



Research Article

A novel approach for clean energy production and decarbonization using floating photovoltaic systems: Türkiye case

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ABSTRACT

Floating photovoltaic systems (FPVs) have many advantages over traditionally used photovoltaic systems, such as preventing water evaporation, using agricultural lands for different purposes, and having higher energy efficiency. Therefore, FPVS can be an effective solution to reduce dependence on fossil energy sources and minimize carbon emissions. There are limited number of studies on FPVs application in Türkiye, especially in terms of the CO₂ emission reduction. Therefore, determination of optimum tilt angle, annual energy production and decarbonization for FPVs applications in water bodies in Türkiye were investigated through this research. The results show the effects of FPVS installed in five different water bodies on energy output and greenhouse gas emission reduction. The simulation of FPVs was carried out in the PVGIS software. Firstly, the annual energy production (AEP) of FPVs with different tilt angles scenarios (5°, 12°, 22°, 32°, 42°) is calculated for five different water bodies. Based on the AEP calculations, the monthly energy production of FPVS with 32° tilt angle, which provides maximum energy production, is discussed. The annual energy production of Berdan Dam with 32° tilt angle shown potential of 1588 kWh annually and provides the highest energy output among five different water bodies in Türkiye. CO₂ emission reduction was also calculated and varied between 1 and 1.1 tCO₂/year for observed locations. The obtained results provide important insights in optimum tilt angle for the installation of FPVS for Turkish climatic conditions and emphasize the FPVS effect on reducing carbon emissions and decarbonization contribution.

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INTRODUCTION

Last few years, the number of studies about floating photovoltaic systems (FPVs) increased significantly, but

the application of FPVs is still not researched enough. Traditional photovoltaic systems are installed on places such as roofs and land, but land is used for different

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purposes such as agriculture and housing. At this point, FPVs are a solution to occupying lands by placing them on water bodies such as dam reservoirs, rivers, miner queries and lakes [1].

Fereshtehpour et al. [2] emphasized that FPVS have additional advantages due to not occupying useful land area, preventing water evaporation and algal blooming. When the performance of FPVs is discussed, it is concluded that they can produce approximately 195 GWh and 260 GWh of energy per kilometer annually. In this way, if FPVs cover one kilometer area of each dam, the energy needs for approximately 90 thousand people can be satisfied. It is also concluded that the investment cost applied for the installation of FPVs can be paid back within 5 or 6 years. Considering the environmental impact of photovoltaic systems, it is emphasized that these systems will reduce carbon emissions by approximately 120 ktCO₂ per year and that water savings will be achieved because of covering each dam with FPVs, which is equivalent to the domestic water needs of a city with a population of approximately one million.

El Hammoumi et al. [3] compared photovoltaic systems on ground and FPVS with the same thermal and electrical performances, and concluded that FPVS, which are integrated into existing photovoltaic systems that provide sustainable and clean energy production, provide higher efficiency. In addition, the surface temperature of FPVS is approximately 3 °C colder than land photovoltaic systems, due to the water-cooling effect. It is also emphasized that thanks to the cooling effect of water, FPVS provide approximately 2% more energy production than land photovoltaic systems. Similarly, Chaurasiya et al. [4] concluded that an increase in solar irradiance of 1000 W/m² can contribute to the increase in PV temperatures up to 7 °C.

Kazmak and Sahin [5] developed a new design for FPVS exposed to extreme weather conditions in their study, and it was stated that FPVS can contribute to effective energy production in calm waters, and at the same time, they can contribute to effective energy production in FPVS that are not exposed to strong winds over short distances. Türkiye as a country with a lot of sunny hours during the year is very suitable for FPVs, as researched by Adan and Başaran Filik [6]. Further, Vidovic et al. [7] supported the idea that the study they conducted on solar panels installed on lakes and water reservoirs, which showed that many countries with hot climates face the problem of global water scarcity, and therefore these environmentally convenient systems can reduce water evaporation, increase the use of hydroelectric power plants, and thus provide many advantages by contributing to clean electricity production. For example, for large plants the cost calculation for India and China is approximately 0.6 USD/W_p and 1 USD/W_p respectively.

In addition, Gorjian et al. [8] explained that FVP systems with cooling systems show more improvement and can have a long-lasting with their study on the latest technical developments in the field of renewable energy of

FPVs. It is stated that an improvement of approximately 15% can be achieved in electricity production thanks to the water veil cooling technique. Further, it is concluded that the high-water depth is a critical factor as it will cause a decrease in energy efficiency. Furthermore, the authors emphasize that the covering rate for FPVs in hydroelectric power plants will provide optimum conditions between 40% and 60%, and that this rate will control algal density and that this rate is important for hydroelectric efficiency as well.

Bajc and Kostadinovic [9] investigated the possibility of FPVs application on six large lakes in the Republic of Serbia and explained that FPVs have significant advantages in terms of sustainability by showing the annual energy production, the amount of saved water, and the amount of carbon dioxide emissions reduction. The authors emphasized that FPVs have the capacity to produce approximately 9000 kWh of energy per year and that these systems can reduce carbon dioxide emissions by 126.8 tons over 20 years. In addition, these systems can reduce water evaporation by more than 3000 million cubic meters per year.

For the case of Türkiye, Karipoğlu et al. [10] did the analysis of the suitable site selection for the FPVs on several locations (Beyşehir Lake, Tuz Lake and Van Lake) using fuzzy analytical hierarchy process and they concluded that Beyşehir Lake has the best value concerning the investigated criteria such as technical, environmental and social and accessibility criteria.

Similarly, Haspolat et al. [11] performed site selection analysis using fuzzy sine trigonometric model for 15 hydro-power plant reservoirs in Türkiye and they concluded that using their approach, that reservoir Sarıyar, with the lowest GHI was selected as the most suitable for installation of FPVs. They performed comprehensive study including a lot of criteria, but to get clearer picture, it would be necessary to perform cost-benefit analysis as well.

