International Journal of Innovative Engineering Applications

Journal homepage: https://dergipark.org.tr/ijiea

INVESTIGATION OF THE BENEFITS OF THE FLOATING SOLAR POWER PLANT TO BE ESTABLISHED ON KEBAN DAM LAKE USING PENMAN, LINACRE AND ARTIFICIAL NEURAL NETWORKS METHODS

Savaş Kurt*[*1], Hikmet Esen[2], Ünal Toka[3]

[1]Department of Renewable Energy Systems, Faculty of Technology, Fırat University, Elazığ, Turkey
[2]Department of Mechanical Engineering, Institute of Science and Technology, Fırat University, Elazığ, Turkey
[3]Internal Audit Unit, Munzur University, Tunceli, Turkey

Abstract

Original scientific paper

In this study, it will be calculated how much water evaporation will be prevented if a Floating Solar Power Plant (FSPP) is installed on a certain part of the Keban Dam lake in Elazığ (38.41˚N, 39.14˚E), Türkiye by using the Penman and Linacre methods and the Artificial Neural Networks (ANN) method, which are widely used in evaporation calculation. Thus, it will be calculated how much energy can be produced with this saved water. Keban Hydroelectric Power Plant (HPP), examined in this study, is Türkiye's 3rd largest hydroelectric power plant with an installed power of 1.330 MWe. It is the fourth largest lake in Türkiye and the second largest dam lake after the Atatürk Dam. Keban Dam meets the electrical energy needs of 1.750.733 people in their daily lives with an average electricity production of 5.794.927,279 kWh.

It has been calculated that thanks to a floating photovoltaic power plant that will cover 10% of the dam lake, a total of 31.305.282 m^3 of water in normal water code will be prevented from evaporating annually, and thanks to this water, energy benefit will be provided with the power plant with an installed power of 6.624,84 MWe. In addition, it has been analyzed that 11.297.018 kWh of electricity can be produced from the dam turbines with the water prevented from evaporating thanks to FSPP. Approximately 72.39 MWe energy is needed for the Ağın, Pertek, Serince, Palu-Kovancılar, Uluova, Kuzova irrigation projects around the Keban Dam lake. It has been determined that the amount of water and energy needed for irrigation of these plains can be obtained thanks to FSPP.

Keywords: *Floating solar power plant, Keban Dam Lake, irrigation system, evaporation, energy efficiency gains.*

Abbreviations

ASKI	:	Ankara Water and Sewerage Administration General Directorate
FPVF	:	Floating Solar Photovoltaics
FSSPF	:	Floating Solar Power Plant
HDPE	:	High Density Polyethylene
MGM	:	General Directorate of Meteorology
MEVBİS	:	Meteorological Data Information Presentation and Sales
LSTM	:	Long Short-Term Memory
RNN	:	Recurrent Neural Network
CNN	:	Convolutional Neural Networks
GRU	:	Gated Recurrent Unit
SGD	:	Stochastic Gradient Descent
SPP	:	Solar Power Plant

1 Introduction

FSPP is a relatively new form of renewable energy and is experiencing rapid growth in use today. FSPP decarbonizes the energy supply while reducing land use pressure, offers higher electricity generation efficiency compared to ground-based systems, and reduces water body evaporation [1]. Another potential benefit of floating photovoltaic panel systems is that they can outperform traditional photovoltaic (PV) systems in terms of energy efficiency due to the cooling effect of water. Open system designs, where the floating system's PV panels are extensively exposed to the water surface, lead to an increase in the heat loss coefficient (a measure for the cooling effect) of the floating PV panels by up to 22 W/m^2K [2].

Annual specific efficiencies of PV systems compared to reference PV systems were estimated by the measured irradiance-weighted temperature difference and a PVsyst model containing inputs of heat loss coefficients. Based on these calculations, it has been observed that the gain in energy efficiency from the cooling effect of FSPP systems compared to reference PV systems is up to 3% in the Netherlands and 6% in Singapore. A prototype modeled on the concept of evaporation pans has been built to mimic the situation of solar panels floating on reservoirs. Observations are made regarding the evaporation rate and compared to a control. Experimental results have shown that floating solar panels on water bodies have the effect of reducing evaporation rates by approximately 30% [2,3]. FSPPs on water prevent heating and make it easier for

*Corresponding author.

E-mail address: s.kurt@firat.edu.tr (S. Kurt)

Received 27 February 2025; Received in revised form 20 May 2025; Accepted 10 June 2025

 Doi: https://doi.org/10.46460/ijiea.1647566

them to move and turn, which helps achieve higher levels of efficiency [4]. Floating PV systems can contribute to irrigation stability and synergy between the agriculture and energy production sectors, given their ability to prevent surface evaporation while simultaneously generating power [5]. While the floating photovoltaic industry is in its infancy, it is growing at an incredible pace. Floating PV systems have many benefits such as higher efficiency, less evaporation, and less erosion [6].

