiation. Thus, solar energy could be a major component in meeting the energy demand of the country. In this study, it was suggested that solar energy systems require minimum solar radiation of 1300 $kWh/m^2/year$ for economical operation. Similarly, Wang et al. (2016) state that receiving an annual solar radiation of 7000– 8400 MJ/m^2, Tibet region's rich solar energy resource is seen as a promising opportunity by the state government which implements special policies to encourage PV installations. When selecting a suitable site for solar PV in Oman, Charabi and Gastli (2011) considered solar irradiation as one of the study's three main criteria which will be maximized. As a part of selecting the optimal sites for constructing solar energy plants in Ismailia, Egypt, Effat (2013) used two different models to exclusively calculate the highest amounts of solar irradiation.

2.4.2 Annual Sunshine Hours

Climatic conditions, such as annual sunshine hour, have significant impacts on construction, foundations, system design and layout of FPVs. Also annual sunshine hours has impacts on system's reliability. Annual sunshine hours represent direct solar radiation duration exceeding a direct normal irradiance of 120 W/m^2. Sunshine hours are directly correlated with the amount of electricity production. For instance, Kırcalı and Selim (2021) used sunshine duration to be one of the main criteria in their study on Antalya's site suitability analysis and suggested that it plays a significant role in increasing the efficiency of solar PV. In a site suitability analysis of Kuwait, Hassaan et al. (2021) also argued that areas with lower average temperatures, lower average relative humidity, and higher sunshine duration are more favorable for siting solar PV systems. Parallel to the previous study, Shorabeh et al. (2019) related annual sunshine hours in direct relationship with other parameters such as latitude, cloudiness and dust. In comparing four provinces, Yazd is found to be one of the country's most significant regions for establishment of the power plants with more than 3000 hours average annual sunny day whereas Mazandaran has 1587 hours of average annual sunny day and does not have any prominent solar power plant. Suh and Brownson (2016) considered annual sunshine hours to be a main criteria in site selection and used the data of the past 20 years to calculate the annual sunshine hours in Ulleung Island in Korea.

2.4.3 Average Temperature

Temperature is another essential criterion in determining the efficiency of solar PV panels. It refers to the daily average temperature from 9 AM to 4 PM in summer (between the summer solstice and autumnal equinox day). Whenever the photovoltaic system exceeds 25 °C, it is highly disadvantageous for the photovoltaic system since high temperature can affect negatively on the system performance and the production capacity of silicium cells (Carrión et al., 2008). For every 1°C rise in the cell temperature above 25 ◦C, generated energy declines by about 0.4%–0.5% (Huld and Gracia-Amillo, 2015). Conversely, at temperatures below 25, the efficiency of solar PV panels increases. Indeed, high-temperature values affect the cells temperature, which causes a drop in the electricity production and the systems performance ratio also exemplified in the study concerning Eastern Morocco (Merrouni et al., 2016). In other words, high temperature risks the durability and lifetime of PV panels since they cause thermal stress on cells interconnectors and at the modules. Another study on average temperature carried out by Kesler et al. (2014). They conducted an analysis of PV power potential of Manavgat during winter season. Manavgat has famously one of the highest solar energy potentials in Europe. Yet, in winter and summer the temperature alters between 12 °C and 40 °C, respectively. Thus, Kesler et al. (2014) found that changes in temperature affects the performance of the PV systems because of the overall high temperature of the region. Consequently, Kırcalı and Selim (2021) found 21.1 °C and above of annual temperature the best in their study and noted that average temperature criterion is just as important as solar irradation and sunshine duration.

2.4.4 Topographic Elevation

The topographic elevation is concerned with the thickness and the compounds of the atmosphere. The atmosphere has influence on the entrance of energy of the sun to the earth. As the elevation of a region gets lower than sea level, the thickness of the atmosphere level increases. Thus, regions at higher elevations receive greater solar radiation than lower regions due a higher intensity of solar irradiance and shorter distance for the solar energy to reach the ground which result in large amounts of power generation (J. Liu et al., 2017). Likewise, PV panels can benefit from the clearer skies which are benefits of higher altitudes. An experiment on the Alps in Austria validates perfectly that high grounds have more solar potential than lower grounds. It was found that higher altitude has 42% more solar power output on the same experiment than it would have at a lower altitude (Chitturi et al., 2018). On the other hand, the topography of the land around the dam reservoir can create a shading effect on the water surface, affecting radiation values coming to the solar PV panel surface. For instance, in a site suitability study conducted on Demirköprü Dam in Manisa province, Yılmaz et al. (2022) found that the total amount of radiation falling on the surface decreases in the regions closer to the shoreline due to the effect of shading caused by the topography. Interestingly, Yousefi et al. (2018) used elevation as a subcriteria of the economic criteria and pointed out that it is challenging and uneconomic to build solar PV farms in mountainous high altitude lands, thus excluding areas above 2200 m from sea level unsuitable. Similarly, E. Noorollahi et al. (2016) estimated that 35.8% of the areas in Iran are restricted areas and advised for the implementation of small off-grid solar technology in those areas.

2.4.5 Water Depth

In order to operate a floating PV system, it is obvious that the reservoir requires sufficient water depth since the water depth directly affects the floating panels on the surface of the water. Furthermore, water depth would inevitably affect both the installation and maintenance of the panels on the surface of the water. The water depth is generally calculated by subtracting the dead water level of each reservoir from the water level. Water depth also pertains to water level fluctuation, seasonal changes, frozen regions and inflow of floating matters. Most significantly, López et al. (2022) has highlighted the importance of including water depth restrictions on floating photovoltaic modules. In their study on FPV potential in three dam reservoirs in Spain, variations of water level and depth restrictions were included in the analysis to determine electricity generation potential. With that being said, Spencer et al. (2019) demonstrated that covering 27% of water bodies with FPV in a water depth of 2 m can potentially account for 9.6% of the country's electricity generation. For smooth installation and operation of floating PVs, Kim et al. (2019) recommended that a reservoir having a water depth greater than 5 m and the water depth should be at least 1 m. According to Kim et al. (2019), a reservoir should have a minimum water depth over time for smooth installation and operation of FPV systems. In a study about the irrigation dams potential in Ethiopia, Nebey et al. (2020) has classified water depth greater than 4 m as highly usable, 3-4 m as usable, 2-3 m as moderately usable and less than 2 m as unusable. Finally, it is worth mentioning that water depth can be a useful parameter to increase energy output with different kinds of floating solar PV technology. For instance, Mittal et al. (2020) drawn conclusion that for submerged floating PV systems, water depth up to 8-10 cm can yield an increase in efficiency of the floating solar PV owing to the reduction of light reflection and absence of thermal drift.

2.4.6 Distance to Settlements

Although the criterion of distance to settlements is a standard parameter, approaches in the literature underlying them are considerably different. For a site suitability analysis in South Gondar, Ethiopia Nebey et al. (2020) considered the farthest distance from a town highly suitable and shortest as unsuitable for solar PV. Shorabeh et al. (2019) put forward the idea that installing solar power plants near urban districts and residential areas may have a negative impact on growth rate. Thus, for Shorabeh et al. (2019) areas within less than 500 m from residential regions are defined as limitations. Colak et al. (2020) highlighted also the fact that the site selection for solar PV plants should bear in mind the developmental direction of residential areas. Yet, the study also maintained that solar power plants should be close to the settlements to ensure that the energy needs of the region as well as the costs are met. Similarly, Yousefi et al. (2018) suggested that areas with a distance more than 20 km and less than 2 km to urban areas and more than 7 km and less than 500 m to rural areas were assessed as unsuitable. Another example would be, Taoufik et al. (2021) who concludes that a buffer distance is to prevent the most direct impacts and resistance of local communities, selecting regions more than 12 km to be highly suitable for solar farms' establishment. In light of aforementioned studies, areas which are closer to the settlements are determined to eliminate additional land permits and transportation costs in this study as well.

2.4.7 Distance to Grid Connections

Easy access to grid connections is highly beneficial in all stages of solar PV systems such as construction, operation and maintenance. Consequently, as the distance to the existing electricity grid becomes closer, transmission costs and power losses are significantly lowered. Grid connections must also be as close as possible to avoid possible electricity loss. Moreover, the construction of new lines would be considered uneconomic since they are more costly than having stations already in close proximity. In other words, distance to grid connection is a technical requirement as well as an economic concern. In this regard, Wang et al. (2016) presented the dilemma of Tibet. Although Tibet looks highly promising in terms of its solar energy potential, at the same time it faces a fundamental obstacle due to poor electrical infrastructure and lack of strategic planning on the issue. Having found the costs of construction of the electrical grid too high, the study ultimately decided to prioritize potential sites which are closer to electric substations. Similarly, in the study conducted on the regional potential for solar power for E-28 countries, Perpiña-Castillo et al. (2016) considered locations closer to existing roads more suitable than those far from the existing road network, with a cut-off value of 5000 m for unfeasible location. Yet, this can be said to change in different studies. For instance, in Mongolia's site suitability analysis Munkhbat and Choi (2021) rated power grids less than 25 km as good sites. On the other hand, in a case study of Algeria, Settou et al. (2021) preferred a buffer of 500 m and a limited distance of 50 km of proximity to the power line. Uyan (2013) considered less than 3000 m of grid connection as the perfect site selection for Turkey.

2.4.8 Local Average Wind Speed

Local average wind speed can either have a positive or a negative impact on floating PV systems' performance. López et al. (2022) reclassified wind speed as one of the main criteria in a study about the floating solar PV panels in bodies of water in mainland Spain. Similarly, Liu et al. (2017) also emphasized that wind speed should definitely be taken into consideration in the practical design of floating PV systems. In terms of positive impacts, Golroodbari and van Sark (2020) explained as other atmospheric conditions do, wind speed in particular, can reduce the cell temperature of a PV module. It is also known that wind speeds in open water tend to be higher than on land, thus facilitating module cooling (ESMAP, 2019). Hence, wind speed can have a significant effect on electricity generation. On the other hand, wind is mainly responsible for wave generation, which can affect the floating PV panels' performance. Since floating PV floats on the water surface, the installation can be predicted to move or rotate depending on wind speed. Indeed, high wind speeds can destabilize and damage FPV systems and substructures, calling for additional stress testing of structural components (Deveci et al., 2022). Habib et al. (2020) stated that wind speed exceeding 25-30 m/s is likely to be harmful for the PV panels’ surfaces. Although dusting in floating solar PV is significantly lesser than land-based solar PV, wind speed also plays a role in clearing the accumulation of dust particles off PV cell surfaces.

2.4.9 Impacts on Regional Development and Local Economies

The potential of new job opportunities inevitably arise during the installation process of floating solar PV technologies which, in return, will contribute to local development in terms of economy. In doing so, FPVs can contribute to the local development in terms of economy. It must be noted that floating solar energy creates lesser job opportunities compared to conventional solar energy technologies (Silva and Branco, 2018). Consequently, Solangi et al. (2019) observed that the more renewable energy resources create more job opportunities, the more they will be preferred by locals. Thus, a site selection plan that pays attention to the goals of regional development and takes into account local residents will likely provide profit by drawing in new investors to the area. Hence, economic efficiency of the solar power plants can be better ensured. In this regard, Sindhu et al. (2017) advised that the selected PV site must act as a supplementary source of employment with agriculture and farming sector to workers and must help in increasing the employment chances for deprived and exploited part of population such as women and poor young people suffering from long-duration unemployment. Furthermore, it is worth remembering that renewable energy systems such as floating solar energy can readily strengthen a country's economy by reducing its reliance on fossil fuels and by generating more electricity from renewables. In the conclusion of the study of Mondino et al. (2015), it is emphasized that problems of finding investors and creating enough financial income should always come first before any consideration on landscape can even begin. Doljak and Stanojević (2017) expressed their intention to deepen their analysis on site selection for solar PVs in Serbia through incorporating socio-economic factors which in turn will be useful for the establishment of national strategies and spatial plans.

2.4.10 Social Acceptance

It is important to establish a solid understanding that energy is the underlying force behind how societies are composed of and how those societies form their social practices. Shove and Walker (2014) emphasized that reframing the energy problem in terms of social theory is inseparable from the discussions of climate change and sustainability. As mentioned above, identifying the most suitable site for solar PV installations is a complex process due to a wide range of environmental, technical and socioeconomic criteria. Among such criteria, the social acceptance of the general public is essential in successful implementation of FPVs. In this case, social acceptance of the public can also include issues concerning the effects of solar PV technology on the local economy and tourism. Additionally, social acceptance is critical because time needed to complete a project may depend upon the potential delays which can be caused by public disapproval of the energy project (Lee and Chang, 2018). A big part of social acceptance is related to the visual component of the solar power plant. For instance, Fang et al. (2018) noted that majority of people living in potential PVP sites are mainly ethnic minorities. It is said that in China, belonging to different religious beliefs may hinder the social acceptance of such facilities. In fact, Fernandez-Jimenez et al. (2015) proposed "observability" as a part of the social acceptance problem as well as a part of social ranking criteria to find feasible places to establish floating solar systems. However, social criteria have been often omitted in previous research, which are just as significant as other criterion Fang et al. (2018). Similarly, Sindhu et al. (2017) acknowledged this research gap in the context of India. Furthermore, it is suggested that raising consumer awareness is crucial to break the social bias around renewable energy.

2.5 Floating Solar Power Plants

Floating PV is a new promising solar energy generation technology. Significant rise in electricity demand, fast depletion of fossil fuels and other environmental concerns worldwide have led to a remarkable increase in the employment of solar PV plants.