The Main Advantages and Disadvantages of FPVs

FPVs have a lot of advantages in comparison to the traditional system for electricity production and the most significant ones are shown in Table 1. In different studies, the authors researched the decrease in water evaporation, the impact on the environment, the increase of energy efficiency, increase of water quality, the reduction of the land occupation, and FPVs resistance in harsh conditions and the most significant conclusions are sorted in Table 1. On the other hand, there are some disadvantages of FPVs that must be considered, such as: decrease of efficiency in harsh climatic conditions, negative impact of water, waves and wind on the material and FPVs' structure and its degradation during the time and the price of the installation.

The integration of floating photovoltaic (FPV) systems into hydropower plants offers a multifaceted approach to enhancing renewable energy generation while optimizing water and land resources. This hybrid configuration enables complementary energy production, wherein solar energy is

Table 1. Advantages and disadvantages of FPVS

ADVANTAGES	DISADVANTAGES
The Decrease in Water Evaporation: Water evaporation will be reduced by approximately half by covering only 30% of the water body [12].	
The Increased Energy Efficiency: FPVS of the same size produces approximately 19% more energy and provides approximately 980 kL of water compared to traditional photovoltaic systems [13].	Decrease in Efficiency due to Harsh Climatic Conditions: Natural events such as tides, storms and waves have a negative effect on the lifespan and components of FPVs. The climatic effects will not only affect the components, but also energy efficiency, which can be reduced due to constantly changing temperature and humidity rates. In addition, researchers emphasize the importance of regular cleaning on the shores of FPVS installed in water bodies such as rivers or lakes [19,20].
Environmental impact: The FPVs installation on water bodies used for different purposes, such as artificial lakes and reservoirs, has less negative impact on the environment than terrestrial photovoltaic systems. The installation of terrestrial photovoltaic systems causes environmental problems such as deforestation and erosion, while FPVs are shown as a new alternative solution for using solar energy since they do not cause such environmental problems [14].	
The Increase in Water Quality: The FPVs prevent growth of phytoplankton and algae, improved water quality and increased the productivity of some culture species. The FPVS installed in aquaculture areas provided approximately 1.5 times more efficiency in milkfish [15].	
Resistance to Harsh Climatic Conditions: FPVS are safe under adverse environmental conditions such as waves because they are below the yield strength of the PosMAC material, which has a yield strength of approximately 400 MPa [16].	Degradation of Monitoring Performance of Systems due to Waves: FPVs can have some technical problems such as decrease in tracking performance of UAV systems due to waves on the water [21].
The Power Efficiency: As a result of the effect of installing FPVS in Hubei, Jiangsu, and Yunnan regions, water saving can be achieved by about 13%, 11% and 19% respectively [17].	
Reducing Land Occupation: A study on the sustainability of FPVs, a technological new model installed on water bodies in Spain, emphasizes that the installation of FPVs on existing water bodies will prevent occupation of useful land area and land can be used for different purposes [18].	Installation Costs: Installation costs of FPVs are higher than traditional ones due to the installation on water. CAPEX costs are maximum 30% higher than terrestrial photovoltaic systems [21,22].

harnessed during daylight hours and hydropower generation can be modulated to meet peak demand or provide grid support during periods of low solar output [23]. Such synergy not only contributes to improved energy reliability but also enhances overall system efficiency. Empirical studies indicate that covering approximately 10% of a reservoir's surface with FPV installations can augment hydropower output by up to 65%, largely due to reduced water evaporation and improved reservoir management [23]. In water-scarce regions, the evaporation-mitigating effect of FPVs is particularly valuable. For instance, a recent analysis of Lake Nasser in Egypt demonstrated that covering 50% of the reservoir surface with FPV panels could decrease

evaporation losses by 61.7%, preserving over nine billion cubic meters of water annually [24]. Additional advantages include enhanced photovoltaic efficiency due to the natural cooling effect of water, improved water quality through reduced algal proliferation, and lower sedimentation rates, which help to maintain reservoir capacity over time. Economically, this co-location strategy reduces the need for additional land and infrastructure investments, thereby lowering capital expenditures. Collectively, the integration of FPV systems with hydropower infrastructure presents a technically viable, environmentally sustainable, and economically advantageous solution for accelerating the global transition to renewable energy.

Efficiency of FPVs

Many researchers discussed the efficiency of FPVs. Liu et al. [25] reported that efficiency of FPVs in China according to their study, that approximately 2% more power generation efficiency can be achieved than traditional photovoltaic systems. At the same time, it is shown that 160 GW can be obtained from these systems that cover half the water area of 5000 km² and thus can prevent the evaporation of approximately 2.1027 m³ of water per year. Further, Sahu et al. [26] stated that there are several solar installation classifications such as land-based, roof-top, canal-top, off-shore and reservoir and lake-based floating solar systems. Among these systems, it is emphasized that floating solar is more efficient than land-based and roof-top systems. In their review, FPVs provide approximately 10% more energy efficiency compared to terrestrial PV systems, while contributing more than 50% to prevent water evaporation.

Furthermore, Singh et al. [27] show that on how FSPV used in dam reservoirs in India affect economic aspects, water saving and CO₂ emission reduction. In their research, they show that FPV systems produce 2% more energy than land-based photovoltaic (LBPV) systems. In addition, FSPV systems can make a positive contribution to the environment by providing approximately 3 tons more carbon reduction. Moreover, they can save approximately 70 cm of water per year and use this water in places such as irrigation, drinking water, and power generation thanks to FPV systems.

Additionally, Abid et al. [28] examined the studies conducted between 2001 and 2017 to observe the advantages and effects of floating photovoltaic technologies, especially in regions such as South Asia and Central Asia, which experience water scarcity. In line with the study, it was emphasized that FPVs will have increased energy efficiency due to the cooling effect of water, and at the same time, these systems will contribute to the water saving, and in addition, land areas can be used for different purposes thanks to the installation of these systems on the water surface. The environmental advantages of FPVs systems are that they reduce algae formation and reduce greenhouse gas emissions.