Floating solar photovoltaic systems were first developed in 2000-2010; the first small-scale system was built in Japan in 2007, and the first commercial system was built in California in 2008 [7]. Installations larger than 1 MWp were not developed until 2013. As of the end of 2019, the total installed capacity of floating PV systems exceeded 2 GWp [8]. By 2030 there will be an estimated 62 GWp of floating PV systems globally. Today, Asia dominates the FSPP market with 87% of global capacity [9].

Conditions taken into account in FSPP site selection; solar radiation, climate conditions, buildable water area and reservoir conditions, bathymetry of the reservoir, reservoir depth, intra-annual water level change, wind and wave conditions, ground structure of the reservoir, shading and pollution, environmental conditions and finally the distance to the grid connection point. By examining these data, the suitable physical installation area will be determined. Depending on this, the float type to be selected, the layout plan with the photovoltaic panel is drawn up, and then the panel-inverter configuration and system power are determined [10]. Floating solar energy system components: consists of floating structure, mooring system, PV solar module, cabling and grid connection station [11]. In floating PV systems; It is important to investigate the use of pre-existing electrical infrastructure of a hydroelectric power plant. FSPP systems have shown that the existing electricity production and transmission infrastructure of the hydroelectric power plant can be technically integrated into the hydroelectric power plant. It is more economically feasible than applying it in other water bodies such as natural lakes, ponds or canals [12]. The electrical infrastructure of the dams has the capacity to support an additional energy production unit such as a Floating Solar Plant. Floating PV systems are modular and can reduce the cost of electricity transmission when combined with a hydroelectric power generation facility. Its modular structure enables easy installation and provides convenience in terms of both production and transmission infrastructure [13]. The future FSPP proposed for sea and large lake areas envisages laminated thin film PV, which will ensure that the structure is flexible and resilient to incoming waves, and designs that will withstand harsh weather conditions and be submerged [14]. Taking environmental factors into account, energy production prediction models based on regression analysis and neural networks are presented and their accuracy is compared. This comparison confirms that the accuracy of the energy production prediction model using neural networks is approximately 2.59% higher than that of the regression analysis method [15]. Regarding the type of water, the use of fresh water (lakes, artificial and natural basins, rivers) has many advantages over sea water, for example, limited corrosion problems, reduced effect of waves and wind, limited algal bloom. On the other hand, seaside space is much more available, but of course the cost of support rafts and moorings may be higher [16]. The supporting structures for a FSPP system with rigid PV modules differ from conventional ones (coastal systems) because they do not have a fundamentally solid fixing (the problem of wind folding) and have an uneven surface (due to waves). Rigid PV modules, when exposed to wind and water loads, may suffer from cell crack formation due to their limited flexibility and mechanical properties [17]. So far, the development of floating GESs has been focused mainly on onshore deployments, as it is thought that the harsh marine environment may compromise the long-term stability of such structures. Typhoon Faxai, which affected Japan in 2019 and caused a fire in one of the floating solar power plants, although rare, still posed a real risk that could deter investment in this technology [18].

Türkiye is in a better situation than Germany, one of the leading countries in the solar industry, in terms of sunshine duration and total solar radiation. Although Sinop province is at lower levels in terms of solar radiation (1400-1500 kWh/m^2), it is higher than Germany's highest center of solar potential, the State of Bavaria [19]. The estimated power we will obtain when 1% of the surface area of the water reserves of hydroelectric power plants in Türkiye is used is 512.69 GW, and this capacity is approximately 214 times the power of the Atatürk dam. In addition, for this 1% surface area, an average of 30.761.400 tons of water is prevented from evaporating annually with the shading effect of FSPPs [20]. It has been announced that if the FSPP planned to be built on Eğirdir Lake in Isparta province is put into operation and photovoltaic panels cover approximately 75% of the installed area, it will help reduce the evaporation problem in the lake. Additionally, it has been determined that it is possible to produce 992 MWh of electricity per year by utilizing the sun [21]. There are 944 dams currently in operation in Türkiye that are not intended for drinking water purposes. These dams have a reservoir surface area of 5300 km^2. It is estimated that if FSPPs are installed on 10% of the surface area of this reservoir, 1/4 of Türkiye's electrical energy needs can be met. It has also been stated that it works 10% more efficiently than terrestrial FSPPs and enables the utilization of unused reservoir surface areas and bringing them into the economy [22].