2.5.1 Background

The first pilot study on FPV technology was completed in 2007 and built in California in 2008. In a 2016 study, Kim Trapani and Miguel Redón Santafé pointed out that floating solar projects were introduced to meet the niche needs of specific areas. In this regard, Far Niente Wineries in California is a good example; floating solar panels were established because land itself was more valuable as it was being utilised for vineyard (Trapani, 2015). Trapani and Santafé presented the development of floating solar power plants in two phases. The first examples of FPV were built between the years 2007-2009. In this era of floating solar power plants, there is not a single system or design for the panels. In the literature, the first FPV studies date back to 2007 with the installation of a 20 kW in the reservoir of a hydroelectric dam in Aichi, Japan installed by the Japan National Institute of Advanced Industrial Science and Technology to investigate the performance of water and air-cooled PVs. Some of the other highlights of the era include the power plant in Bubano, Italy, where a commercially connected system of 500 kW was constructed. In this system, the panels were exposed to snow and ice for the first time. Again in 2009, 'Lotus Project' was established on top of an irrigation pond in Solarolo, Italy. Floating structure in the project was designed to float straight to land which the system makes easily accessible. Notably, in this era, evaporation reduction was emphasised and research was conducted on the subject. In Far Niente Wineries, it is realised that reduced water evaporation was one of the advantages of using floating solar power plants (Trapani, 2015).

Projects between 2010 and 2013 brought new concepts and innovations to floating solar power plants. In 2011, Petra Winery in Italy introduced a feature that enabled a tracking system that rotated according to the Sun's movement. A smaller version of this project was implemented on Lake Colignola in 2011. This installation followed a unique design as it included mirrors for additional solar radiation reflection onto the PV panels, much like the land based systems. The company SCINTEC which went on to deploy floating solar systems around the world, contributed to the advancement of technology quite a bit as they utilised and adapted different strategies for each unique terrain and climate condition. In this era, floating solar power plants were established for both industrial use and research purposes. In 2013, a research was carried out in Singapore, where estate prices are extremely expensive due to limited land. Another FPV installation for research purposes took place in Canada to further expand on the climate aspect of the floating solar power plants (Trapani, 2015).

By the end of 2014, a total of 22 photovoltaic power plants had been built in the world with the installed capacity from 0.5 to 1157 kW (Liu et al., 2017). Up to this point, floating solar panels were mainly limited to industrial and research purposes. Thus, they were contained to ponds, lakes, and otherwise small water bodies. After this initial phase of floating solar power plants, different projects started extending the use of FPVs in reservoirs of all purposes and scales worldwide. For instance in a study concerning the floating solar potential of Bangladesh in 2017, it was suggested that while land based solar power plants were not feasible for a populated country at that scale, the country's 57 rivers presented perfect grounds for implementing the floating option (Barua et al., 2017). Similarly, analysing the potential of pit lakes in Korea, Jinyoung Song and Yosoon have found that using the pit lakes in an open-pit mine for a large-scale floating PV system is economically beneficial and could significantly reduce greenhouse gas emissions (Song and Choi, 2016). Looking at this brief history, it would be safe to conclude that although there is a long way to go in terms of researching and developing the particulars of the floating solar power plants, it stands as an exciting branch of renewable energy sources with its own strengths and potentials to yield in the future.

2.5.2 Floating Solar PV System Technology and Components

Floating solar PV technology can be described as a type of PV system which floats on top of a body of water. In brief, it is technically and economically a feasible alternative to solar PV technology for its application of solar PV arrays on the surface of lakes, hydropower reservoirs, agriculture reservoirs, industrial ponds, and near-coastal areas. Floating solar PVs stand out since they help eliminate land-use competition and have higher energy yields (Sahu et al., 2016).

Regarding the general layout, FPV systems are similar to land-based PV systems, with few notable differences. A typical floating solar PV consists of a floating system (pontoon), an anchoring and mooring system, a PV system and an underwater cable. The PV modules on top of floating platforms are called floats to convert solar irradiation to energy and are kept in place by an anchoring and mooring system. Mooring system enables adjustment and stability against water level fluctuations and wind speed. Direct current generated by PV modules gathers in combiner boxes which are then converted to alternating current by inverters. An underwater cable can be used to transform electricity to the closest substation. It should be noted that there are different choices available under each component which renders floating solar PV technology highly adaptable and widely applicable (George and Patel 2019).

A schematic of a typical FPV system with its key components is shown in Figure 2.1.

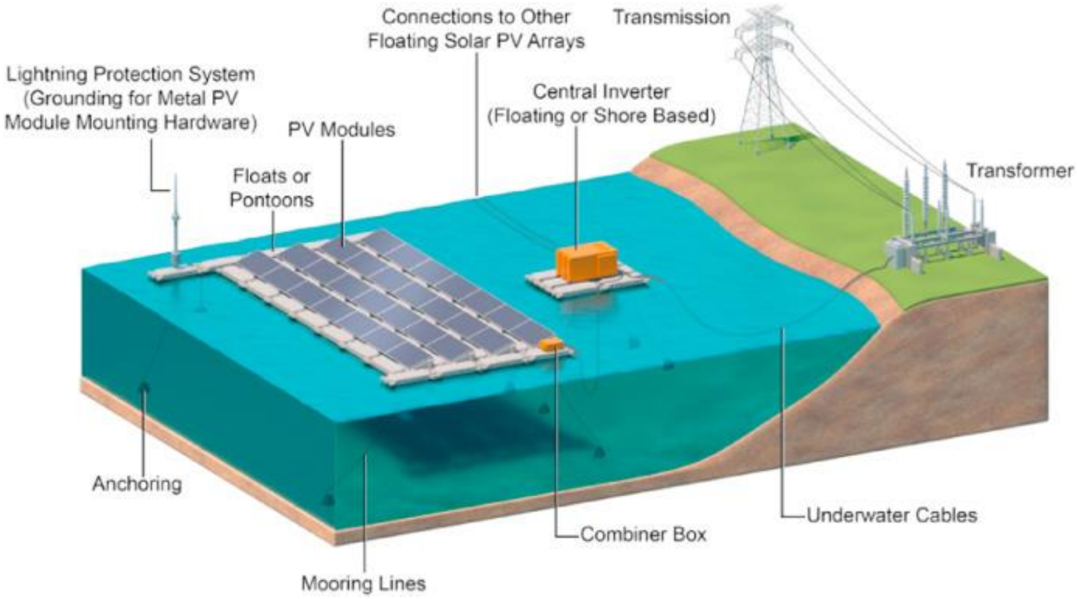

Figure 2.1 A schematic of a typical FPV retrieved from N. Lee et al. (2020)

2.5.2.1 Design and Configuration

The electrical configuration of floating PVs is similar to land-based PVs, except for PV arrays floating on water (ESMAP, 2019). The floating solar power plants can be implemented on different water bodies, including ponds, lakes, rivers, near-shore, and off-shore. Each surface has different design needs due to wind, waves, tides, and other conditions. In other words, different types of floating structures have their own characteristics in terms of ease of installation, convenience of expansion, structural stability, and cost (Ma et al., 2021). Furthermore, in order to increase the low output voltage of PV modules, various converter configurations are utilized which have the ability to raise the voltage to the desired value and make the grid integration of PV systems possible (Ranjbaran et al., 2019). As far as configuration is concerned, modular designs are usually done on flat water surfaces with a limited tilt for wind load consideration. Row spacing and configurations on floating islands can be determined by floating solar structure (ESMAP, 2019).

2.5.2.2 Platforms

Platforms are the foundations of any solar energy operation and they can be adjusted in design and material to fit the needs of the specific environment the solar PV is going to be built. Most operations prefer putting panels at a fixed angle on pontoon type floats, which are then anchored. However, the floating makeup can consist of floats alone which are “pure-float designs.” A pure float design has advantages because the operation can be scaled up or down without significant changes.

On the other hand, modules are installed very close to the water and the constant movement stresses joints and connectors. This can be problematic in off-shore operations, where the rough climate and water conditions are. Another solution is to cover the water surface to create a quasi-base to mount panels. This is simply achieved by spreading rubber mats for the panels to stand on. For areas with evaporation concerns, this mounting proves particularly useful. A completely different approach to this solution is to semi-submerge the panels into the water, which brings cooling benefits, although this remains an experimental concept (ESMAP, 2019).

2.5.2.3 Anchoring and Mooring

Anchoring and mooring design of a floating solar PV is a critical issue since these components are responsible for preserving the system's stability against water depth alterations and winds (Sahu et al., 2016). 3 types of anchoring and mooring are generally used in floating PV design: bank anchoring, bottom anchoring, or piles. Bottom anchoring is a well-established anchoring solution that is widely used in water-related industries as well as the vast majority of floating solar power plants across the world. Since bottom anchoring is implemented in developed industries, anchors can hold for up to 25 years, making them suitable for large-scale floating solar power plants. Bank anchoring is preferred for shallower water bodies such as ponds and is ideal for smaller operations. It is preferable to bottom anchoring since it is a more cost-effective mooring option. For shallow water bodies, piles can also be used. Usage of piles requires drilling and more workforce. Thus, it is more costly than anchoring (ESMAP, 2019).

2.5.2.4 Unconventional Floating PV Concepts

Since FPVs are subjected to many different terrains and climates, there have been unique FPV concepts that are innovative and novel. One of these concepts is tracking, which is achieved by rotating the entire platform from east to west following the Sun. Although the tracking systems can be costly, the pilot tacking operations in Navacchio and Suvereto in Italy (see Figure 2.2) were established to observe their performance (Patil et al., 2017). Another concept is the “Concentrated FPV” in which Fresnel lenses are incorporated to create a degree of concentration, making it a natural pair to track.

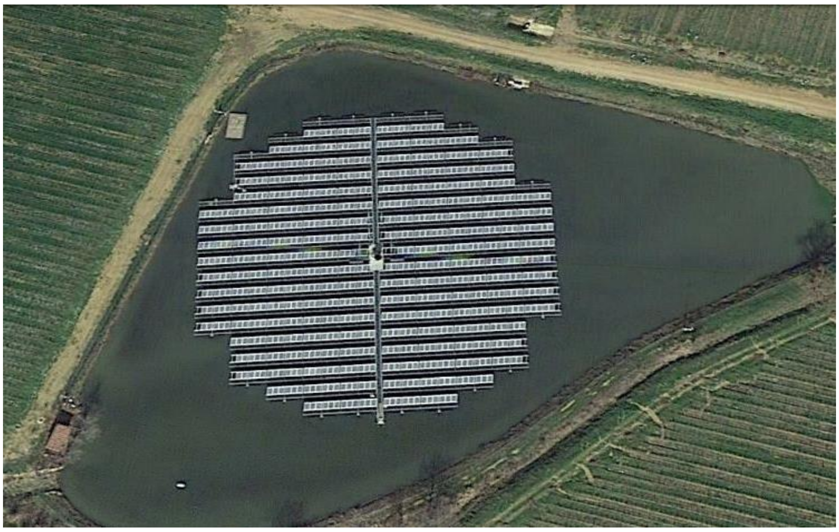

Figure 2.2 FPV plant with tracking on the Suvereto, Italy irrigation basin retrieved from Tina et al. (2018)

Other novel concepts lean towards the cooling advantages of water surfaces. One such concept is “Submerged FPV” in which PV panels are in direct contact with water to maximize the cooling effect of water (see Figure 2.3). Although the concept has safety and maintenance concerns, a test was set in motion in Sudbury, Canada, in 2010 (Patil et al., 2017). Another exciting concept with cooling in its center is “active cooling” in which sprinklers are implemented to cool off the PV modules (ESMAP, 2019).

Figure 2.3 Submerged FPV in Sudbury, Canada retrieved from (ESMAP, 2019)

2.5.3 Benefits of Floating Solar PV

Floating solar PV systems have some attractive benefits. The most pronounced advantage of floating solar PV is that it helps to solve land and water scarcity, especially in highly populated countries. Since an existing electrical infrastructure can already allow its installation, it can also be used in hard-to-access terrains, including a renewable energy system, such as floating wind or hydropower. FPVs are accepted as suitable for operating as a part of a hybrid energy system. Indirectly, it helps to block excessive water evaporation and helps to improve the economic value of water bodies, especially those that remain unused. The technology is also considered environmentally friendly since it enhances the water quality through decreased algae growth (Patil et al., 2017). It is generally considered to have a higher energy yield due to several benefits of being installed in water, such as its cooling effect and elimination of dust and shading, which would be likely on land installations (ESMAP, 2019).

2.5.3.1 Land Use

While solar power and other environmentally friendly energy options are becoming more and more prominent in the field, the question of logistics remains an issue to be tackled. Projects in remote areas bring out extra transmission costs and raise a concern about wildlife. Feasible sites for the installation of solar power plants close to the settlements and agricultural regions can cause problems due to the high value of the land. This point is significant for smaller countries or countries with limited terrain. FPVs can be established without having these types of issues (ESMAP, 2019).

2.5.3.2 Technology and Design

The foremost technological advantage of FPVs is the energy return. Although FPV technology is pretty new to its land-based counterpart and R&D remains in progress, the observations from existing FPVs suggest that the overall energy production around the world will increase. This increase stems from the surface characteristics, evaporative cooling effect, and design. For instance, in terms of the operating environment, FPVs are established in open and flat surfaces. FPVs are also in synergy with existing electrical infrastructure; they can also be used in combination with hydropower reservoirs. Array configuration, mounting and support structures, electrical equipment as well as safety all pertain to the design of FPVs (ESMAP, 2019).