Moreover, Kjeldstad et al. [29] conducted a study in which FPVs were installed on a dam in Kilinochchi, Sri Lanka, and a practical study was conducted by analyzing the performance and reliability of these systems, and the calculation of heat coefficients. According to the statistical data obtained after this study, it was concluded that FPVs were approximately 0.5% more efficient compared to traditional photovoltaic systems. In addition, no change was observed in the performance of FPVs when the dam was refilled with water after the drought period. The U-value in February and May was 33 W/m² K, while this value changed in March and April and became 20 W/m² K.

Yakubu et al. [30] compared the performance analysis of land-based and FPVs on mono-facial and bifacial surfaces with the same characteristics in Ghana. According to the obtained data, bifacial land and bifacial floating PV

systems produce more energy. For instance, compared to mono-facial PV systems, bifacial land-based PV systems show approximately 2.5% efficiency and floating bifacial PV system shows approximately 5% efficiency.

Elminshawy et al. [31] performed the experimental investigation of floating PV modules in laboratory conditions and concluded that for finned F-FPV module, temperature dropped 7.7% in comparison to the conventional FPV module.

The Novelty of Research

This research highlights the potential of FPVs application on water bodies in Türkiye, taking into consideration lakes and dams. The available data on applicability of FPVs worldwide and in Türkiye as well are still limited. This research evaluates the application of FPVs in Türkiye from different perspectives than the offered in the existing literature, showing the results for AEP based on the optimum tilt angle of FPVs for different water bodies and possible CO₂ emission reduction, which have not been extensively investigated before. Therefore, the paper presents a novelty side in terms of suitability of FPVs for application in Türkiye. The results obtained contribute to the more profound knowledge of FPVs applications and the potential of decarbonization of the electricity production sector and provide the stakeholders with the information which will contribute to the investments in this sector. Furthermore, there are no standards on the FPVS design and application in the Republic of Türkiye, and these results helps to the policymakers with valuable data.

MATERIALS AND METHODS

This study researches the potential of FPVs installation on water bodies in Türkiye. For these purposes, the following methodology is developed and shown in Figure 1.

As a first step, lakes and dams in Türkiye were researched using available databases and Global Solar Atlas [32] and information about their positions and features was collected. In the second step, a model was designed for FPVs and in a third step, the annual energy production was compared with different tilt angles of 5, 12, 22, 32 and 42 degrees using the PVGIS software [33]. In this way, the optimal tilt angle was determined, and monthly energy production values were compared. In addition, the reduction in GHG emissions was evaluated with the determined optimal tilt angle for five depicted water bodies.

The PVGIS software was used to obtain the annual energy production of FPVs located in different water bodies at different tilt angles. Solar radiation values are calculated according to the latitude and longitude of the locations of different water bodies. The PVGIS software provides online analysis of the performance of photovoltaic systems on hourly, daily and monthly basis for all regions except the North and South Poles.

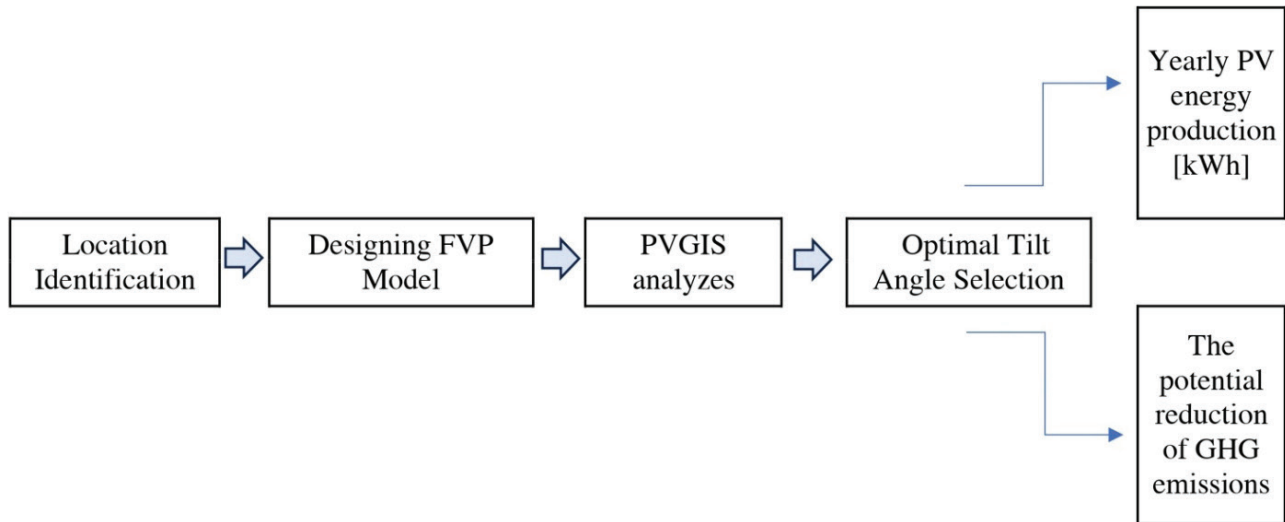


Figure 1. Methodology diagram.

Studied Area Selection

To obtain the highest possible energy yields from FPVs, choosing the optimal location is one of the first important steps. In this study, the selection of regions available for application of the installation of photovoltaic systems in Türkiye was firstly taken into consideration. The characteristics of the dams and lakes evaluated for the study are given in Table 2. Important parameters such as area, water volume and depth, possibility of connection to the existing grid and protected areas have been evaluated.

Furthermore, the global horizontal irradiation (GHI) for water bodies in Türkiye based on the Global Solar Atlas [32] is analyzed and shown in Figure 2.

Based on all mentioned important criteria, five water bodies: Van, Ilgın, Berdan Keban and Kralkızı are evaluated. Since Berdan, Keban and Kralkızı dams are already

used for hydroelectric power plants, they are more favorable for FPVs concerning the necessary infrastructure and grid connection. The other two lakes are considered since the existing electrical grid is very close to them and there is a possibility of implementing FPVs into the existing infrastructure as well. All the natural protected areas are excluded from this study.

According to the Figure 2, the global horizontal irradiations for the selected lakes and dams are as follows: for Ilgın it is 1711 kWh/m², for location Berdan it is 1795 kWh/m², for Keban it is 1775 kWh/m², for location of Kralkızı, it is 1794 kWh/m² and for location of Van it is 1790 kWh/m². These results slightly vary from the exact coordinates of the location at the lake, since the solar irradiation changes with each change of location.