ASKI General Directorate announced that work is being carried out for the installation of floating solar power plants on the Bayındır Dam. It has been announced by the institution that a on-grid floating solar power plant installation with a photovoltaic panel capacity of 990 kWp is planned on the Bayındır Dam [23]. When the costs of the FSPP built on the Büyükçekmece Lake are examined, it is more expensive than terrestrial solar power plants. The most important reason for this is that these systems are R&D projects and have not reached mass production level. However, not using any soil surface and protecting drinking water by reducing evaporation will cause FSPPs to be preferred [24]. Floating GESs working 10 % more efficiently than terrestrial GES; It provides the evaluation of the reservoir surface areas in the case of the economy. Floating GESs can be installed in all dam reservoirs, except for drinking water purposes. Türkiye is in a very lucky position in terms of floating GES potential. In our country, there are 944 dams in the form of drinking water in the form of drinking water, 5 thousand 300 kilometers of square such as a very wide reservoir surface area. If the floating GES is installed in 10 %of this surface area, it is foreseen that 53 thousand MW installed power and 79 billion 500 million kilowatt hours (about one quarter of our country's electrical energy needs) can be produced. It is estimated that the amount of water to be saved by preventing evaporation thanks to the floating GESs will be at a level of 540 million cubic meters annually. Moreover, thanks to these facilities, the amount of carbon dioxide to be released into the atmosphere will be reduced by over 51 million tons [25].

2 Material and Methodology

2.1 Preparation of Data Set

The data needed to calculate the amount of evaporation was obtained by requesting an official letter from the Turkish General Directorate of Meteorology (MGM) Meteorological Data Information Sales and Presentation System (MEVBİS). The data set was taken from a total of 13 meteorological observation stations around the Keban Dam lake in the MGM 13th Elazığ region, taking into account the points on the map shown in Fig. 1. These stations have meteorological parameters measured between 2014 and 2023. These parameters are given in detail in Table 1.

Figure 1. The geographical locations of the 13 weather stations around the Keban Dam Lake [26].

Daily total open surface evaporation, daily total evaporation evapotranspiration, daily total global solar radiation, daily total insolation intensity, daily total insolation intensity global and daily total precipitation (manual) parameters are measured only in Elazığ center and Tunceli meteorological station. These data were prepared by MGM in Excel format, with parameter values as month and day cross tabulation. With the Python programming language, these Excel tables were converted into appropriate formats to be used in calculations and transferred to the Mysql database.

While there are very few empty or invalid values in the basic meteorological parameters such as temperature, pressure, humidity and wind in the data set, there are many empty or invalid values in parameters such as evaporation and solar radiation. There are no values between 2014-2017 in the parameters especially related to solar radiation, measured only in Elazığ Center and Tunceli. Fig. 2 shows the change in solar radiation values of these two stations over time.

Table1. Weather parameters used in this study.

Parameter	Unit	Weather Stations
Daily Vapor Pressure	hPa	All
Daily Duration of Sunshine	hour	All
Daily Maximum Wind Speed	m/s	All
Daily Maximum Wind Direction and Speed	(°)-(m/s)	All
Daily Maximum Wind Hour	UTC	All
Daily Maximum Temperature	°C	All
Daily Mean Soil Temperature (5 cm depth)	°C	All
Daily Minimum Temperature	°C	All
Daily Mean Actual Pressure	hPa	All
Daily Mean MSLP	hPa	All
Daily Mean Relative Humidity	%	All
Daily Mean Temperature	°C	All
Daily Aboveground Temperature	°C	All
Daily Total Open Surface Evaporation	mm	Elazığ Center and Tunceli
Daily Total Evapotranspiration	mm	Elazığ Center and Tunceli
Daily Total Global Solar Radiation	kWh/m^2	Elazığ Center and Tunceli
Daily Total Intensity of Solar Radiation	Cal/cm^2	Elazığ Center and Tunceli
Daily Total Intensity of Global Solar Radiation	W/m^2	Elazığ Center and Tunceli
Daily Total Precipitation - MANUEL	$mm=kg/m^2$	Elazığ Center and Tunceli
Daily Total Precipitation - Automatic Weather Stations	$mm=kg/m^2$	All

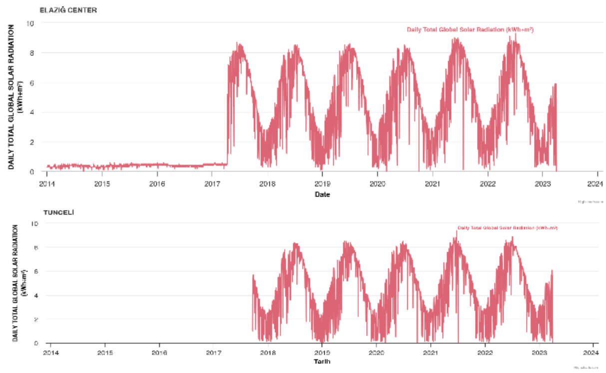

Figure 2. Daily Total Global Solar Radiation values by years (Elazığ Center - Tunceli).