Surface provides three main advantages for FPVs. Firstly, the water bodies which carry the systems are rarely surrounded by urban development. As a result, panels are less prone to be disturbed by the shade. In addition, tilt angles of FPV arrays are kept low to minimize wind loads. These two factors create a reduced inter-row shading. Secondly, water bodies are less prone to dust than other power plants, which are often established in desert-like areas where dust is abundant. As a result, panels do not gather as much dust and provide an advantage in maintenance. Lastly, because the wind speed over open water is much higher than on land, wind can be utilized to enable easier module cooling (ESMAP, 2019).

2.5.3.3 Environmental

FPVs not only create energy opportunities on uncontested surfaces but also become an invaluable option for an environmentally sustainable solution to an ever-increasing demand for clean energy. Although the total environmental impact of floating solar systems is yet to be investigated, Goswami et al. (2018) studied Neel-Nirjan Dam in terms of a potential floating solar power plant. It was revealed that the floating solar might be an ideal system for maintaining ecological balance since they observed a decrease in evaporation and increased water conservation. Furthermore, the impact on the existing ecosystem was minimal, and the system proved particularly beneficial since it controlled the algae bloom and improved water quality (Goswami et al., 2018).

The high evaporation rate of water causes a reduction in water quality. Evaporation prevention is one of the key advantages of FPVs. In 2012, a study in Australia revealed that open reservoir water bodies were prone to evaporate up to 40% of the water mass depending on the location and climate (Helfer et al., 2012).

2.5.4 Challenges and Drawbacks of FPVs

Floating solar power plants is an exciting new technology that has the potential to shape the future of sustainable energy. However, certain challenges and disadvantages come along with the technology. While some of the disadvantages stem from the nature of the concept, others emerge purely from limited experience and research. Y.G. Lee et al. (2014) noted that floating-type systems produce less energy than land-type systems. In order to obtain more reliable data for evaluating efficiency, many years of continuous measurements are needed.

Since floating PVs face the challenge of adapting to many different environments, each project's design and construction remain unique. The floating power plants that have been established so far are built in many different terrains and climate conditions. Therefore from modules to tilting, each project presents its unique challenge, and the design remains a complex process (George and Patel, 2019). Thi (2017) points out these technological difficulties:

- Floating PV system depends on hydraulic and weather conditions, resulting in unstable power output.
- Floating system may affect fishing and transportation activities.
- A system located in a water environment could lead to corrosion of modules and structures, reducing the system's lifespan.

Water operation raises workplace safety concerns for workers, a constant matter during maintenance. In addition, electrical safety, anchoring, and mooring need careful consideration and workforce availability (ESMAP, 2019).

Floating solar power plants also present legal and financial challenges. Since the technology is reasonably new, procedures, permits, and other legal issues are prone to a lack of clarity in regulations and legislation. This reflects the financial aspects of the projects, making floating solar power plants a higher-risk investment compared to land-based systems (ESMAP, 2019).

2.5.5 Comparison of Land-Based Solar PVs and Floating Solar PVs

A comparison to land-based solar power plants should be considered while discussing FPVs. Both types of power plants display an array of advantages and disadvantages.

2.5.5.1 Surface Use

FPVs utilise the water surface which can potentially spare land needed for land-incentive activities such as agriculture, mining, tourism,conservation (Cagle et al., 2020). Especially in big cities where land is increasingly valuable, floating solar technologies can help to solve problems related to land or property and transform unexploited and non-revenue water surfaces into energy hubs (Sahu et al., 2016). On the other hand, land-based operations are more complicated and may present challenges in finding suitable lands within the project budget. The budget is further strained if the land available is distant from settlements, resulting in high cost transmission.

2.5.5.2 Design of Panels

The design of FPV systems are identical to the traditional land based PV systems except that the latter must be in accordance with the terrain. The floats are typically made of HDPE (high density poly-ethylene), known for its tensile strength, maintenance free, UV and corrosion resistance. They are also only fixed to pontoons whose only function is to provide buoyancy; in which case, there is no need for specially designed floats. With that being said, floating PVs offer modular design opportunities since they lay on flat surfaces. They can also be installed easily as they do not require ground level. However, FPV designs require regular maintenance of anchoring cables, whereas land-based PVs are easier to monitor (M. Kumar et al., 2021).

2.5.5.3 Performance/ Energy Yield

FPV installations can differ from ground-mounted ones in terms of energy yield. There are various factors to take into consideration. Firstly, different studies prove that despite the potential shortcomings of floating solar PV technology, when compared to overland PV, they have an increased energy yield by up to %12 (Ranjbaran et al., 2019). The main reasons for its superiority lies in the cooling effect of water and being deprived of shading which collectively enhance the energy yield (Choi, 2014). However, FPV installations may suffer from bird soilings. Furthermore, the degradation rates of electrical components as well as electrical safety of equipment placed near reservoirs can differ from rates seen on traditional solar PV. Finally,for FPVs, the range of tilt angles depends on float design. Land based PVs have the added benefit of being able to optimize the tilt; however, they are prone to temperature loss depending on the climate.

2.5.5.4 Installation and Deployment

Land-based PV and FPV installations heavily depend on location and workforce availability. Arranging and developing the potential area for land-based operations is quite important. For instance, the soil quality is part of conventional solar PV installation. Floating PV installation is considered to be an easier process; however, depending on the location, workforce versatility is favored. Due to the challenges in transportation of floating PV systems, local production should be preferred (ESMAP, 2019).

2.5.5.5 Power System Benefits

Land based solar operations require connecting grids to be covered by the developer which can be costly. Floating solar PVs on the other hand, can be combined with existing transmission and distribution infrastructure which are already a part of hydroelectric power plants. In this way, they can enlarge the existing power capacity by complimenting them (Rauf et al., 2020).

2.5.5.6 Environmental

Although solar PV systems are known as environmentally friendly systems, both conventional solar technologies and floating solar PV systems have some environmental impacts. The former is usually criticised for damaging the environment during the construction period which may result in loss or harm of the existent habitat. As of now, the environmental effects of floating PVs are not yet thoroughly investigated. It is suggested that floating PVs can have an effect on plankton propagation and coastal bird habitat. It is also true, however, that floating PVs can help to reduce water evaporation and algae growth (M. Kumar et al., 2021).

2.5.5.7 Investment

In terms of investment, land based PVs are recognised in finance sector because a great number of systems have been installed so far. Therefore the risk calculation is lower compared to FPVs and cost continues to drop because of government intervention and overall commercialization of the technology. Floating PVs, a newer technology, have a higher calculated risk and are more expensive on average than land based PVs due to the floating system and mooring lines. However, it must also be noted that there are not enough installations to be able to make an accurate analysis of installation, maintenance and operation costs. Therefore, costs of FPVs may very well change in the upcoming years when the technology gets thoroughly established (Gorjian et al., 2021).

2.5.5.8 Operation and Maintenance

Both Land-based and FPVs have different advantages and disadvantages in terms of operation and maintenance. Land-based PVs are affected more by vegetation, whereas Floating PVs are affected more by animals, especially birds. While it is easier to create maintenance routines for Land-based PVs, FPVs are harder to reach for replacing parts and other operational issues. Although easy access is an advantage for Land-based PVs, Floating PVs have less potential to be subjected to vandalism and theft (ESMAP, 2019).

2.5.5.9 Durability

Lifespan of Floating PVs can change from 5 to 10 years while land-based PVs offer more than 20 years of warranty for major components. This is one factor in which FPV plants have disadvantages over land based systems. FPV plants may not be able to withstand extreme weather conditions such as heavy waves, high tides and tsunamis. Salinity of the water body can also deteriorate panels and reduce its performance. Moreover, the fluctuating wind levels make PV modules vulnerable to cracking (George and Patel, 2019).

2.5.5.10 Safety

Land-based PVs are considered to be generally safe, whereas floating PVs present certain risks. Work security is a concern with floating PVs since workers and staff are subjected to potential water accidents. Insulation resistance which is lower than the ground is known as another risk. Lastly, equipment grounding is much more complicated due to constant movement which also makes cleaning of FPV panels much more difficult and requires cleaning mechanisms to be designed (Sahu et al., 2016).

2.5.5.11 Regulations and Permits

Floating and land-based PVs have significant differences in legal and bureaucratic matters. Since Land-based PV is a more established practice, regulations are clear and the permit process is habitual. This is not the case for Floating PVs since there are not specific regulations. Besides regulations on natural lakes are tougher than artificial lakes for FPVs (ESMAP, 2019).

2.5.5.12 Level of Maturity

Land based PVs have been used for several decades across thousands of projects around the world.This experience provides land-based PVs with a recognized reputation. While conventional solar technologies have been experimented with, developed and proved on the field many times, there are many elements about floating PVs which have not been researched enough or we have very little knowledge about. Floating PV technologies have been tested out with only a few years of experience in large-scale projects (ESMAP, 2019).

2.5.6 Current Status in Global

Floating photovoltaic systems are a relatively new concept in renewable energy production. Although it has merely ten years of development history, the number of studies and attention to floating PV around the world is on the rise. According to Solar Asset Management, as of 2016, there are 70 floating PV systems around the world. Only seven countries already account for 75% of installed capacity such as China (77.4 GW), Japan (42.8 GW), Germany (41.3 GW), USA (40.9 GW), Italy (19.3 GW), India (9.1 GW) and Korea (4.4 GW) (Thi, 2017). The floating photovoltaic systems generated only 1 percent of the global solar installation in 2019, but this figure is expected to double by an average of 22% from 2019 through 2024 (Cox, 2019). In the last three years, countries such as Japan, USA, Korea, Australia, Brazil, India are increasingly more investing in FPVs installations due to investment incentives and the decline in PV systems cost as well as improved PV system efficiency. In particular, growing Asian economies such as India and China are expected to boost the floating PV market because they have such high electricity demand. For instance, India has taken on the challenge of installing 100 GW capacities of solar power installation and generation by the year 2022 (Sahu et al., 2016). The Float Solar Market Report published by The World Bank Group (2019), suggests that with 150MW peak capacity, China has the largest FPV capacity up to now. China has also directed its attention towards installing FPVs in flooded mines. As of now, China has become the market leader by installing large FPV systems over the past two years, with a market share of 73% and an installed capacity of 950MW. Figure 2.4 shows the global installed FPV capacity in 2018.

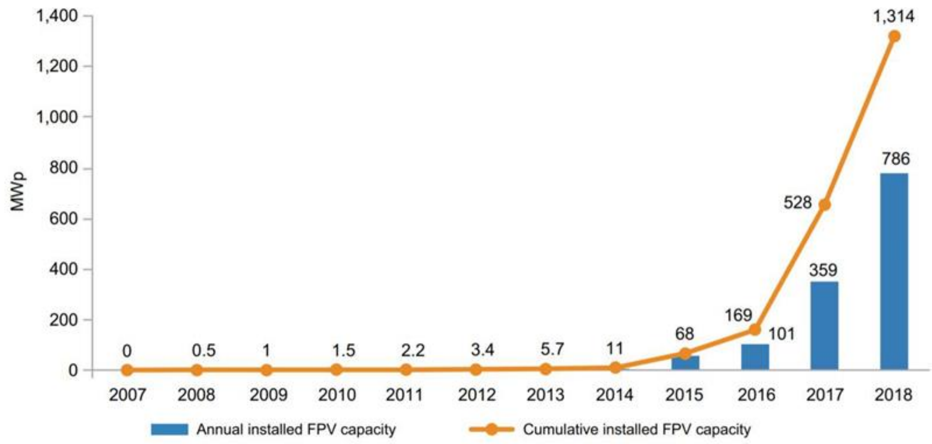

Figure 2.4 Global installed Floating PV Capacity in 2018 (World Bank Group, ESMAP and SERIS, 2019)

2.5.7 Current Status in Turkey

As discussed above, Turkey's solar radiation and energy potential are sufficiently high. Especially in big cities, it is important to address the energy supply problem through sustainable and renewable energy systems without compromising from much valued land. Among other things, Turkey is also under risk of becoming water scarce which FPV technology can help with through reducing evaporation from water bodies. Kaymak and Şahin (2022), underline that since there are no significant differences between land-based PV and FPV systems, FPVs could be a better solution. Since there are a lot of dams and reservoirs spread across the country, FPVs can save fresh water and land acquisition costs. Therefore, the combination of hydropower plants and FPVs can make decisive impacts. For instance, only 3% of the Atatürk Dam Lake's area is enough for FPV to match the peak capacity of the hydropower plant (Deveci et al., 2022). However, specific MCDM studies that exist at present to determine suitable sites for FPVs in Turkey are still very new and low in numbers which also gets reflected in the actual implementation of the FPV technology. In this regard, a need for experimental and scientific studies in this field has been noted (Dal, 2021).

Currently, there are 2 applications of FPVs in Turkey. One is in Büyükçekmece Lake, İstanbul (see Figure 2.5). This project is constructed with 960 polycrystalline panels with a total power generation capacity of 249.6 kW (İstanbul Enerji, 2022). FPV systems for this particular project were designed keeping in mind the extreme weather conditions, especially harsh waves and high wind loads. It is thought that the FPVs on Büyükçekmece Lake can decrease both water evaporation and carbon dioxide emissions by nearly 180 tons. Finally, it is planned that this project itself will be expanded over the next three years with expansion to Terkos and Ömerli dams to be installed by 2022 (C40 Cities, 2017).