Table 2. Characteristics of the Five Different Water Bodies Evaluated in The Study [34] [created by author]

Lake (River)	Area (km ²)	Water volume	Altitude (m)	Depth (m)	Site location	Type	Possibility to connect to existing HPP grid
Van	3.755 km ²	607 km ³	1640 m	171 m	38°38'0"K 42°49'0"D	natural	yes
Ilgın (Çavuşçu)	27 km ²	~ 135 hm ³	1026 m	2-10 m	38°20'45"K 31°52'36"D	natural	yes
Berdan Dam	6.70 km ²	88 hm ³	66 m	~ 13 m	36°57'58"K 34°53'43"D	artificial	yes
Keban Dam	675 km ²	31 km ³	210 m	163 m	38°48'25"K 38°45'25"D	artificial	yes
Kralkızı Dam	57.50 km ²	1919 hm ³	113 m	~ 33 m	38°20'56"K 40°01'17"D	artificial	yes

Description of The Model for Simulations

The proposed model for simulation consists of PV modules, floats, mooring system and electrical components [9].

Input data for FPVs used in PVGIS simulation are shown in Table 3. The system capacity of FPVs is normalized as 1 kWp and system loss adopted as 14% [33]. In addition, several different values for the tilt angle of the system are simulated and the results are shown in detail in the result section of the article.

Table 3. Input data of simulated FPVS

Input data of the FPVS used in the simulation	
PV system type	Fix angle
PV module type	Crystalline silicon
PV system capacity	1 kWp
Tilt angle	Optimal
System loss	14%

RESULTS AND DISCUSSION

Simulations of FPVs were performed for five different locations where are Ilgın, Berdan, Keban, Kralkızı and Van in Türkiye and the obtained results are shown and discussed within this section.

Energy Production of the FPVS with Different Tilt Angles

For this study, the optimum tilt angle value for the installation of FPVs for water bodies in Türkiye was not adopted from the literature due to the limited number of studies, but it was simulated using PVGIS software. Looking at the existing results in the literature, [35] showed the initial design and installation of FPVs in Büyükçekmece Lake in Türkiye and examined the resistance of these systems to the

weather conditions. In their study, the researchers determined the tilt angle of 34°.

In another study, [14] showed that the new model FPVs for Büyükçekmece Lake is dependent on climate changes and geographical conditions, and they examine the performance analysis of FPVs with a 120 kWp power and a tilt angle of 13°.

Having in mind the limited number of studies showing the tilt angle, in this study, the optimum tilt angle value was determined by comparing the maximum annual energy production obtained from FPVs with different tilt angles of 5°, 12°, 22°, 32° and 42°. The annual energy production of FPVs installed on five different water masses according to different slope angle values was compared using the data

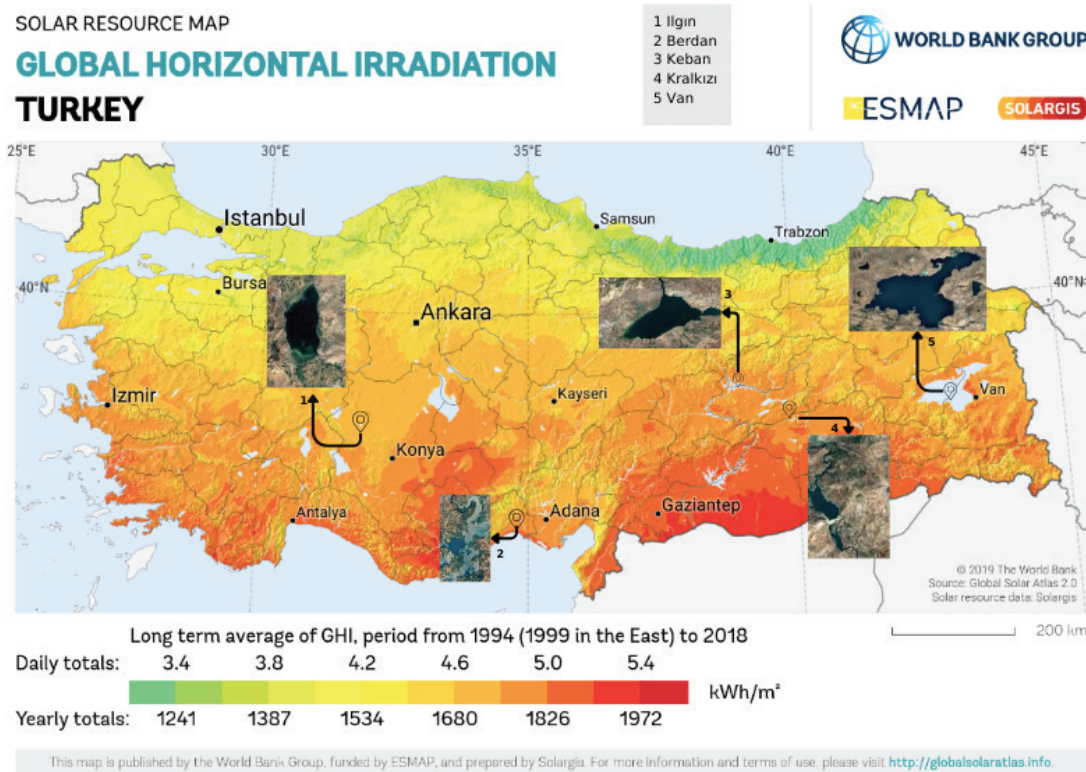


Figure 2. Locations of selected water bodies on the global horizontal irradiation map (1-Ilgın, 2- Berdan, 3 – Keban, 4- Kralkızı, 5-Van) [32] [created by author].