Similarly, open surface evaporation values in mm were measured only between 1 April and 30 October each year. Fig. 3 shows the change in daily total open surface evaporation values of these two stations over time.

Figure 3. Daily Total Open Surface Evaporation values by years (Elazığ Center - Tunceli).

The parameters needed in the calculations were completed using various interpolation methods.

2.1.1 Evaporation Calculation

Evaporation is the process of liquid water turning into gas and can occur at any temperature. Moving water molecules gain energy by colliding and when they reach enough energy, they move away from the water surface.

There are many meteorological parameters that affect evaporation at different levels. Temperature, pressure, wind and humidity are some of these parameters. Increasing temperature will cause water molecules to move faster and reach higher kinetic energy. As a result, they will separate from the water surface. There is a direct proportion between temperature and the amount of evaporation. Air pressure acts on the water surface and puts pressure on the molecules trying to separate. For this reason, high pressure causes less evaporation. There is an inversely proportional relationship between them. Humidity and evaporation are inversely proportional. Humidity refers to the water vapor in the air. A high level of water vapor means that the air is saturated with water vapor and cannot carry any more. For this reason, it becomes difficult for water molecules to escape into the atmosphere and evaporation occurs slowly. Wind allows the vapor on the water surface to be transported and water molecules that have enough energy to separate to rise more easily into the atmosphere. For this reason, there is a directly proportional relationship between wind and evaporation. Surface area and depth of water are other factors that affect evaporation.

In Table 2 below, the wind directions at the eight stations where measurements were taken are given together with their numbers [27].

Pyet, an open source Python package, was used to calculate the daily evaporation in Keban Dam Lake. The Pyet module calculates daily PET (Potential Evapotranspiration) using eighteen different methods. Detailed information about the content of the Pyet module is given in Table 3 [28].

Table 2. Wind directions and numbers taken from 8 weather stations for the period 2014-2024.

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
AĞIN	20	13	36	92	286	323	203	63	24	70	184	251	336	829	776	43
ELAZIĞ MERKEZ	34	10	23	116	326	469	394	201	138	57	39	86	428	665	609	49
ELAZIĞ -HARPUT	403	269	162	115	180	124	66	148	298	207	265	210	225	207	383	196
KOVANCILAR-YARIMCA	81	191	110	58	40	119	393	383	273	148	363	645	470	202	105	55
ELAZIĞ -YURTBAŞI	92	87	122	305	259	90	69	34	92	100	187	209	304	223	139	104
ARAPGİR	96	158	154	119	158	227	444	175	279	401	259	421	78	101	429	75
ÇEMİŞGEZEK	950	215	31	20	40	111	119	127	594	451	178	53	166	153	137	227
TUNCELİ	91	61	144	98	49	25	92	114	510	265	277	183	207	717	751	67

Table 3. Evaporation calculation methods and input parameters in the Pyet module.

Method name	Pyet function	T	RH	R	U2	Lat.	El.	Benchmark
Penman	penman	✓ [a]	✓ [b,c]	✓[d]	✓	✓ [d]	✓ [e]	✓
Penman-Monteith	pm	✓ [a]	✓ [b,c]	✓ [d]	✓	✓ [d]	✓ [e]	✓
ASCE-PM	pm_asce	✓ [a]	✓ [b,c]	✓ [d]	✓	✓ [d]	✓ [e]	✓
FAO-56	pm_fao56	✓ [a]	✓ [b,c]	✓ [d]	✓	✓ [d]	✓ [e]	✓
Priestley-Taylor	priestley_taylor	✓	✓ [h]	✓ [h]	-	✓ [h]	✓ [e]	✓
Kimberly-Penman	kimberly_penman	✓ [a]	✓ [b,c]	✓ [d]	✓	✓ [d]	✓ [e]	-
Thom-Oliver	thom_oliver	✓ [a]	✓ [b,c]	✓ [d]	✓	✓ [d]	✓ [e]	-
Blaney-Criddle	blaney_criddle	✓	- [i]	- [i]	- [i]	✓	-	✓
Hamon	hamon	✓	-	-	-	✓	-	✓
Romanenko	romanenko	✓	✓	-	-	-	-	✓
Linacre	linacre	✓ [j]	-	-	-	-	✓	✓
Haude	haude	✓	✓ [k]	-	-	-	-	✓
Turc	turc	✓	✓	✓	-	-	-	✓
Jensen-Haise	jensen_haise	✓	-	✓[l]	-	✓ [l]	-	✓
McGuinness-Bordne	mcguinness_bordne	✓	-	-	-	✓	-	✓
Hargreaves	hargreaves	✓ [m]	-	-	-	✓	-	✓
FAO-24 radiation	fao_24	✓	✓	✓	✓	-	✓ [e]	-
Abtew	abtew	✓	-	✓	-	-	-	✓
Makkink	makkink	✓	-	✓	-	-	✓ [e]	✓
Oudin	oudin	✓	-	-	-	✓	-	-