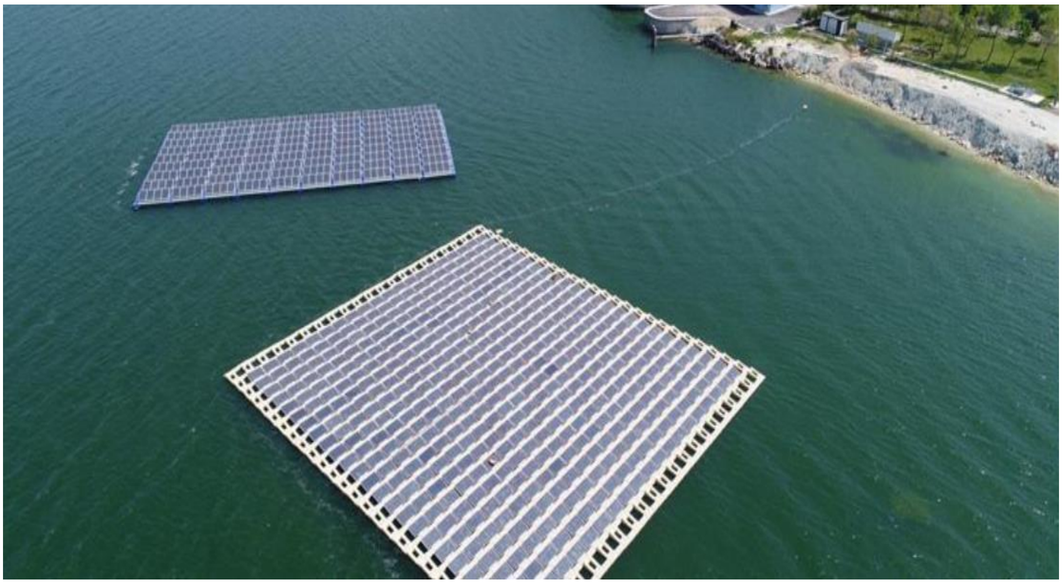

Figure 2.5 FPV installation in Büyükçekmece Lake, Istanbul (retrieved from Istanbul Metropolitan Municipality)

The other FPV application in Turkey is in Azmak 2 HEPP, Mersin (see Figure 2.6).

Figure 2.6 FPV installation in Azmak 2 HEPP, Mersin (Bulut et al., 2018)

CHAPTER 3

METHODOLOGY

In this chapter, Analytic Hierarchy Process (AHP) and Ordered Weighted Averaging (OWA) methodologies are explained briefly. Then, how the questionnaire about the site selection criteria was conducted to experts is explained. Following this, reasons of 8 alternative site selection for this study are explained and 8 alternative sites are introduced with their properties. Finally, the second questionnaire conducted for the alternative sites is described.

Multi-Criteria Decision Making (MCDM) methods not only include a wide range of distinct models but also have evolved over time to suit the needs of various types of applications. AHP, TOPSIS, ELECTRE, PROMETHEE and Fuzzy Sets are the most commonly used techniques in solar PV site selectionstudies. Tscheikner-Gratl et al., 2017 stated that it is possible to divide these methods into three groups : (i) value measurement models such as AHP, (ii) goal or reference level models such as TOPSIS and (iii) outranking models such as ELECTRE and PROMETHEE (Tscheikner-Gratl et al., 2017). Benefits and drawbacks of TOPSIS, ELECTRE, PROMETHEE and Fuzzy Sets are summarised in the following.

TOPSIS:

Developed by Yoon and Hwang in 1981, Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method is based on assessing the advantages and disadvantages of given alternatives, which measured on Euclidean Distance, ultimately strives to be closer to "positive – ideal solution" and furthest from "negative - ideal solution" (Balioti et al., 2018). In other words, TOPSIS can be used to measure the distance of an alternative from the ideal references determined (Y. Wang, 2018). Efficient computing, practical, rational and understandable decision making process makes TOPSIS a good choice for practical problems. One of the main drawback of TOPSIS is knows as "rank reversal",It lies in the case of adding or removing primary elements during the decision making process which can potentially invert what was formerly considered the best alternative into the worst (García-Cascales and Lamata, 2012). It is also suggested that a weakness of the TOPSIS method is the need for vector normalization in multi-dimensional problems. Thus, it does not take into consideration the relative importance of distances. Finally, a major shortcoming of this technique is its failure to respond to ambiguous, uncertain and vague issues in real analysis (Sindhu et al., 2017).

ELECTRE:

Elimination Et Choix Traduisant la REalite model or Elimination and Choice Expressing Reality, also known as ELECTRE is a part of outranking methods (Tscheikner-Gratl et al., 2017). The main methodology is based on alternatives outranking one another, thereby suggesting that the outranking alternative is at least as good as the outranked alternative (Sánchez-Lozano et al., 2014). Following this, an exploitation procedure begins to elaborate on the recommendations obtained in the first place. The concordance and discordance indexes can be viewed as measurements of dissatisfaction that a decision maker uses in choosing one alternative over the other. Although there are several models in the scope of ELECTRE, they are generally models which work well with uncertainty and vagueness, mainly based on concordance analysis which can be viewed as a measurement of the satisfaction of a decision maker. The major disadvantage attributed to ELECTRE is that the outranking method causes the strengths and weaknesses of the alternatives to not be directly identified, nor results and impacts to be verified (Velasquez and Hester, 2013).

PROMETHEE:

Similar to ELECTRE, Preference Ranking Organization Methods for Enrichment Evaluations (PROMETHEE) is an outranking model in which the alternative pairwises for each criterion are compared to find the strength of preferred alternative.

In other words, the combination takes the criteria as the basis to determine the superiority of given alternatives. The main advantage of this method is the fact that it allows for the direct operation on the variables included in the decision matrix, without requiring any normalization and it is applicable even when there is limited information (Tscheikner-Gratl et al., 2017). Yet, it can often be time-consuming when a number of criteria are involved in the problem. Furthermore, it does not provide an exact method to assign values and weights (Sabaei et al., 2015).

FUZZY SETS:

Since MCDM is bound to be flexible and dynamic, FUZZY sets theory is usually used to strengthen and extend the existing decision theory. FUZZY can prove advantageous for it allows working with not strictly defined or imprecise input. In fuzzy set theory, membership function lets define degrees of satisfaction or membership for each alternative according to the fuzzy criteria (Dikmeoğlu, 2019). However, it can be hard to fully develop a fuzzy set theory before putting it in actual use. Table 3.1 shows the comparison of the MCDM methods according to the literature review.

Table 3.1 Advantages and Disadvantages of MCDM Methods

MCDM Method	*Advantages*	*Disadvantages*
Analytical Hierarchy Process (AHP)	-the hierarchical structure weighs criteria and compares alternatives easily (Yap et al., 2019) - applies to complex and unstructured problems (Merrouni et al., 2018) - reduces bias in decision making (Saaty, 1990)	-rank reversal (Yap et al., 2019) -uncertainty and inconsistency in judgment and ranking criteria (Turcksin et al., 2011) -does not allow grading criterion (weakness/ strength) in isolation but always in comparison with the rest (Konidari and Mavrakis, 2007)

Table 3.1 Advantages and Disadvantages of MCDM Methods (continued)

MCDM Method	*Advantages*	*Disadvantages*
Analytical Hierarchy Process (AHP)		-demands data collected based on experience (Siksnelyte-Butkiene et al., 2020)
Fuzzy Sets	-allows solving a lot of problems dealing with imprecise and uncertain data (Zadeh, 1965) -helps to solve problems not easily dealt with through MCDM (Dikmeoğlu, 2019)	-hard to develop (Velasquez and Hester, 2013)
Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	-the steps of the method remain scalable regardless of any number of criteria or alternatives (Iç, 2012) -straightforward application, faster compared to other methods (Siksnelyte et al., 2018)	-does not take into account the correlation between the elements of the model (Yap et al., 2019) -need for vector normalization for multi-dimensional problems (Tscheikner-Gratl et al., 2017) -rank reversal (García-Cascales and Lamata, 2012) -does not consider any difference between positive and negative values (A. Kumar et al., 2017) -the attribute values are only monotonically increasing or decreasing (A. Kumar et al., 2017)

Table 3.1 Advantages and Disadvantages of MCDM Methods (continued)

MCDM Method	*Advantages*	*Disadvantages*
The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)	-helps decision makers to determine the most optimal alternative (Siksnelyte et al., 2018) -no demand for normalization of scores (Sabaei et al., 2015)	-does not provide a clear way to assign the weights and values to the criteria and alternatives (Fulop and Yat, 2005) -depends on the decision maker to assign weight -experts are only users (A. Kumar et al., 2017)
ELimination Et Choix Traduisant la REalité (ELECTRE)	-works well with uncertainty and vagueness (A. Kumar et al., 2017) -deals with qualitative and quantitative criteria (Sabaei et al., 2015)	-does not directly identify the strength and weaknesses of the alternatives, nor verify the results and impacts of the results (Velasquez and Hester, 2013) -considerably long computation process (Siksnelyte et al., 2018)

Ultimately, Analytical Hierarchy Process was the method of choice in this study because the liability of both qualitative and quantitative, subjective and objective criteria can be traced and assured to make the optimal decision. It is worth noting that in previous studies concerning site selection AHP or AHP combinations with other methods are among the most applied techniques. In AHP methodology, a complex decision-making problem answered by multiple decision makers is decomposed and ordered into a system of hierarchies. Each alternative is given a score and weights are assigned to each criterion, representing the importance of that criterion. At the end of the process, the relative importance of each factor through multiple comparison schemes reaches the maximum weight which is then decided upon as the ideal solution. Similar to the TOPSIS method, as a downside rank reversal also applies in AHP. Furthermore, it is argued that AHP could cause a loss of information due to the potential compensation effects between the difference of good scores on some criteria and bad scores on others which could potentially result in a loss of information. However, through consistency index, expert input can be eliminated from any potential inconsistencies (Saaty, 1980).

The methodology of this study is visualized in detail for the site selection technique proposed to determine the ideal floating solar power plant site. The flowchart for the methodology shows the steps taken in this study (see Figure 3.1).

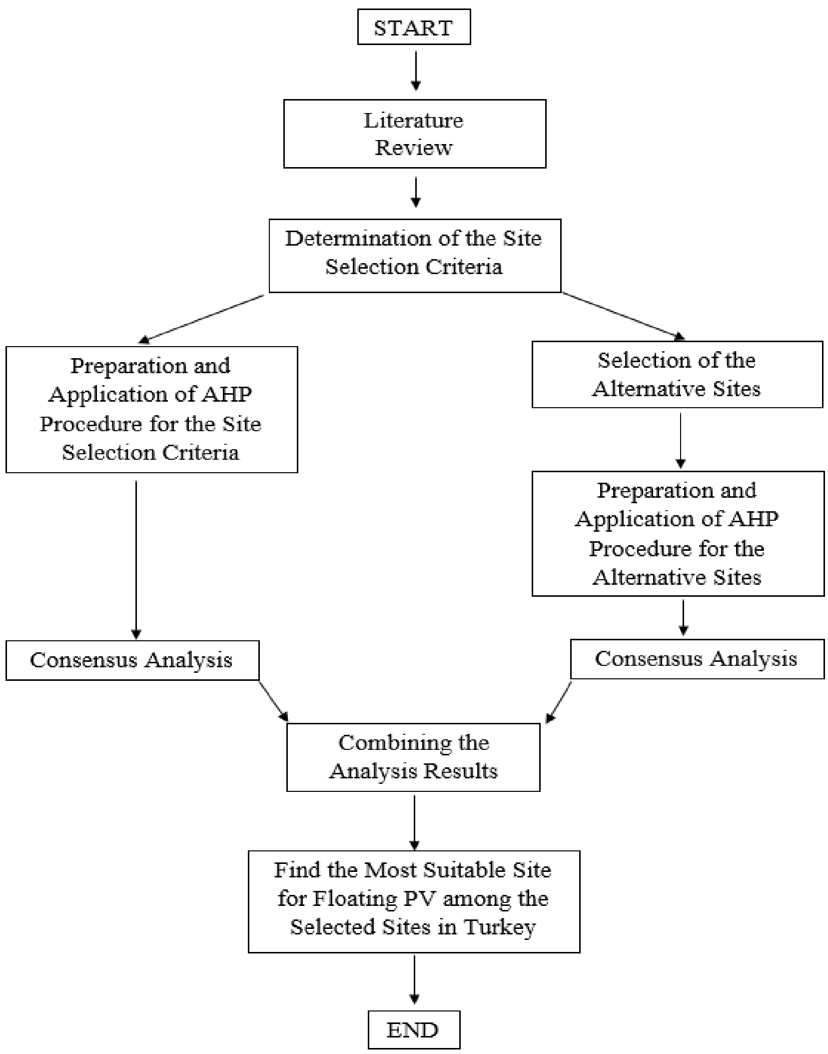

Figure 3.1. Flowchart of this study

This study identifies 10 main criteria, including solar irradiation, annual sunshine hours, average temperature, topographic elevation, water depth, distance to settlements, distance to grid connections, local average wind speed, impacts on regional development and social impact. After that, solar irradiation, annual sunshine hours, average temperature and topographical elevation are found to be the top four decision criteria in this study, which will be discussed in the following sections. Although several previous studies have concentrated on solar site selection in the context of Turkey (Suprova et al., 2020), this study focused on socio-economic criteria as main criteria as well.