Table 4. Annual FPV Energy Production [kWh] of Water Bodies Respect to Different Tilt Angle Values [34] [created by author]

Name of the lakes and dams	Location	Slope	Yearly PV energy production [kWh]
Ilgin	38°20'45"K 31°52'36"D	5	1377.4
		12	1433.23
		22	1484.71
		*132	1502.8
		42	1485.85
Berdan	36°57'58"K 34°53'43"D	5	1438.94
		12	1502.61
		22	1563.6
		*32	1587.87
		42	1574.52
Keban	38°48'25"K 38°45'25"D	5	1360.75
		12	1416.08
		22	1466.19
		*32	1482.13
		42	1463.73
Kralkızı	38°20'56"K 40°01'17"D	5	1367.8
		12	1425.97
		22	1481.2
		*32	1501.6
		42	1486.64
Van	38°38'0"K 42°49'0"D	5	1396.7
		12	1457.66
		22	1515.58
		*32	1538.6
		42	1525.05

*Stands for the tilt angle which enable the highest value of energy production.

obtained from the PVGIS simulation program. Annual energy production from FPVs with different tilt angles is shown in Table 4.

According to the data obtained from the PVGIS software, the annual energy production [kWh] increases as the tilt angle values increase from 5°, 12°, 22° to 32° for all water bodies. However, a significant decrease in the annual energy production [kWh] is observed at the tilt angle value of 42°. As a result of the analysis, it was found that the best tilt angle for all water mass is 32°, which enable maximum annual energy production [kWh], since production starts to drop with the increase of tilt angle above this value.

According to the data obtained from the PVGIS simulations, the annual energy production of the Keban Dam with a tilt angle of 32° is about 1480 kWh of energy. Comparing with the results obtained from other authors, [36,37] confirms in his study the potential of FPVs in Türkiye stating that Keban Dam provides approximately 25% of Türkiye's electricity needs with the installation of FPVS with an installed capacity of approximately 1 MW on this dam.

In addition, it is explained that the FPVs installed on the Keban Dam by the regional directorate are expected to produce approximately 1.8 million kWh of energy. This project was already implemented for Keban in Türkiye, and it is in correlation with the results obtained by simulations.

Monthly Energy Production of FPVS

In this part of the study, annual energy production rates evaluated with different tilt angles for all water masses in Section 3.1 were analyzed, and the optimum tilt angle of 32° was determined for all water bodies. In this context, the monthly energy production of all water bodies with a 32° tilt angle is shown in Figure 3.

Energy production in five different water bodies in Türkiye increases continuously from January to July and August. Maximum energy production for each lake is more than 160 kWh in July and August. Monthly energy production for all water bodies decreases continuously from August until December but it still contributes to the electricity production. Keban Dam produced the least energy

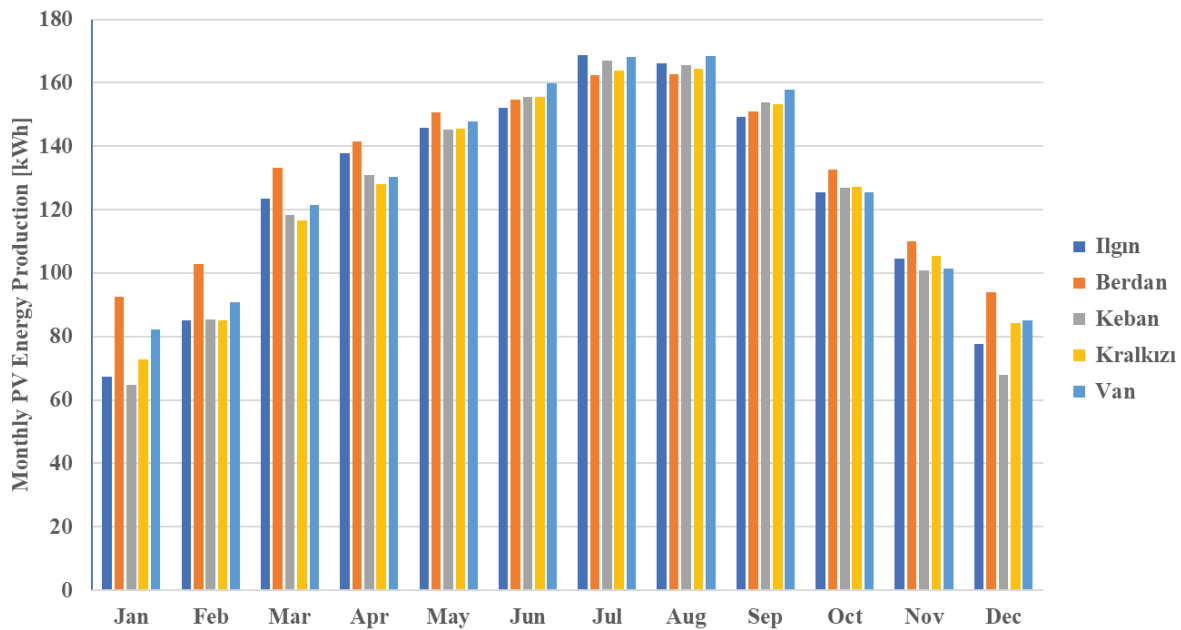


Figure 3. Monthly energy output for fix angle FPVs.

in December with the PVGIS simulation result, which was obtained. At the same time, according to the obtained data, the least energy production of all water bodies in Türkiye was observed in January, with 65 kWh in monthly energy production. Annual energy production in Berdan dam provides the highest energy production when compared with the other four water bodies, while in any month the energy production has exceeded the energy production produced by other water bodies. As can be seen from the results, Berdan dam has shown maximum efficiency by showing regular monthly increases and decreases in solar energy and 1587.87 kWh has been obtained annually from solar energy. The lowest monthly energy production of Ilgın Lake is 67 kWh, while the highest energy production is 169 kWh in July. Energy production decreases after July.

The monthly energy production of Berdan dam is the same as 162 kWh for July and August dams. The lowest energy production of Berdan dam was observed in January with 92 kWh. It was observed that the monthly energy production increased continuously between February and August.

The monthly energy production of the Keban dam with the highest area is observed in Figure 4 and the highest energy production was observed in July with 167 kWh. The simulation result shows that the Keban dam, which has a regular monthly energy production, produced 100 kWh in November, while a sharp decrease was observed, and it could only produce 68 kWh in November.