T: Daily Mean Temperature [°C]
R: Solar Radiation [MJ m-2 d-1]
Lat: Latitude [rad]
El: Elevation [m]
RH: Daily Mean Relative Humidity [%]
U2: Daily Mean Wind Speed [m/s]

(a) *Daily Maximum Temperature or Daily Minimum Temperature can also be provided.*

(b) *Daily Maximum Relative Humidity or Daily Minimum Relative Humidity can also be provided.*

(c) *If actual vapor pressure is provided, Relative Humidity is not needed*

(d) *Input for radiation can be (1) Net radiation, (2) solar radiation or (3) sunshine hours. If (1), then latitude is not needed. If (1, 3) latitude and elevation is needed.*

(e) *One must provide either the atmospheric pressure or elevation.*

(f) (h) *If net radiation is provided, RH and Lat are not needed.*
(g) *If method==2, Daily Mean Wind Speed, Daily Minimum Wind Speed and sunshine hours are required.*
(h) (j) *Additional input of Daily Maximum Temperature and Daily Minimum Temperature, or Dew Point Temperature.*
(i) (k) *Input can be Daily Mean Relative Humidity or actual vapor pressure*
(j) (l) *If method==1, latitude is needed instead of incoming solar radiation*
(k) (m) *Daily Maximum Temperature and Daily Minimum Temperature also needed*

In this study, Penman and Linacre methods in the Pyet module were chosen to calculate the daily evaporation in Keban Dam Lake. Python programming language was used for calculation and the open source and free PyCharm 2023.2.2 (Community Edition) package was used as the code development environment.

2.1.1.1 Penman Method

The Penman method is a method developed by Howard Penman in 1948 to calculate evaporation on an open water surface using temperature, wind speed, air pressure and solar radiation parameters [29]. The Penman equation is as follows [30]:

$$E_{pan} = \left(\frac{\Delta}{\Delta+\gamma}\right) x (R_n - G) + \left(\frac{\gamma}{\Delta+\gamma}\right) x \frac{6.43(1+0.53u_2)(e_s-e_a)}{\lambda} \quad (1)$$

In the equation:

E_{pan}: daily pot evaporation amount (mm/day),
Δ: slope of the saturated vapor pressure curve at the current temperature of the air (kPa / °C),
γ: psychometric value (kPa / °C),
R_n: daily net radiation (MJ/m^2 day)
G: Heat flux density of the soil (MJ/m^2 day),
λ: latent heat of evaporation of water,
u_2: wind speed at 2 m above the ground (m/s),
e_s: saturated vapor pressure (kPa),
e_a: actual (current) vapor pressure (kPa).

2.1.1.2 Linacre Method

Linacre is another method used to calculate evaporation from open water surfaces; It uses air temperature, latitude and altitude parameters [31]. To estimate evaporation and potential evaporation values, Linacre developed the following relations.

$$E_{pan} = \frac{\left(\frac{500T_m}{100-A}\right)+15(T-T_{dp})}{80-\text{T}} \quad (2)$$

$$T_m = T - 0.0006h \quad (3)$$

In equality;

E_{pan}: daily container evaporation amount (mm/day),
A: degree of latitude (°),
T: daily average air temperature (°C),
T_m: temperature coefficient decreasing with altitude
h: altitude (m),
T_{dp}: daily average dew point temperature (°C).

Linacre is another method used to calculate evaporation from open water surfaces; It uses air temperature, latitude and altitude parameters [32].