3.1 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is one of the most commonly applied MCDM techniques for site selection studies developed by Saaty in the 1970s. AHP organizes and evaluates complex decisions based on mathematics and human judgement and provides decision-makers to choose the optimal solution (Jankowski, 1995).

The main purpose of AHP is to compare each criterion in pairs to assign a relative importance. By using the Scale of Relative Importance shown in Table 3.2, a number of importance value is assigned to a criterion to compare over another.

Table 3.2 Scale of Relative Importance (Saaty, 1977)

Importance Value	*Definition*
1	Two factors are Equally Important
3	One factor is Slightly more Important than the Other
5	One is Strongly more Important
7	One is Very strongly more Important
9	One is Absolutely more Important
2, 4, 6, 8	Intermediate Values of one criterion over the other

After assigning an importance value to each criterion, the pairwise comparison matrix is formed. Cells in the matrix of are multiplicatively inverse diagonally. In

Table 3.3, there is an example of the pairwise comparison matrix taken a part from an actual questionnaire conducted by a participant in this study.

Table 3.3 An example of the pairwise comparison matrix

	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Criterion 1	1	2	4	3
Criterion 2	1/2	1	1/2	1/2
Criterion 3	1/4	2	1	1/2
Criterion 4	1/3	2	2	1

After forming the comparison matrix, the algorithm of AHP continues as each column in the matrix are summed as shown in Table 3.4.

Table 3.4 Sum of each column in the pairwise comparison matrix

	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Criterion 1	1	2	4	3
Criterion 2	0.5	1	0.5	0.5
Criterion 3	0.25	2	1	0.5
Criterion 4	0.333	2	2	1
Sum:	2.083	7.00	7.50	5.00

Following this, every cell in the pairwise comparison matrix is divided by their column sum value as shown in Table 3.5 to form the normalized comparison matrix and the elements of the normalized pairwise comparison matrix are denoted by $\bar{a}_{ij}$.

$$\bar{a}_{ij} = a_{ij} / \sum_{k=1}^{n} a_{ik} \qquad (1)$$

The average of each row gives the relative weights of the each criterion denoted by W_i and the sum of the relative weights of each criterion equals to 1.

$$W_i = \frac{1}{n} \sum_{k=1}^{n} \bar{a}_{ki} \qquad (2)$$

Table 3.5 An example of the normalized comparison matrix and the relative weights of each criterion

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Relative Weights
Criterion 1	0.48	0.286	0.533	0.6	0.475
Criterion 2	0.24	0.143	0.067	0.1	0.137
Criterion 3	0.12	0.286	0.133	0.1	0.160
Criterion 4	0.16	0.286	0.267	0.2	0.228
The sum of the relative weigths=					1.00

In this example, the relative weight of each criterion are as follows; Criterion 1 (0.475), Criterion 2 (0.137), Criterion 3 (0.160) and Criterion 4 (0.228). As it can be seen, the most important criterion in the example is Criterion1 with a relative weight of 0.475 among all the criteria.

After calculating the relative weights of each criterion, it is required to check the consistency of the importance values assigned by the decision-maker. The consistency is checked by the Consistency Ratio (*CR*) and has to be less than 0.1. *CR* is represented as follows:

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} \quad (3)$$

where *RI* is the Random Consistency Index and *CI* is the Consistency Index. RI value is obtained by the number of the criteria (n) as shown in Table 3.6.

Table 3.6 RI values for the number of the criteria (n)

n	1	2	3	4	5
RI	0.00	0.00	0.58	0.90	1.12
n	6	7	8	9	10
RI	1.24	1.32	1.41	1.45	1.49
n	11	12	13	14	15
RI	1.51	1.54	1.56	1.57	1.59

CI is represented as follows:

$$\boldsymbol{CI} = \frac{\boldsymbol{\lambda_{\max} - n}}{\boldsymbol{n - 1}} \tag{4}$$

where λ_{max} is the maximum eigenvalue of the matrix and n is the number of the decision criteria.

λ_{max} is calculated by dividing the importance values of the criteria assigned by the decision-maker at the first stage by the relative weights of each criterion in the pairwise comparison matrix columns. Then each row is summed and the sum of the rows are divided by the relative weights of the criteria again to obtain the sum/relative weights. The average value of the sum over relative weights gives λ_{max}. In Table 3.7 the example of obtaining λ_{max} can be seen. In this example n is taken as 4.

Table 3.7 The example of obtaining the maximum eigenvalue of the matrix, λ_{max}

Relative Weights	0.475	0.137	0.160	0.228	Sum	Sum / Relative Weight
	Criterion 1	Criterion 2	Criterion 3	Criterion 4		
Criterion 1	0.475	0.275	0.639	0.684	2.073	4.366
Criterion 2	0.237	0.137	0.080	0.114	0.569	4.140
Criterion 3	0.119	0.275	0.160	0.114	0.667	4.177
Criterion 4	0.158	0.275	0.320	0.228	0.981	4.299
					λmax=	4.245

According to the Equation (2), *CI* is calculated as 0.082 in the example after calculating λ_{max} value and regarding *RI* value for 4 criteria is 0.90 from Table 4.6. In the end, *CR* value is calculated as 0.091 using Equation (3). As the calculated *CR* value is 0.091 and less than 0.1, the decision made by the decision maker is considered as consistent.

3.2 Ordered Weighted Averaging (OWA)

Ordered Weighted Averaging (OWA), one of the combination methods in MCDM, deals with the problem of aggregating multi-criteria to form an overall decision function. It was introduced and developed by Yager in 1988. In this MCDM method, various maps and cases can be obtained by changing the criteria and parameters (Shorabeh et al., 2019). OWA includes two types of weights: importance or criterion weights and order weights. For each location in a study area, a specific criterion is given importance or criterion weight to indicate how important it is according to the decision-makers' choices (Dikmeoğlu, 2019). On the other hand, order weights are an essential part of OWA operations. Order weights are assigned to reordered criterion values, independent from the criterion source for each value with decreasing order. Therefore, the first order weight is allocated to the highest weighted criterion values at each location, while the second order weight is assigned to the second highest weighted criterion values. This operation continues until the last order weight is given to the lowest weighted criterion values (Dikmeoğlu, 2019). The OWA model prioritizes presenting findings based on various levels of risk and offers a wide range of options to fulfill decision-makers' needs (Malczewski, 2006). Several land use strategies can be developed and sorted from extremely worst to extremely optimistic circumstances using the OWA operations. Hence, OWA has been used in combination with GIS multi-criteria decision analysis over the last decade. The GIS-OWA approach has given successful outputs in various socio-economic applications, such as land use evaluation, health care, tourism and residential quantity assessment (Shorabeh et al., 2019).

Decision makers tend to select aggregation operators involving preferences to perform the satisfactory aggregation process. Quantifier-guided multi-criteria evaluation is the process of combining the criteria based on an expression describing the relationship between the evaluation criteria (Yager, 1996). Language-based quantifiers are divided into absolute, relative, and proportional linguistic quantifiers according to the type of claims (Zadeh, 1983). Examples of absolute quantifiers are the phrases about 3, almost 6, and more than 8. At the same time, terms like all, most, many, and a few can be categorized as relative linguistic quantifiers, which are statements that refer to proportionate quantities (Malczewski, 2006).

Ordered Weighted Averaging consists of three steps. First, weights are allocated to every input according to the induction information. Secondly, the results get reordered. Lastly, the order weights, which only rely on the selected value, which are and are independent of the chosen criteria, are calculated and applied (Dikmeoğlu, 2019).

$$\left(\frac{i}{n}\right)^{\alpha} - \left(\frac{i-1}{n}\right)^{\alpha} \tag{5}$$

Table 3.8 The linguistic quantifiers for selected values of the α parameter (Malczewski, 2006).

α	*Quantifier*
α → 0	At least one
α = 0.1	At least a few
α = 0.5	A few
α = 1	Half (identity)
α = 2	Most
α = 10	Almost all
α = 1000	All

In this study, OWA is used in combination with AHP in order to enhance the decision-making process. It should be recognized that the strengths of OWA arise mainly from its flexibility in meeting the needs and priorities of decision-makers. It can provide different results with different levels of risk and compensation.

Each iteration starts with forming the pairwise group matrix for which the following equation is used:

$$g_{ij} = \prod_{r=1}^{p} \left(a_{ij,r}\right)^{\rho} \tag{6}$$

At this point, $a_{ij,r}$ is the element aij in the pairwise comparison matrix for r^{th} participant (total of r participants) and p is the same p is the weight of decision makers, which in this study, it is assumed to be the same for all participants. Once the group pairwise comparison matrix is formed, the individual group comparison index (GCI) for participant r is calculated as (Caceoğlu et al., 2022):

$$GCI_r = \frac{1}{n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij,r} g_{ji} \tag{7}$$

Next, group comparison index for r^{th} participant (GCI_r) values are compared. The participant who has the highest value would mean the most different opinion of the group. The modified pairwise comparison matrix whose elements are a_{ij}, one of the participants is formed by:

$$a_{ij}^{*} = \left(a_{ij}\right)^{\alpha} \left(g_{ij}\right)^{1-\alpha} \tag{8}$$

The individual pairwise comparison matrix will be updated until the iteration stops by obtaining the limit value. The expression a is the measure of how much the individual pairwise comparison matrix is to be updated, which was determined $\alpha = 0.5$ as exemplified in Dong and Saaty (2014).

3.3 The Questionnaire for Site Selection Criteria

After deciding which criteria would be included in this study in Section 2.4, a questionnaire was prepared. One sheet of the questionnaire can be seen in Figure 3.2 as an example (See Appendices A). Similar sheets are prepared for the rest of the site selection criteria to prepare pairwise comparison matrix discussed in Section 3.1.

1st criterion	1st criterion is more important								Equal	2nd criterion is more important								2nd criterion
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Annual Sunshine Hours
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Average Temperature
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Topographic Elevation
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Water Depth
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Settlements
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Grid Connection(Substations)
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local Average Wind Speed
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Impact

Figure 3.2. Questionnaire prepared for pairwise comparison matrix

Following this, solar energy experts from all over the world are determined and asked them fulfill the questionnaire via e-mail. In order to apply AHP method in a proper way in this study, field experts of public institutions and private sector in Turkey and academicians were also asked to conduct the questionnaire. The professions of the participants are civil engineering, electrical engineering, electrical and electronical engineering and mechanical engineering. Some participants have MSc and PhD degrees as well.

17 participants in total fullfilled the questionnaire and with their answers pairwise comparison matrix is formed (see Section 3.1). An example of the pairwise comparison matrix can be seen in Table 3.9.

Table 3.9 An example of pairwise comparison matrix formed by a participant for the site selection criteria

Criteria	Solar Radiation	Annual Sunshine Hours	Average Temperature	Topographic Elevation	Water Depth	Distance to Settlements	Distance to Grid Connection	Local Average Wind Speed	Impacts on Regional Development	Social Impact
Solar Radiation	1	3	3	6	8	8	3	5	9	9
Annual Sunshine Hours	0.333	1	1	2	3	3	1	2	3	3
Average Temperature	0.333	1	1	2	3	3	1	2	3	3
Topographic Elevation	0.167	0.5	0.5	1	1	1	0.5	1	2	2
Water Depth	0.125	0.333	0.333	1	1	1	0.333	0.5	1	1
Distance to Settlements	0.333	0.333	0.333	1	1	1	0.333	0.5	1	1
Distance to Grid Connection	0.333	1	1	2	3	3	1	2	3	3
Local Average Wind Speed	0.2	0.5	0.5	1	2	2	0.5	1	2	2
Impacts on Regional Development	0.111	0.333	0.333	0.5	1	1	0.333	0.5	1	1
Social Impact	0.111	0.333	0.333	0.5	1	1	0.333	0.5	1	1

3.4 Alternative Sites

The main purpose of thesis is to determine the best suitable site for installing floating PV systems in Turkey considering some of the existent HEPPS. For this purpose, a list of 8 hydroelectrical power plant reservoirs actively producing electricity are studied.

While selecting 8 HEPP reservoirs, mainly solar irradiation, annual sunshine hours, average temperature and topographical elevation data are used following the relevant literature.

In site selection, the spatial data existing on the General Directorate of State Hydraulic Works (DSİ) is considered. In this study, more than 100 HEPP reservoirs are listed and their solar irradiation and daily ground average temperature data is taken from Global Solar Atlas. Annual Sunshine values are taken from the Turkish State Meteorological Service and scaled from “very low” to “very high”.

First, GHI values of the reservoirs are ordered from high to low, then annual sunshine hours, average temperature values and topographical elevations are ordered as well. It would be so straight forward choice to select alternative sites from high solar energy value regions of Turkey, however it it is paid attention to select alternatives from diffirent regions of Turkey.

After deciding on 8 alternative sites, the rest of the information concerning the water reservoirs is mainly acquired from Global Wind Atlas, Google Earth and Open Infrastructure Map, which are utilized for data required to determine the criteria such as local average wind speed, distance to settlements and distance to grid connections. The locations of the selected alternative sites are given in Figure 3.3.

Figure 3.3. Locations of the selected areas

General characteristics of each alternative site are summarized in the following subsections. Data source of all sites are listed in Table 3.10. Water depth values represent the difference between maximum and minimum operation depth of the water reservoir.