The monthly energy production produced by Kralkızı dam is constantly increasing from January to August. The lowest monthly energy production is observed in January

at 73 kWh. The highest energy production reaches a peak of 164 kWh in July and August. The annual energy production of Kralkızı dam, where no sharp decrease is observed in monthly energy production, is 1502 kWh.

According to the monthly energy output obtained from FPVs for Van Lake, the lowest monthly energy output is seen in January with 82 kWh, while the lowest output is seen in December with 85 kWh. Except for December, January and February, the energy output is over 100 kWh for each month. The highest energy production reaches a peak of 168 kWh in July and August. Similarly, [38] showed in their study that the installation of FPVS in Turkish water reservoirs is based on 6 different scenarios with different water surface coverage rates. In this study, it is claimed that when 10% of the Van Lake reservoir is covered with FPVs, the annual electrical energy production is 1,166.7 (GWh) and the carbon dioxide reduction is 0.7 Mt.

The energy produced for observed water bodies is almost the same with some slight differences. According to the results obtained from the PVGIS software program, the minimum annual energy production is 1,48 [MWh] in Keban Dam, while the maximum annual energy production is 1,59 [MWh] for FPVs at Berdan Dam. The annual energy production for Kralkızı Dam and Ilgın Lake is 1,50 [MWh], obtained by PVGIS software program. This value for Van Lake is higher than Ilgın Lake and Kralkızı Dam and is 1,54 [MWh].

When annual energy production is summed for all water masses, approximately 7613 kWh of energy yearly can be produced from FPVs.

Potential Reduction of GHG Emissions

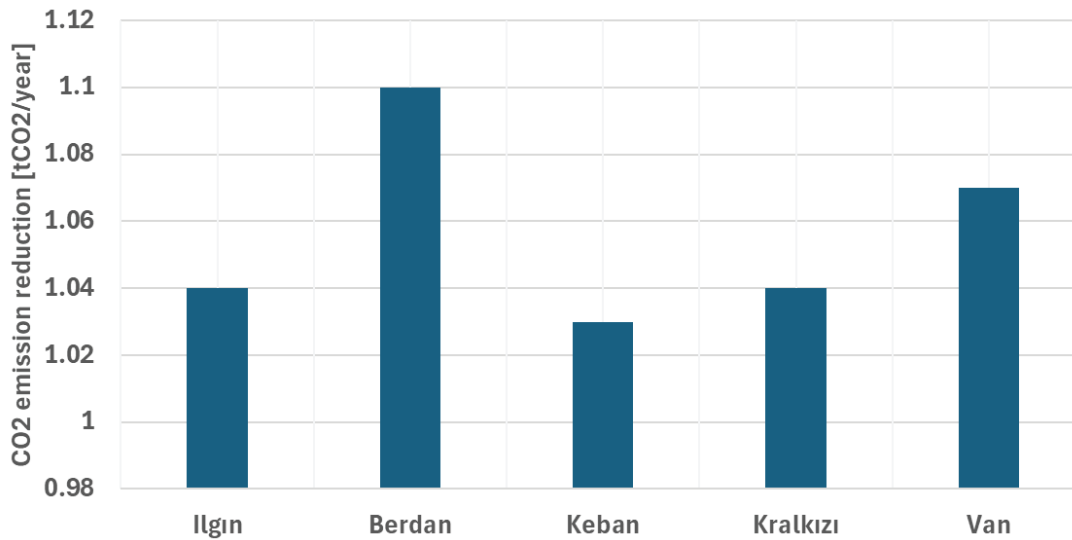


Figure 4. Annual CO₂ emission reduction [tCO₂/year] for different water bodies and optimal slope of 32°.

FPVs contribute to clean electricity production and decarbonization of the electrical sector. Khan in his study [39] on the evaluation of the importance of greenhouse gas emissions, mentioned that the need for electricity increases with the increase in population. Thus, author emphasized the importance of choosing renewable energy sources that will minimize carbon emissions and provide maximum efficiency to provide this electricity need.

FPVS installed on water bodies will not only produce green energy but also contribute to the reduction of greenhouse gas emissions. The potential reduction of greenhouse gases for five different locations in Türkiye was calculated using the following equation [40]:

$$G_t = E_s \cdot G \cdot (1 + \beta) \quad (1)$$

where:

G_t [tCO₂/year] is reduction in annual greenhouse gas amount, E_s [MWh/year] is an annual electricity production, G [tCO₂/ MWh] is the value of greenhouse gas emissions for the country and β is average loss in power transmission and distribution.

To calculate annual carbon emissions, taking annual energy production as reference at a tilt angle of 32°, the annual greenhouse gas reduction was adopted as 0.62 [tCO₂/MWh] from the literature [41] and the average loss in power transmission and distribution was taken as 0.12 according to the literature [42] for Türkiye.

The potential annual carbon emission reduction for five observed water bodies in Türkiye is shown in the Figure 4. As shown in Figure 4, the annual reduction of carbon dioxide emissions for all water bodies varies between 1 and 1.1 tCO₂/year. The annual reduction of carbon dioxide emissions of Berdan Dam, which has the highest annual energy

production of 1.58787 MWh, reaches the highest value with 1.10 tCO₂/year, followed by Van with 1.07 tCO₂/year.

It has been observed that the annual reduction of carbon dioxide emissions of two lakes with very high annual energy production, Lake Ilgin with 1.5028 MWh and Kralkızı dam with 1.50164 MWh, is 1.04 tCO₂/year. When the annual reduction of carbon dioxide emissions for all FPVs at five water bodies is summed up, approximately 5.28 tCO₂/year carbon emission can be reduced.

CONCLUSION

This study concludes the electricity generation potential and CO₂ emission reduction of FPVs in five different water bodies in Türkiye. As a result, according to the obtained data, photovoltaic systems have a significant impact on energy generation and carbon dioxide emission reduction for Türkiye. The methodology used in the study considers appropriate FPVs model selection, study of the most suitable locations and types of water bodies and various simulations using PVGIS software.