Meteorology station information and parameter data, which were previously read and written to the database with the Python openpyxl module, were read from the database with the MySQLdb module, missing data were filled in with the linear interpolation method using the Pandas module, and were prepared as input to the Pyet module for evaporation calculation. Then, the evaporation values calculated by the Penman method of the Pyet module were written back to the database for easier querying and visualization.
The Python code that performs this operation is given below:

```
import pandas as pd
import MySQLdb
import numpy as np
import pyet

db = MySQLdb.connect(host="localhost", user="****", passwd="****", db="meteo")
cur = db.cursor()
cur.execute("SELECT * FROM station WHERE istno='17165' or istno='17201'")

for row in cur.fetchall():
    cur.execute("SELECT * FROM params WHERE istno='"+row[0]+"'")
    result = list()
    for rowdt in cur.fetchall():
        result.append([rowdt[2], rowdt[0], rowdt[12], rowdt[9], rowdt[16], rowdt[3], rowdt[4], rowdt[20]])

    data = pd.DataFrame(result, columns=['station','time','rad','rel','t','tmax','tmin','vv'])
    meteo = pd.DataFrame({"time":data.time,

"tmean":data.t.interpolate(method='linear', limit_direction='forward'),

"tmax":data.tmax.interpolate(method='linear', limit_direction='forward'),

"tmin":data.tmin.interpolate(method='linear', limit_direction='forward'),

"rh":data.rel.interpolate(method='linear', limit_direction='forward'),

"wind":data.vv.interpolate(method='linear', limit_direction='forward'),

"rs":(data.rad*3.6).interpolate(method='linear', limit_direction='forward'),
                        })
    time, tmean, tmax, tmin, rh, wind, rs = [meteo[col] for col in meteo.columns]
    lat = float(row[3])*np.pi/180
    elevation = int(row[7])

    pet_u = pd.DataFrame()
```

```
pet_u["tarih"] = time
pet_u["penman"] = pyet.penman(tmean, wind, rs=rs, elevation=elevation, lat=lat, tmax=tmax, tmin=tmin, rh=rh).fillna(0)
pet_u["linacre"] = pyet.linacre(tmean, elevation=elevation, lat=lat, tmax=tmax, tmin=tmin, rh=rh).fillna(0)

for count, pn in enumerate(pet_u["penman"]):
    sql = "UPDATE params SET penman = "+str(pn)+" WHERE tarih = '"+str(pet_u["tarih"][count])+"' and istno= '"+row[0]+"'"
    cur.execute(sql)
db.commit()
```

```
for count, pn in enumerate(pet_u["linacre "]):
    sql = "UPDATE params SET linacre = "+str(pn)+" WHERE tarih = '"+str(pet_u["tarih"][count])+"' and istno= '"+row[0]+"'"
    cur.execute(sql)
db.commit()

db.close()
```

Meteorological parameters prepared to be used in evaporation calculations and their statistical information are given in Table 4.

Table 4. The main statistical parameters of weather parameters [2014-2024].

Station name: Elazığ Center

	Solar Radiation	Relative Humidity	Mean Temperature	Max. Temperature	Min. Temperature	Wind Speed
Total Number of Observations	3378	3611	3648	3649	3649	3645
Mean	3.19	50.85	14.74	21.32	8.54	8.58
Standard Deviation	2.89	22.08	9.95	11.54	8.18	3.43
Minimum	0.00	10.80	-9.70	-5.40	-15.40	2.30
25%	0.40	30.00	6.10	11.10	2.00	6.00
50%	2.40	49.90	14.40	21.20	8.30	8.20
75%	5.90	70.40	23.80	32.00	15.60	10.60
Maximum	9.30	99.00	33.30	42.40	30.50	26.30

Station name: Tunceli

	Solar Radiation	Relative Humidity	Mean Temperature	Max. Temperature	Min. Temperature	Wind Speed
Total Number of Observations	2219	3652	3652	3652	3652	3652
Mean	4.00	55.25	13.93	21.29	7.55	6.43
Standard Deviation	2.66	20.87	9.87	11.50	8.24	2.03
Minimum	0.00	15.00	-14.50	-8.00	-19.20	0.00
25%	1.70	36.68	5.40	11.10	1.00	5.10
50%	4.00	53.80	13.80	21.40	7.30	6.20
75%	6.40	72.00	22.80	31.70	14.50	7.20
Maximum	9.40	99.40	32.10	41.80	25.50	18.50

Since solar radiation data for the Penman method is available at only two stations and must be given as input in the calculations, this code was run using Elazığ Central and Tunceli Meteorology station data. The daily values of the calculated evaporation results obtained from the Penman and Linacre programs between 2014 and 2023 are given in Fig. 4 in mm.

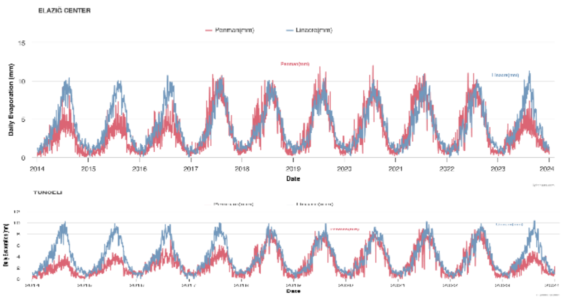

Figure 4. Daily evaporation computed by the Penman and Linacre methods.