Table 3.10 Data Source of the Alternatives

Alternative Site Property	*Data Source*
Coordinates	Google Earth
GHI (kWh/m^2)	Global Solar Atlas
Annual Sunshine Scale	Turkish State Meteorological Service
Average Temperature (°C)	Global Solar Atlas
Topographic Elevation (m)	Enerji Atlasi
Water Depth (m)	Enerji Atlasi
Distance to Settlements (m)	Google Earth
Distance to Grid Connection/Substations (m)	Open Infrastructure Map
Local Average Wind Speed (m/s) <10m height	Global Wind Atlas

3.4.1 Site 1: Menzelet, Kahramanmaraş

Menzelet Dam is located in Kahramanmaraş, Mediterranean Region of Turkey, between latitude 37°40'35" and longitude 36°51'01" as seen in Figure 3.4.

Figure 3.4. Site 1: Menzelet, Kahramanmaraş

It is built over the Ceyhan River, 26 kilometers in the northwest of Kahramanmaraş, which might be considered relatively close to the city center. In terms of sunshine duration, it can be rated as medium-high having an average temperature of 16.1 °C. Compared to other alternative sites, it receives the most solar irradiation with 1793.9 kWh/m^2 and has the highest water depth levels of 49.2 meters. It also has an average wind speed of 4.45 m/s. The dam lake attracts local tourists from all over the city with its natural beauties, especially over the weekends. The area around the dam is allocated to be used for picnics and it includes kid's parks, cycling routes and water sports facilities. The properties of the selected site Menzelet are given in Table 3.11.

Table 3.11 Properties of Menzelet, Kahramanmaraş

Menzelet	*Value*
Coordinates	37°40'35", 36°51'01"
GHI (kWh/m^2)	1793.9
Annual Sunshine Scale	medium-high

Table 3.11 Properties of Menzelet, Kahramanmaraş (continued)

Menzelet	*Value*
Average Temperature (°C)	16.1
Topographic Elevation (m)	609.4
Water Depth (m)	49.2
Distance to Settlements (m)	4700
Distance to Grid Connection/Substations (m)	580
Local Average Wind Speed (m/s) <10m height	4.45

3.4.2 Site 2: Oymapınar, Antalya

The second biggest dam in Antalya, Oymapınar Dam is located in the northern district of Manavgat. Dominated by the Mediterranean climate, the dam is situated between latitude 36°54'31", and longitude 31°31'57" as seen in Figure 3.5.

Figure 3.5. Site 2: Oymapınar, Antalya

Oymapınar Dam has an elevation of only 184 meters. Typical of climate, Antalya has very high potential, receiving 1671.8 kWh/m² of GHI with an average temperature of 20.4 °C, rated high for an annual sunshine hour. Manavgat is known as of the tourist attraction location in Turkey. Likewise, with its green scenery, Oymapınar Dam lake is a tourist attraction site with historic aqueducts, viewing areas and boat trips. The properties of the selected site Oymapınar are given in Table 3.12.

Table 3.12 Properties of Oymapınar, Antalya

Oymapınar	*Value*
Coordinates	36°54'31", 31°31'57"
GHI (kWh/m^2)	1671.8
Annual Sunshine Scale	high
Average Temperature (°C)	20.4
Topographic Elevation (m)	184
Water Depth (m)	18
Distance to Settlements (m)	6000
Distance to Grid Connection/Substations (m)	2450
Local Average Wind Speed (m/s) <10m height	9.84

3.4.3 Site 3: Torul, Gümüşhane

Torul Dam is situated in the Torul district of Gümüşhane in the Black Sea Region between 40°38'37" latitude and 039°13'47 longitude as seen in Figure 3.6.

Figure 3.6. Site 3: Torul, Gümüşhane

Torul Dam is established over Harşit Stream, which is a part of the Eastern Black Sea Basin surrounded by mountainous terrain. It has the lowest solar irradiation rates of 1452.7 kWh/m^2, a low-medium rated annual sunshine hour rate and one of the lowest temperatures of 8 °C among selected alternative sites. Torul Dam stands at an elevation of 917 meters. Thanks to the mild climate conditions Kağızman district, where the dam is located, proves to be the third most developed district of the city. It is 9.8 kilometers from the closest village. However, Torul's rich water sources are said to encourage a growing water tourism potential. Properties of the selected site Torul are shown in Table 3.13.

Table 3.13 Properties of Torul, Gümüşhane

Torul	*Value*
Coordinates	40°38'37", 039°13'47"
GHI (kWh/m^2)	1452.7
Annual Sunshine Scale	Low-medium
Average Temperature (°C)	8
Topographic Elevation (m)	917
Water Depth (m)	27
Distance to Settlements (m)	9800
Distance to Grid Connection/Substations (m)	4000
Local Average Wind Speed (m/s) <10m height	9.4

3.4.4 Site 4: Bayramhacılı, Nevşehir

The biggest power plant in Nevşehir, Bayramhacılı Dam is located in the touristic Avanos district between latitude 38°45'55.7" and longitude 34°57'58.8" as seen in Figure 3.7.

Figure 3.7. Site 4: Bayramhacılı, Nevşehir

Bayramhacılı is built over River Kızılırmak. This area is known to host a myriad of civilizations with its fertile lands. Bayramhacılı stands at 980 meters with a high-rated annual sunshine hour of 1739 kWh/m² GHI. The dominating continental climate has an average temperature of 13.3 °C. The dam is highly popular among locals and people intend it to be utilized as a part of the world-famous district's touristic attractions by becoming a hub for restaurants, water sports and fishery. Some of the properties of Bayramhacılı are summarized in Table 3.14.

Table 3.14 Properties of Bayramhacılı, Nevşehir

Bayramhacılı	*Value*
Coordinates	38°45'55.7", 34°57'58.8"
GHI (kWh/m^2)	1739.8
Annual Sunshine Scale	high
Average Temperature (°C)	13.3
Topographic Elevation (m)	980
Water Depth (m)	5
Distance to Settlements (m)	5000
Distance to Grid Connection/Substations (m)	225
Local Average Wind Speed (m/s) <10m height	2.97

3.4.5 Site 5: Demirköprü, Manisa

Demirköprü Dam is in Salihli, Manisa is located between latitude 38°36'58" and longitude 28°18'40" as seen in Figure 3.8.

Figure 3.8. Site 5: Demirköprü, Manisa

It is established over Turkey's second-longest and much fertile river, River Gediz in the Aegean Region. The third most developed district of Salihli, Manisa, is based and populated mainly around the plains of River Gediz. This dam is important especially for irrigation, prevention of overflows, as well as energy production and fishing. Consequently, the dam stands at an elevation of 244.2 meters with a high rated annual sunshine hour. The average temperature is indicated as 17.3 °C and a high GHI of 1742.1 kWh/m² is reported fort his region. Although it is not strictly established like Menzelet Dam, it attracts people from nearby for occasional picnics and fishing activities. Table 3.15 summarizes some of the properties of Demirköprü.

Table 3.15 Properties of Demirköprü, Manisa

Demirköprü	*Value*
Coordinates	38°36'58", 28°18'40"
GHI (kWh/m^2)	1742.1
Annual Sunshine Scale	high

Table 3.15 Properties of Demirköprü, Manisa (continued)

Demirköprü	*Value*
Average Temperature (°C)	17.3
Topographic Elevation (m)	244.2
Water Depth (m)	22.4
Distance to Settlements (m)	3800
Distance to Grid Connection/Substations (m)	2400
Local Average Wind Speed (m/s) <10m height	3.18

3.4.6 Site 6: Yukarı Kaleköy, Bingöl

Yukarı Kaleköy is a recently built dam in the small district Solhan in Bingöl over River Murat between latitude 38°46'44" and 41°04'22" longitude as seen in Figure 3.9.

Figure 3.9. Site 6: Yukarı Kaleköy, Bingöl

As a district, Solhan is situated over high plateaus with a combination of meadow ground and rugged terrain dominated by a harsh climate. Population mainly gathers around the valley hosting the river. Agriculture and cattle breeding are fundamental economic activities. Yukarı Kaleköy Dam stands at an elevation of 1235 meters with an average temperature of 12.2 °C. Similarly, it has a medium-high annual sunshine hour rating with 1705.5 kWh/m² GHI. The properties of the selected site Yukarı Kaleköy are given in Table 3.16.

Table 3.16 Properties of Yukarı Kaleköy, Bingöl

Yukarı Kaleköy	*Value*
Coordinates	38°46'44", 41°04'22"
GHI (kWh/m^2)	1705.5
Annual Sunshine Scale	medium-high
Average Temperature (°C)	12.2
Topographic Elevation (m)	1235
Water Depth (m)	25
Distance to Settlements (m)	1700
Distance to Grid Connection/Substations (m)	1600
Local Average Wind Speed (m/s) <10m height	3.55

3.4.7 Site 7: Alparslan 2, Muş

Alparslan 2 Dam is located in Varto, Muş in Eastern Anatolia Region, between latitude 39°03'40" and 041°30'38" longitude as seen in Figure 3.10.

Figure 3.10. Site 7: Alparslan 2, Muş

It impounds the Murat River, the primary purposes of which are water supply, irrigation and hydroelectric power production. Recently established, Muş Plain is used to render unsuitable and unused for agriculture and livestock production due to limited water supply. However, Alparslan 2 Dam is expected to bring life to the city's economy and revitalize nearby provinces of Van, Muş, Bitlis and Hakkari as well. The Dam lies at an elevation of 1368 meters, which makes it the highest site in this study whereas the average temperature stands at 10.4°C. It is rated medium-high for annual sunshine hour and the solar irradiation is an average of 1749.8 kWh/m^2. Characteristics of Alparslan 2 are given in Table 3.17.

Table 3.17 Properties of Alparslan 2, Muş

Alparslan 2	*Value*
Coordinates	39°03'40", 041°30'38"
GHI (kWh/m^2)	1749.8
Annual Sunshine Scale	medium-high
Average Temperature (°C)	10.4
Topographic Elevation (m)	1368
Water Depth (m)	28
Distance to Settlements (m)	2400
Distance to Grid Connection/Substations (m)	200
Local Average Wind Speed (m/s) <10m height	2.95

3.4.8 Site 8: Kemer, Aydın

Kemer Dam is located in Bozdoğan, Aydın residing within the Mediterranean Region, 37°34'18.1" latitude, 28°31'30.6" longitude as seen in Figure 3.11.

Figure 3.11. Site 8: Kemer, Aydın

It is built on Akçay Stream. The dam has an annual sunshine rating of high with an average temperature of 18.7 °C and solar irradiation of 1762 kWh/m². It stands at a low elevation of 292.5 meters. Notably, Kemer Dam is the furthest from settlements at 11.5 kilometers. The properties of the selected site Kemer are given in Table 3.18.

Table 3.18 Properties of Kemer, Aydın

Kemer	*Value*
Coordinates	37°34'18.1", 28°31'30.6"
GHI (kWh/m^2)	1762
Annual Sunshine Scale	high
Average Temperature (°C)	18.7
Topographic Elevation (m)	292.5
Water Depth (m)	43.85
Distance to Settlements (m)	11500
Distance to Grid Connection/Substations (m)	250
Local Average Wind Speed (m/s) <10m height	3.19

3.5 Questionnaire for the Alternative Sites

After determining which alternative sites would be included in this study in Section 3.4, a second questionnaire was prepared. This questionnaire was only conducted to fewer participants who are from academia and are working on solar energy. The total number of the participants is 4.

The properties of the alternative sites were given to the participants and they were asked to conduct the questionnaire for each criterion by comparing all the alternative sites. In Figure 3.12 there is an example of a filled questionnaire for one criterion. This time the pairwise comparison matrices were formed more easily compared to the questionnaire of the site selection criteria, as the participants have experience in MCDM methods, especially in AHP, so that it was not needed enlarge the pairwise comparison matrix as shown in Figure 3.2 in Section 3.3.

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer
Menzelet	1	4	7	2	2	2	1	1
Oymapınar	0.25	1	2	0.50	0.50	0.50	0.33	0.33
Torul	0.14	0.50	1	0.25	0.25	0.33	0.20	0.17
Bayramhacılı	0.50	2	4	1	1	1	1	0.33
Demirköprü	0.50	2	4	1	1	1	1	0.33
Yukarı Kaleköy	0.50	2	3	1	1	1	0.50	0.50
Alparslan 2	1	3	5	1	1	2	1	1
Kemer	1	3	6	3	3	2	1	1

Figure 3.12. An example of pairwise comparison matrix formed by a participant for the alternative sites for one site selection criterion

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the decisive results of the questionnaires will be discussed and the most suitable site to install an FPV on among the selected alternative sites will be given.

4.1 Results of the Consensus Analysis of the Site Selection Criteria Questionnaire

The goal of the consensus analysis is to determine a definitive decision of participants by combining all opinions in one pairwise comparison matrix and to get the relative weights of the site selection criteria using OWA technique discussed in Section 3.2.

The first questionnaire of 10 main criteria are answered by 17 participants and 10 of which are found to be consistent according to AHP consistency measures. The questionnaire has been conducted via e-mail or face to face.

Using linguistic quantifier value α as 0.5, 12 iterations are conducted in total and when the standart deviation reached to 0.008, the iterations are stopped. According to the consensus analysis, the group decision matrix for site selection criteria obtained shown in Table 4.1.