The most important findings of the study are as follows:

- According to the data obtained from PVGIS simulation program, FPVs installed in five different water bodies in Türkiye can produce up to 7613 kWh of energy.
- The analysis included discussion for several tilt angles (5°, 12°, 22°, 32°, 42°) which is also one of the contributions of this study. It was found that the best tilt angle for all water masses is 32°, which can provide the maximum annual energy production [kWh].
- Finally, Türkiye will be able to meet a significant portion of its electrical energy demand and with this clean production to reduce up to the 5.28 tCO₂/year of carbon emission.

The importance of performed research is that contributes to the fulfillment of the research gap due to the limited number of studies on the application potential of FPVS in the Republic of Türkiye, which has many water bodies and high GHI. Based on the findings of AEP, the installation of FPVs in different water bodies in the Republic of Türkiye, showing significant contribution to the electricity production and CO₂ emission reduction, will increase awareness of the contribution of the use of renewable energy sources in energy production. Based on the data obtained in this study, the importance of FPVs in reducing carbon emission rates in the Republic of Türkiye was highlighted. Clean energy production can be provided by using FPVs instead of fossil fuels, which cause many global problems by increasing carbon emissions. The use of FPVs on water bodies allows lands usages for different purposes such as agriculture, industry and living, bearing in mind that population is constantly increasing. FPVs do not only contribute to the energy production and carbon emission reduction in countries with sufficient water bodies and GHI such as Türkiye but also prevent water evaporation which is of a tremendous importance in rigid areas. In addition, FPVs contribute to the increase of the water quality of water bodies and limits the growth of phytoplankton and algae. Furthermore, the results contribute to the higher awareness, therefore it facilitates access to the information about FPVS applicability in Türkiye and encourages further research on this topic from different perspectives. The Republic of Türkiye, surrounded by seas on three sides and with several suitable water bodies, has the strong opportunity exploit renewable energy sources, especially FPVs.

With reference to this article for future research, it is suggested to investigate, for instance, the water evaporation reduction potential or the mechanical performance of these systems in-situ in terms of energy efficiency. Future research will also be dedicated to the effect of hybrid use of FPVs with other renewable energy sources, the efficiency performance of bifacial photovoltaic systems, the efficiency performance of the materials used in the design of FPVs, and the mechanical analysis of these systems against corrosion that will occur due to continuous exposure to weather conditions and financial aspects as well.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

REFERENCES

- [1] Hammoumi A, Chtita S, Motahhir S, Ghzizal A. Solar PV energy: From material to use, and the most commonly used techniques to maximize the power output of PV systems: A focus on solar trackers and floating solar panels. *Energy Rep* 2022;8:11992–12010. [\[CrossRef\]](#)
- [2] Fereshtehpour M, Sabbaghian RJ, Farrokhi A, Jovein EB, Sarindizaj EE. Evaluation of factors governing the use of floating solar system: A study on Iran's important water infrastructures. *Renew Energy* 2021;171:1171–1187. [\[CrossRef\]](#)
- [3] Hammoumi A, Chalh A, Allouhi A, Motahhir S, Ghzizal A, Derouich A. Design and construction of a test bench to investigate the potential of floating PV systems. *J Clean Prod* 2021;278:123917. [\[CrossRef\]](#)
- [4] Chaurasiya PK, Sheik MA, Rajak U, Verma TN, Pandey V. Numerical investigation of the effect of operating conditions on performance of PV-PCM system. *Proc Inst Mech Eng E* 2024. [\[CrossRef\]](#)
- [5] Kaymak MK, Sahin AD. Problems encountered with floating photovoltaic systems under real conditions: A new FPV concept and novel solutions. *Sustain Energy Technol Assess* 2021;47:101504. [\[CrossRef\]](#)
- [6] Adan HK, Filik UB. Performance Investigation of On-Grid Solar Photovoltaic System in Eskişehir/Turkey. *Deu J Sci Eng* 2021;23:557–566. [\[CrossRef\]](#)
- [7] Vidović V, Krajačić G, Matak N, Stunjek G, Mimica M. Review of the potentials for implementation of floating solar panels on lakes and water reservoirs. *Renew Sustain Energy Rev* 2023;178:113237. [\[CrossRef\]](#)