In the Penman method, since solar radiation values are missing in these two stations in the first years, the evaporation amounts calculated from the interpolated values are lower than they should be. Evaporation values calculated with the Penman method are closer to their real values between 2018 and 2023. Since the Linacre method does not use solar radiation in the calculation, the results obtained are closer to the actual open surface evaporation values.

In the following sections, these values will be evaluated together with the measured daily total open surface evaporation values and the evaporation values estimated with artificial neural networks (ANN).

2.2 Artificial Neural Networks

ANN are an approach used in many decision-making processes, thanks to their flexible and powerful structure provided by their learning and generalization capabilities. ANN is an effective system in solving different and complex problems depending on its many features. There are different network structures suitable for solving each problem. It is up to the decision maker to decide which solution network is suitable for these problems. This may vary depending on the problem being studied [33, 34].

ANN generally consists of the following three layers. It is the input, hidden and output layer. An ANN model may have more than one hidden layer. ANN processes the information coming from the input layer in the middle layer and converts it into output. A general layer structure of ANN is given in Fig. 5.

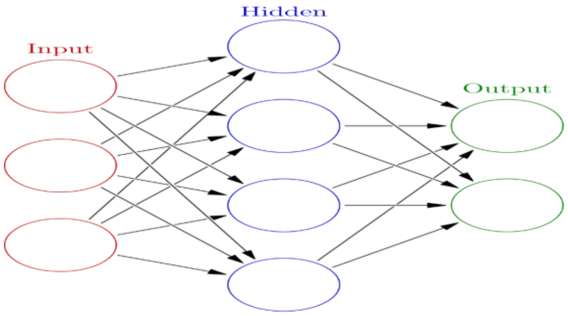

Figure 5. Neural network architecture [35].

2.2.1 Deep Learning

It can be defined as training multilayer artificial neural networks with the backpropagation algorithm. There are many different deep learning models such as CNN, RNN, LSTM and GRU [36, 37].

The long short-term memory model (LSTM) we use in predictions is a recurrent RNN developed by Hochreiter and Schmidhuber in 1997 [38]. The problems experienced in training RNN neural networks are completely eliminated in LSTM. LSTM is widely used in time series problems because it can learn long-term dependencies [39].

Tensorflow and Pytorch are two of the widely used deep learning modules in the Python programming language. In this study, daily evaporation amounts were tried to be estimated using the LSTM model of the Pytorch module (Fig. 6) and the temperature, humidity, pressure, wind and relative humidity data obtained from MGM.

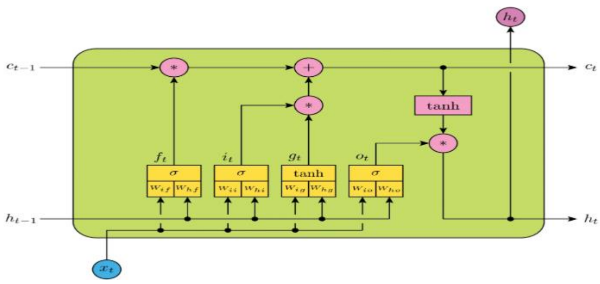

Figure 6. An annotated illustration of the LSTM cell in PyTorch [40].

2.2.2 Correlation

The correlation between meteorological parameters that are input to LSTM is shown in Fig. 7.

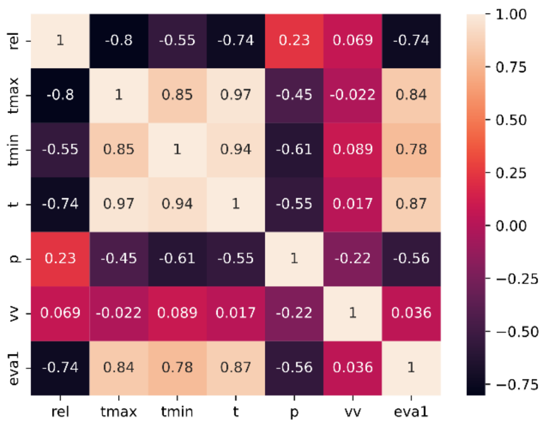

Figure 8. Correlation values of meteorological parameters.

The correlation graph is divided into 2 diagonally in the middle. With a different color palette, colors can mean different things. In the graph, colors that start from 0 and turn black, starting from -1, show negative correlation, and colors that start from 0, and go towards 1, turn red, show positive correlation.

The correlation matrix function of the Pandas module is corr(), the default analysis value is set to "Pearson". There is a very strong correlation (0.8 to 1 or -0.8 to -1.0) between evaporation (eval) and temperature (t) (0.87) and maximum temperature (tmax) (0.84). There is a strong correlation (0.6 to 0.8 or -0.6 to -0.8) between evaporation (eval) and minimum temperature (tmin) (0.78) and relative humidity (rel) (-0.74). There is a moderate correlation (0.4 to 0.6 or -0.4 to -0.6) between evaporation (eval) and pressure (p) (-0.56).