Table 4.1 Group Decision Matrix for Site Selection Criteria

Site Selection Criteria	Solar Irradiation	Annual Sunshine Hours	Average Temperature	Topographic Elevation	Water Depth	Distance to Settlements	Distance to Grid Connection	Local Average Wind Speed	Impacts on Regional Development	Social Impact
Solar Irradiation	1.00	3.50	3.96	7.23	6.64	7.46	4.49	5.99	8.02	8.22
Annual Sunshine Hours	0.29	1.00	1.48	3.43	3.38	4.15	2.25	3.21	4.57	4.72
Average Temperature	0.25	0.68	1.00	2.90	3.11	4.05	1.82	2.69	5.17	5.59
Topographic Elevation	0.14	0.29	0.34	1.00	1.14	1.34	0.82	1.33	3.21	3.31
Water Depth	0.15	0.30	0.32	0.88	1.00	1.45	0.69	0.88	3.05	2.92
Distance to Settlements	0.22	0.24	0.25	0.74	0.69	1.00	0.33	0.45	0.99	1.24
Distance to Grid Connections	0.22	0.45	0.55	1.21	1.44	3.07	1.00	1.96	3.93	4.64
Local Average Wind Speed	0.17	0.31	0.37	0.75	1.14	2.23	0.51	1.00	3.80	3.84
Impacts on Regional Development	0.12	0.22	0.19	0.31	0.33	1.01	0.25	0.26	1.00	1.06
Social Acceptance	0.12	0.21	0.18	0.30	0.34	0.80	0.22	0.26	0.94	1.00

The relative weights of each criterion are found to be consistent with the initial ratings of the questionaires conducted by the participants and literature review. For this study, the most important criterion by a wider margin is found to be solar irradiation with a relative weight of 0.348. The second most important criterion is annual sunshine hours with a relative weight of 0.155 and the third most important criterion is average temperature with a relative weight of 0.137. All of the relative weights of the site selection criteria can be seen in Table 4.2.

Table 4.2 Relative Weights of the Site Selection Criteria

Site Selection Criteria	*Relative Weight*
Solar Irradiation	0.348
Annual Sunshine Hours	0.155
Average Temperature	0.137
Topographic Elevation	0.062
Water Depth	0.056
Distance to Settlements	0.037
Distance to Grid Connections	0.089
Local Average Wind Speed	0.064
Impacts on Regional Development and Local Economies	0.026
Social Acceptance	0.025

The ranking of the site selection criteria from the most important to the least important according to their relative weights is shown in Table 4.3.

Table 4.3 Ranking of the Site Selection Criteria According to Their Relative Weights

Site Selection Criteria	*Ranking*	*Relative Weight*
Solar Irradiation	1	0.348
Annual Sunshine Hours	2	0.155
Average Temperature	3	0.137
Distance to Grid Connections	4	0.089
Local Average Wind Speed	5	0.064
Topographic Elevation	6	0.062
Water Depth	7	0.056
Distance to Settlements	8	0.037

Table 4.3 Ranking of the Site Selection Criteria According to Their Relative Weights (continued)

Site Selection Criteria	*Ranking*	*Relative Weight*
Impacts on Regional Development and Local Economies	9	0.026
Social Acceptance	10	0.025

4.2 Results of the Consensus Analysis of Alternative Site Questionnaire

The goal of the consensus analysis is to determine a definitive decision of participants by combining their opinions in pairwise comparison matrices for each site selection criteria separately using OWA technique discussed in Section 3.2.

The second set of questionnaires are conducted among 4 experts. They are asked to rate the alternative sites for each site selection criteria. In total, 40 questionnaires are conducted and pairwise comparison matrices and relative weights of the alternative sites are obtained for each criteria.

Solar Irradiation Criterion: Using α value as 0.5, 4 iterations are conducted in total and when the standart deviation reached to 0.0024, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for solar irradiation criterion obtained can be seen in Table 4.4.

Table 4.4 Group Decision Matrix and Relative Weights of the Alternative Sites for Solar Irradiation Criterion

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer	Relative Weights
Menzelet	1.00	3.78	6.74	1.74	1.74	2.18	1.16	1.00	0.204
Oymapınar	0.26	1.00	2.17	0.50	0.50	0.58	0.39	0.33	0.060
Torul	0.15	0.46	1.00	0.24	0.24	0.31	0.21	0.17	0.030
Bayramhacılı	0.57	2.00	4.18	1.00	1.00	1.33	1.00	0.40	0.119
Demirköprü	0.57	2.00	4.18	1.00	1.00	1.33	1.00	0.40	0.119
Yukarı Kaleköy	0.86	1.72	3.18	0.75	0.75	1.00	0.63	0.46	0.104
Alparslan 2	0.86	2.54	4.77	1.00	1.00	1.59	1.00	0.69	0.143
Kemer	1.00	3.00	5.79	2.52	2.52	2.17	1.45	1.00	**0.221**

Annual Sunshine Hours Criterion: Using α value as 0.5, 5 iterations are conducted in total and when the standart deviation reached to 0.0021, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for annual sunshine hours criterion obtained shown in Table 4.5 below.

Table 4.5 Group Decision Matrix and Relative Weights of the Alternative Sites for Annual Sunshine Hours Criterion

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer	Relative Weights
Menzelet	1.00	0.51	3.17	0.59	1.15	1.38	1.51	0.81	0.120
Oymapınar	1.97	1.00	5.51	1.41	2.31	2.45	2.88	1.83	**0.239**
Torul	0.32	0.18	1.00	0.23	0.40	0.38	0.48	0.28	0.040
Bayramhacılı	1.69	0.71	4.30	1.00	1.79	2.00	2.19	1.17	0.180
Demirköprü	0.87	0.43	2.48	0.56	1.00	1.05	1.23	0.66	0.100
Yukarı Kaleköy	0.66	0.41	2.63	0.50	0.95	1.00	1.17	0.69	0.095
Alparslan 2	0.66	0.35	2.10	0.46	0.82	0.86	1.00	0.59	0.082
Kemer	1.24	0.55	3.62	0.86	1.52	1.45	1.69	1.00	0.144

Average Temperature Criterion: Using α value as 0.5, 13 iterations are conducted in total and when the standart deviation reached to 0.0029, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for average temperature criterion can be seen in Table 4.6 below.

Table 4.6 Group Decision Matrix and Relative Weights of the Alternative Sites for Average Temperature Criterion

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer	Relative Weights
Menzelet	1.00	1.86	0.29	0.44	1.00	0.49	0.28	0.45	0.063
Oymapınar	0.54	1.00	0.18	0.23	0.48	0.26	0.22	0.37	0.037
Torul	3.46	5.55	1.00	1.95	2.97	1.89	1.13	2.32	**0.233**
Bayramhacılı	2.29	4.28	0.51	1.00	2.32	1.13	0.95	2.18	0.161
Demirköprü	1.00	2.10	0.34	0.43	1.00	0.43	0.40	0.89	0.072
Yukarı Kaleköy	3.61	3.78	0.53	0.89	2.32	1.00	0.89	1.62	0.155
Alparslan 2	3.61	4.63	0.89	1.05	2.51	1.13	1.00	1.87	0.183
Kemer	2.21	2.71	0.43	0.46	1.13	0.62	0.53	1.00	0.096

Topographic Elevation Criterion: Using α value as 0.5, 13 iterations are conducted in total and when the standart deviation reached to 0.0083, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for topographic elevation criterion can be seen in Table 4.7.

Table 4.7 Group Decision Matrix and Relative Weights of the Alternative Sites for Topographic Elevation Criterion

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer	Relative Weights
Menzelet	1.00	2.15	0.94	1.02	1.67	0.92	0.92	1.36	0.145
Oymapınar	0.47	1.00	0.50	0.50	0.68	0.61	0.58	0.54	0.072
Torul	1.06	1.98	1.00	1.00	1.38	0.89	0.72	1.38	0.137
Bayramhacılı	0.98	1.98	1.00	1.00	1.38	1.02	0.83	1.38	0.140
Demirköprü	0.60	1.47	0.72	0.72	1.00	0.87	0.68	1.00	0.104
Yukarı Kaleköy	1.09	1.65	1.12	0.98	1.15	1.00	0.83	1.19	0.135
Alparslan 2	1.09	1.73	1.38	1.21	1.46	1.20	1.00	1.15	**0.154**
Kemer	0.74	1.85	0.72	0.72	1.00	0.84	0.87	1.00	0.113

Water Depth Criterion: Using α value as 0.5, 10 iterations are conducted in total and when the standart deviation reached to 0.0028, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for water depth criterion can be seen in Table 4.8.

Table 4.8 Group Decision Matrix and Relative Weights of the Alternative Sites for Water Depth Criterion

Alternative Site	**Menzelet**	**Oymapınar**	**Torul**	**Bayramhacılı**	**Demirköprü**	**Yukarı Kaleköy**	**Alparslan 2**	**Kemer**	**Relative Weights**
Menzelet	1.00	0.38	0.44	0.34	0.40	0.45	0.49	0.74	0.058
Oymapınar	2.63	1.00	1.22	0.99	1.11	1.35	1.43	2.65	0.168
Torul	2.25	0.82	1.00	0.84	0.91	1.00	1.00	2.02	0.134
Bayramhacılı	2.93	1.01	1.19	1.00	1.43	1.71	1.71	2.55	**0.185**
Demirköprü	2.50	0.90	1.10	0.70	1.00	1.00	1.35	2.11	0.143
Yukarı Kaleköy	2.04	0.74	1.00	0.58	1.00	1.00	1.11	1.89	0.127
Alparslan 2	2.04	0.70	1.00	0.58	0.74	0.90	1.00	1.83	0.117
Kemer	1.35	0.38	0.50	0.39	0.47	0.53	0.55	1.00	0.068

Distance to Settlements Criterion: Using α value as 0.5, 13 iterations are conducted in total and when the standart deviation reached to 0.0049, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for distance to settlements criterion can be seen in Table 4.9 below.

Table 4.9 Group Decision Matrix and Relative Weights of the Alternative Sites for Distance to Settlements Criterion

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer	Relative Weights
Menzelet	1.00	0.83	0.72	1.00	1.33	1.70	1.30	0.83	0.129
Oymapınar	1.20	1.00	0.94	1.20	1.19	1.82	1.47	0.82	0.143
Torul	1.38	1.06	1.00	1.21	1.29	1.75	1.55	1.13	**0.156**
Bayramhacılı	1.00	0.83	0.83	1.00	1.20	1.60	1.21	0.87	0.127
Demirköprü	0.75	0.84	0.77	0.83	1.00	1.85	1.20	1.00	0.121
Yukarı Kaleköy	0.77	0.55	0.57	0.62	0.54	1.00	0.68	0.63	0.081
Alparslan 2	0.77	0.68	0.64	0.83	0.83	1.47	1.00	0.78	0.103
Kemer	1.20	1.21	0.88	1.16	1.00	1.58	1.28	1.00	0.141

Distance to Grid Connections Criterion: Using α value as 0.5, 12 iterations are conducted in total and when the standart deviation reached to 0.0049, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for distance to grid connections criterion can be seen in Table 4.10 below.

Table 4.10 Group Decision Matrix and Relative Weights of the Alternative Sites for Distance to Grid Connections Criterion

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer	Relative Weights
Menzelet	1.00	2.63	5.10	0.56	2.63	1.78	0.60	0.90	0.142
Oymapınar	0.38	1.00	2.29	0.22	1.00	0.72	0.21	0.24	0.053
Torul	0.20	0.44	1.00	0.15	0.51	0.35	0.15	0.17	0.029
Bayramhacılı	1.78	4.45	6.61	1.00	3.97	2.55	1.00	1.00	0.214
Demirköprü	0.38	1.00	1.97	0.25	1.00	0.85	0.25	0.30	0.057
Yukarı Kaleköy	1.67	1.40	2.82	0.39	1.18	1.00	0.38	0.45	0.096
Alparslan 2	1.67	4.78	6.87	1.00	3.93	2.63	1.00	1.00	**0.216**
Kemer	1.11	4.12	6.06	1.00	3.38	2.21	1.00	1.00	0.192

Local Average Wind Speed Criterion: Using α value as 0.5, 12 iterations are conducted in total and when the standart deviation reached to 0.0021, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for local average wind speed criterion can be seen in Table 4.11 below.

Table 4.11 Group Decision Matrix and Relative Weights of the Alternative Sites for Local Average Wind Speed Criterion

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer	Relative Weights
Menzelet	1.00	2.88	2.55	0.54	0.62	0.89	0.54	0.62	0.106
Oymapınar	0.35	1.00	0.81	0.25	0.26	0.28	0.25	0.26	0.041
Torul	0.39	1.23	1.00	0.31	0.30	0.39	0.31	0.30	0.050
Bayramhacılı	1.86	3.92	3.19	1.00	1.00	1.39	1.00	1.00	**0.169**
Demirköprü	1.62	3.88	3.33	1.00	1.00	1.13	1.00	1.00	0.163
Yukarı Kaleköy	1.86	3.54	2.55	0.72	0.89	1.00	0.72	1.00	0.142
Alparslan 2	1.86	3.92	3.19	1.00	1.00	1.39	1.00	1.00	**0.169**
Kemer	1.62	3.88	3.33	1.00	1.00	1.00	1.00	1.00	0.161

Impacts on Regional Development Criterion: Using α value as 0.5, 10 iterations are conducted in total and when the standart deviation reached to 0.0026, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for impacts on regional development criterion can be seen in Table 4.12 below.