- [8] Gorjian S, Sharon H, Ebadi H, Kant K, Scavo FB, Tina GM. Recent technical advancements, economics and environmental impacts of floating photovoltaic solar energy conversion systems. *J Clean Prod* 2021;278:124285. [CrossRef]
- [9] Bajc T, Kostadinović D. Potential of usage of the floating photovoltaic systems on natural and artificial lakes in the Republic of Serbia. *J Clean Prod* 2023;422:138598. [CrossRef]
- [10] Karipoglu F, Koca K, Ilbahar E. Convenient Site Selection of a Floating PV Power Plant in Türkiye by using GIS-Fuzzy Analytical Hierarchy Process. *Environ Sci Pollut Res* 2024;31:23193–23210. [CrossRef]
- [11] Haspolat E, Cicek DD, Gokmener S, Melek AB, Devenci M, Oguz E. Site selection of floating photovoltaic systems on hydropower reservoirs using fuzzy sine trigonometric decision-making model: Turkey as a case study. *Renew Sustain Energy Rev* 2024;206. [CrossRef]
- [12] Tina GM, Scavo FB, Merlo L, Bizzarri F. Analysis of water environment on the performances of floating photovoltaic plants. *Renew Energy* 2021;175:281–295. [CrossRef]
- [13] Prinsloo FC, Schmitz P, Lombard A. System dynamics characterisation and synthesis of floating photovoltaics in terms of energy, environmental and economic parameters with WELF nexus sustainability features. *Sustain Energy Technol Assess* 2023;55. [CrossRef]
- [14] Silva GDP, Branco DAC. Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts. *Impact Assess Proj Apprais* 2018;36:390–400. [CrossRef]
- [15] Wang T, Chang P, Huang Y, Lin T, Yang S, Yeh S, et al. Effects of floating photovoltaic systems on water quality of aquaculture ponds. *Aquac Res* 2022;53:1304–1315. [CrossRef]
- [16] Choi SM, Park CD, Cho SH, Lim BJ. Effects of various inlet angle of wind and wave loads on floating photovoltaic system considering stress distributions. *J Clean Prod* 2023;387. [CrossRef]
- [17] Du S, Liang C, Sun H, Wang K, Wang J, Li H, et al. Evaluating the potential benefits of float solar photovoltaics through the water footprint recovery period. *J Clean Prod* 2024;446:141399. [CrossRef]
- [18] Gisbert CF, Gozálviz JJE, Santafé MR, Gisbert PF, Romero FJS, Soler JBT. A new photovoltaic floating cover system for water reservoirs. *Renew Energy* 2013;60:63–70. [CrossRef]
- [19] Panda S, Panda B, Jena C, Nanda L, Pradhan A. Investigating the similarities and differences between front and back surface cooling for PV panels. *Mater Today Proc* 2023;74:358–363. [CrossRef]
- [20] Minoofar A, Zandi A, Gholami A. Precise prediction models for floating and land-based Photovoltaics: Comparative analysis for advancing sustainable energy and water management solutions. *Renew Energy* 2025;255. [CrossRef]
- [21] Niccolai A, Grimaccia F, Lorenzo G, Araneo R, Ughi F, Polenghi M. A Review of Floating PV Systems with a Techno-Economic Analysis. *IEEE Xplore* 2024;14:23–34. [CrossRef]
- [22] Claus R, López M. Key issues in the design of floating photovoltaic structures for the marine environment. *Renew Sustain Energy Rev* 2022;164. [CrossRef]
- [23] Cazzaniga R, Clot MR, Clot PR, Tina GM. Integration of PV floating with hydroelectric power plants. *Heliyon* 2019;5:e01918. [CrossRef]
- [24] Abdelgaied M, Kabeel AE, Zeleňáková M, Abdelhamid HF. Floating Photovoltaic Plants as an Effective Option to Reduce Water Evaporation in Water-Stressed Regions and Produce Electricity: A Case Study of Lake Nasser, Egypt. *Water* 2023;15. [CrossRef]
- [25] Liu L, Wang Q, Lin H, Li H, Sun Q. Power generation efficiency and prospects of floating photovoltaic systems. *Energy Proc* 2017;105:1136–1142. [CrossRef]
- [26] Sahu A, Yadav N, Sudhakar K. Floating photovoltaic power plant: A review. *Renew Sustain Energy Rev* 2016;66: 815–824. [CrossRef]
- [27] Singh NK, Goswami A, Sadhu PK. Energy economics and environmental assessment of hybrid hydel-floating solar photovoltaic systems for cost-effective low-carbon clean energy generation. *Clean Technol Environ Policy* 2023;25:1339–1360. [CrossRef]
- [28] Abid M, Abid Z, Sagin J, Murtaza R, Sarbassov D, Shabbir M. Prospects of floating photovoltaic technology and its implementation in Central and South Asian Countries. *Int J Environ Sci Technol* 2019;16:1755–1762. [CrossRef]
- [29] Kjeldstad T, Nysted VS, Kumar M, Pinto SO, Otnes G, Lindholm D, et al. The performance and amphibious operation potential of a new floating photovoltaic technology. *Solar Energy* 2022;239:242–251. [CrossRef]
- [30] Yakubu RO, Quansah DA, Mensah LD, Togobo WA, Acheampong P, Adaramola MS. Comparison of ground-based and floating solar photovoltaic systems performance based on monofacial and bifacial modules in Ghana. *Energy Nexus* 2023;12:100245. [CrossRef]
- [31] Elminshawy NAS, Osama A, Elbaksawi O, Arici M, Naeim N. Energetic, environmental and economic (3E) analysis of a CSA algorithm optimized floatovoltaic system integrated with heat sink: Modeling with experimental validation. *Eng Anal Bound Elem* 2024;159. [CrossRef]
- [32] The World Bank Group. Global Solar Atlas 2024. Available at: <https://globalsolaratlas.info/map>. Accessed on 19 May 2026.
- [33] PVGIS.COM. PVGIS Software. Available at: <https://pvgis.com/>. Accessed on 19 May 2026.
- [34] Wikipedia. Lakes in Turkey. Available at: https://en.wikipedia.org/wiki/List_of_lakes_of_Turkey. Accessed on 19 May 2026.

- [35] Kaymak MK, Sahin AD, The first design and application of floating photovoltaic (FPV) energy generation systems in Turkey with structural and electrical performance. *Int J Precis Eng Manuf Green Technol* 2021;1–13. [\[CrossRef\]](#)
- [36] Karatas Y, Yilmaz D. Experimental investigation of the microclimate effects on floating solar power plant energy efficiency. *Clean Technol Environ Policy* 2021;23:2157–2170. [\[CrossRef\]](#)
- [37] Bilhan O. An evaluation of hydroelectric and solar energy as renewable energy sources across regions and provinces in Türkiye. *NÖHU J Eng Sci* 2024;13:1504–1516. [\[CrossRef\]](#)
- [38] Kulat MI, Tosun K, Karaveli AB, Yucel I, Akinoglu BG. A sound potential against energy dependency and climate change challenges: Floating photovoltaics on water reservoirs of Turkey. *Renew Energy* 2023;206:694–709. [\[CrossRef\]](#)
- [39] Khan I. Importance of GHG emissions assessment in the electricity grid expansion towards a low-carbon future: A time-varying carbon intensity approach. *J Clean Prod* 2018;196:1587–1599. [\[CrossRef\]](#)
- [40] Durković V, Đurišić Z. Analysis of the potential for use of floating PV power plant on the Skadar Lake for electricity supply of aluminium plant in Montenegro. *Energies* 2017;10:1505. [\[CrossRef\]](#)
- [41] Ozcan M. Increasing voluntary carbon credits potential via renewable energy projects in Turkey. *PU J Eng Sci* 2022;28:710–719. [\[CrossRef\]](#)
- [42] Ozer B, Gorgun E, Incecik S. The scenario analysis on CO2 emission mitigation potential in the Turkish electricity sector: 2006–2030. *Energy* 2013;49:395–403. [\[CrossRef\]](#)