Table 4.12 Group Decision Matrix and Relative Weights of the Alternative Sites for Impacts on Regional Development and Local Economies Criterion

Alternative Site	**Menzelet**	**Oymapınar**	**Torul**	**Bayramhacılı**	**Demirköprü**	**Yukarı Kaleköy**	**Alparslan 2**	**Kemer**	**Relative Weights**
Menzelet	1.00	3.34	0.76	2.20	2.01	0.49	0.49	1.93	0.128
Oymapınar	0.30	1.00	0.22	0.65	0.86	0.19	0.20	0.64	0.043
Torul	1.32	4.57	1.00	2.95	2.94	0.68	0.68	2.70	0.176
Bayramhacılı	0.45	1.55	0.34	1.00	1.34	0.30	0.32	0.98	0.068
Demirköprü	0.50	1.16	0.34	0.75	1.00	0.28	0.28	0.87	0.059
Yukarı Kaleköy	2.05	5.34	1.48	3.29	3.53	1.00	1.00	3.04	**0.230**
Alparslan 2	2.05	4.99	1.48	3.17	3.53	1.00	1.00	3.04	0.227
Kemer	0.52	1.56	0.37	1.02	1.15	0.33	0.33	1.00	0.069

Social Acceptance Criterion: Using α value as 0.5, 10 iterations are conducted in total and when the standart deviation reached to 0.0026, the iterations are stopped. According to the consensus analysis, the group decision matrix and the relative weights of the alternative sites for social acceptance criterion can be seen in Table 4.13.

Table 4.13 Group Decision Matrix and Relative Weights of the Alternative Sites for Social Acceptance Criterion

Alternative Site	Menzelet	Oymapınar	Torul	Bayramhacılı	Demirköprü	Yukarı Kaleköy	Alparslan 2	Kemer	Relative Weights
Menzelet	1.00	4.11	0.80	2.17	1.58	1.49	1.49	1.80	0.178
Oymapınar	0.24	1.00	0.20	0.71	0.91	0.21	0.23	0.80	0.046
Torul	1.24	5.11	1.00	2.65	3.49	0.80	0.80	3.19	**0.194**
Bayramhacılı	0.46	1.41	0.38	1.00	1.24	0.38	0.38	1.22	0.073
Demirköprü	0.63	1.10	0.29	0.80	1.00	0.30	0.33	0.80	0.063
Yukarı Kaleköy	0.67	4.66	1.25	2.64	3.32	1.00	1.00	3.05	0.191
Alparslan 2	0.67	4.44	1.25	2.64	3.03	1.00	1.00	3.05	0.187
Kemer	0.56	1.26	0.31	0.82	1.24	0.33	0.33	1.00	0.067

4.3 Discussions

In this study, 2 questionnaires have been conducted. In the first questionnaire, the participants are asked to rate the site selection criteria.

In the first questionnaire, only 10 of 17 participants are found to be consistent according to AHP procedures. There is no doubt that the participants have certain experience in solar energy sector. The results might be inconsistent because they are not familiar with AHP technique or the procedure could not be tought them clearly. However the consistent results are considered as enough to conduct this study.

Based on experts' opinion, solar irradiation is found to be the most important site selection criterion with a relative weight of 0.348 and annual sunshine hours is found to be the second most important criterion with a relative weight of 0.155. Thirdly, average temperature criterion is found to be important a relative weight of 0.137.

With a relative weight of 0.089, distance to grid connections criterion is also found as an important site selection criterion. However, as the selected alternative sites are HEPP reservoirs and there is currently electricity production by those HEPPs, there are already grid connections close to the selected site. Therefore, as it can be seen in Table 4.9, the relative weights of the alternative sites for distance to grid connections criterion, there is not a large difference on the alternative sites so that this criterion have not played an important role in the site selection study. Yet distance to grid connections criterion has been included to the study for future studies.

Besides, both social acceptance and impacts on regional development and local economies get the lowest ratings from the participants with the relative weights of 0.025 and 0.026 respectively. This shows that these two criteria are the least important concerns for the site selection criteria for installing solar power plants in general.

For the second part, 4 participants who are experienced with solar energy and AHP procedures are asked to conduct the second questionnaire which asks to rate the alternative sites per site selection criteria.

According to their opinion, after consensus analysis is carried out, Kemer is found to be the best site with a relative weight of 0.221 for the most important site selection criterion, solar irradiation. For annual sunshine hours criterion, Oymapınar is found to be the best alternative site with a relative weight of 0.239. For the third important site selection criterion which is average temperature, Torul was found to be the best alternative site with a relative weight of 0.233.

For distance to grid connection criterion, Bayramhacılı and Alparslan 2 sites are found to fit the best with relative weights of 0.214 and 0.216 respectively.

For impacts on regional development and local economies criterion, Yukarıkaleköy, Bingöl and Alparslan 2, Muş sites are found to be the best sites to benefit, as these 2 cities of Turkey are not so developed economically relatively to the other alternative site locations.

Unlike other site selection studies, buffer zones such as military areas, seismic zones, naturally protected areas etc. are not used in this study because the selected alternative sites are HEPP reservoirs.

The relative weight of each criterion is multiplied by the relative weight of each alternative site for the same criterion and the sum of all multiplications give the result of the combination of the both consensus analysis of the questionnaires.

According to these calculations, as the results are shown in Table 4.14, Kemer is found to be the best alternative site to install an FPV with a total score of 0.160. Bayramhacılı and Alparslan 2 share the same score of 0.149 as second-best alternatives. With very little variation, Menzelet with a total score of 0.142 can be considered as another second-best candidate for site suitability. While Yukarı Kaleköy and Demirköprü make up the mid range for site suitability with the total scores of 0.119 and 0.104, the alternative sites such as Oymapınar and Torul are found to be the least suitable sites for floating PV installation in this study with the total scores of 0.092 and 0.086 respectively.

Unsurprisingly, there is not a large difference in the total scores of the alternative sites in this study, as the alternative sites are pre-selected with high solar irradiation, high annual sunshine hours and low-mid average temperature values.

Table 4.14 Combination of the Consensus Analysis Results

Decision Criterion	*Relative weight*	*Menzelet*	*Oymapınar*	*Torul*	*Bayramhacılı*	*Demirköprü*	*Yukarı Kaleköy*	*Alparslan 2*	*Kemer*
Solar Irradiation	0.348	0.204	0.060	0.030	0.119	0.119	0.104	0.143	**0.221**
Annual Sunshine Hours	0.155	0.120	**0.239**	0.040	0.180	0.100	0.095	0.082	0.144
Average Temperature	0.137	0.063	0.037	**0.233**	0.161	0.072	0.155	0.183	0.096
Topographic Elevation	0.062	0.145	0.072	0.137	0.140	0.104	0.135	**0.154**	0.113
Water Depth	0.056	0.058	0.168	0.134	**0.185**	0.143	0.127	0.117	0.068
Distance to Settlements	0.037	0.129	0.143	**0.156**	0.127	0.121	0.081	0.103	0.141
Distance to Grid Connections	0.089	0.142	0.053	0.029	0.214	0.057	0.096	**0.216**	0.192
Local Average Wind Speed	0.064	0.106	0.041	0.050	**0.169**	0.163	0.142	**0.169**	0.161
Impacts on Regional Development and Local Economies	0.026	0.128	0.043	0.176	0.068	0.059	**0.230**	0.227	0.069
Social Acceptance	0.025	0.178	0.046	**0.194**	0.073	0.063	0.191	0.187	0.067
Final Group Alternative Score		**0.142**	**0.092**	**0.086**	**0.149**	**0.104**	**0.119**	**0.149**	**0.160**

CHAPTER 5

CONCLUSION

Site selection takes arguably one of the most significant stages in the overall sucess of a solar PV power plant. In this study, site selection for floating solar PVs has been carried out using AHP and OWA techniques.

After carrying out an extensive literature review in the fields of solar PVs and floating solar PVs, 10 main site selection criteria has been decided on to use. The following criteria are selected for this study: solar radiation, annual sunshine hours, average temperature, topograhic elevation, water depth, distance to settlements, distance to grid connection, local average wind speed, impacts on regional development and social acceptance. Then 8 HEPP reservoirs in diffirent regions of Turkey are studied based on their solar irradiation, annual sunshine hours, topographic elevation and average temperature values. Selected alternative sites are as follows; Menzelet(Kahramanmaraş), Oymapınar(Antalya), Torul(Gümüşhane), Bayramhacılı(Nevşehir), Demirköprü(Manisa), Yukarı Kaleköy(Bingöl), Alparslan 2(Muş), Kemer(Aydın).

2 questionnaires are conducted to the experts of solar energy with diffirent backgrounds such as academia, private sector and public institutions. The results are of the questionnaires are combined using OWA. As the result of questionnaires, the most important decision site selection criterion was found to be "Solar Irradiation" (34.8%). The Following criteria are "Annual Sunshine Hour" (15.5%), "Average Temperature" (13.7%) and "Topographic Elevation" (6.2%). The relative weights were coincided generally consistent with the findings from literature review as well as the experts' initial rating on the questionaires. According to the combination of the consensus analysis conducted, Kemer Dam(Aydın) is found to be the most feasible site (16.0%) for floating solar PV site selection. Following second-best

alternatives are equally scored Bayramhacılı(Nevşehir) and Alparslan 2(Muş) (14.9%). Menzelet(Kahramanmaraş) (14.2%) has also been suggested to be asssesed as equal with other second-best alternatives since the difference in percentage is found to be negligible. Demirköprü(Manisa) (10.4%), Oymapınar(Antalya) (9.2%) and Torul(Gümüşhane) (%8.6) are found to be least suitable sites for floating PV installations in this study.

Floating PV technology is a relatively new field of study which will certainly offer advantegous opportunities for the expansion of environmental friendly energy sources. Hence, more studies are to be concentrated on this newly growing technology in order to not only point out its challenges but also scale up the use of solar energy in Turkey and the world in near future. For similar reasons, this study is believed to be novel and have an important contributation to the literature. As previously mentioned, the literature on FPV technology is only recently emerging. Although there have been case studies on site selection for land based solar power plants in Turkey, this study presents a site selection with a large number of main criteria on many alternative sites in different locations of Turkey for FPV systems.

Methodology used in this study could be an applicable methodology for floating solar PV power plant site selection and could be used as an advantageous tool for determination of national strategies about solar energy. This methodology allows the field experts' opinions to be included in the site selection and could be applied for subjective, vague and imprecise data by controlling the consistency of the experts' evaluations. It could be also modified according to additional criteria such as environmental, economic, technical or regulatory for different sites and for diffirent study cases and could be used as a beneficial tool to select priority sites as long as related criteria are carefully determined and the required data is gathered.

In this study, almost all criteria used in the literature on solar power plant site selection were considered. Also, water depth and socio-economical criteria have been taken into consideration as main criteria in this thesis. There might be other important parameters for developments of a conceptual design. For instance, in the design stage of a Floating PV for a specific site, wave effects due to local wind speed and cloudiness of the weather should be also considered. Because wave effect has also an important role on design of mooring lines which provide stability to the system against tilting of the platform. Similarly, cloudiness of the weather is directly related with the period of the sun shine reaching to the panels so it should be considered in the design stage.

In addition to this study, other MCDM methods could be used with similar criteria and same alternative sites to assess the sensivity of the used methodology. Ecologists, marine biologists and environmental engineers could be asked to participate in the questionnaires in future studies in order to consider the impact of FPVs to environment. Also, potential negative impacts of FPVs on natural bird habitats might be investigated in detail by environmental specialists. Besides cost analysis can be added for future studies as an extension of this study by using cost criterion. This study could also be used for other renewable energy investments by using relevant criteria.

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APPENDICES

A. The Questionnaire for Site Selection Criteria

	1st									2nd								
1st	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	2nd criterion
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

1st criterion	1st criterion is more important								Equal	2nd criterion is more important								2nd criterion
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local Average Wind Speed
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies
Solar Irradiation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance
Annual Sunshine Hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Average Temperature
Annual Sunshine Hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Topographic Elevation
Annual Sunshine Hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Water Depth
Annual Sunshine Hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Settlements
Annual Sunshine Hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Grid Connections

1st criterion	1st criterion is more important								Equal	2nd criterion is more important								2nd criterion
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Annual Sunshine Hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local Average Wind Speed
Annual Sunshine Hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies
Annual Sunshine Hours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance
Average Temperature	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Topographic Elevation
Average Temperature	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Water Depth
Average Temperature	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Settlements
Average Temperature	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Grid Connections
Average Temperature	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local Average Wind Speeds

1st criterion	1st criterion is more important								Equal	2nd criterion is more important								2nd criterion
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Average Temperature	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies
Average Temperature	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance
Topographic Elevation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Water Depth
Topographic Elevation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Settlements
Topographic Elevation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Grid Connections
Topographic Elevation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local Average Wind Speed
Topographic Elevation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies
Topographic Elevation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance

1st criterion	1st criterion is more important								Equal	2nd criterion is more important								2nd criterion
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Water Depth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Settlements
Water Depth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Grid Connections
Water Depth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local Average Wind Speed
Water Depth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies
Water Depth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance
Distance to Settlements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Distance to Grid Connections
Distance to Settlements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local Average Wind Speed
Distance to Settlements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies

1st criterion	1st criterion is more important								Equal	2nd criterion is more important								2nd criterion
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Distance to Settlements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance
Distance to Grid Connections	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Local Average Wind Speed
Distance to Grid Connections	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies
Distance to Grid Connections	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance
Local Average Wind Speed	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Impacts on Regional Development and Local Economies
Local Average Wind Speed	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance
Impacts on Regional Development and Local Economies	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Social Acceptance