The correlation between evaporation (eval) and wind speed (vv) appears to be very low. There may be different reasons for this. There may not actually be a relationship between the parameters, or pairs of variables may not satisfy the assumptions of Pearson correlation analysis. One or both pairs of variables may not have a continuous data type. The variables are not normally distributed or there is no linear relationship between the variables.

SGD was used as the optimization algorithm in the model. MSE was chosen as the loss function. The epochs value was determined as 200, the stacked LSTM (multiple LSTM) model value was determined as 2, the output size was determined as 1, and the number of hidden features (hidden size) was determined as 512. The data is divided into 60% training and 40% testing.

The nn.MSELoss function in PyTorch was used as the loss function to measure the error rate of the model and therefore its performance. The graph showing the training and testing loss of the model is given in Fig. 8. When the Figure is examined, it is seen that the training loss and test loss both decrease and stabilize after a certain point. Since the loss function of the model is examined, it can be said that it has a good fit.

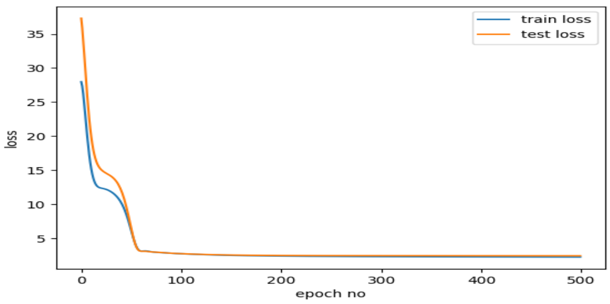

Figure 8. Training and testing loss.

3 Analysis and Evaluation

Annual total open surface evaporation values measured for Elazığ Central and Tunceli Meteorology stations, evaporation estimates of the LSTM model, and the change in evaporation values calculated by the Penman and Linacre method between 2014 and 2023 are given in Fig. 9.

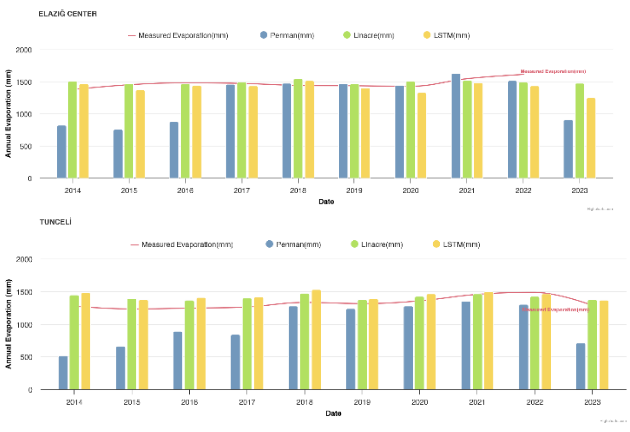

Figure 9. Comparison between calculated from Linacre , Penman, LSTM and the measured evaporation (Elazığ Center - Tunceli).

The change in annual total open surface evaporation values estimated using data obtained from synoptic stations and automatic observation stations around Keban Dam Lake is also given in Table 5.

When Table 5 is examined, it is seen that daily total open surface evaporation values are available for only two stations (Elazığ Center and Tunceli), and likewise, daily total global solar radiation measurement values for only these two stations in Penman are calculated accurately since they are available after 2018. In addition, when Fig. 3 is examined, it is evaluated that outlier values have occurred after 2019 for the daily total open surface evaporation values for Elazığ center, which causes erroneous results in the observed annual total evaporation values. For this reason, especially in recent years, the annual total evaporation values observed for Elazığ center have been very close to or greater than the predicted values. In fact, it is expected that the annual total evaporation observation values will be smaller than expected since evaporation observations for Elazığ center and Tunceli stations are not made from November to April. For these reasons, it was decided to use data from Tunceli station when calculating the Keban Dam lake evaporation estimate.

For Tunceli station, the Linacre average for the last 10 years is 1415 mm, Penman (between 2018-2023 due to missing values) is 1290 mm, LSTM average is 1441 mm and finally the average measured from the evaporation pool is 1323 mm.

Evaporation occurring in evaporation ponds is higher than evaporation occurring in deep waters such as lakes or dams. For this reason, the values measured in evaporation ponds are multiplied by a coefficient to estimate the evaporation amounts in lakes or dams. This coefficient varies between 0.6 and 0.8. For Türkiye, this estimation coefficient is usually taken as an average of 0.7 [41].

In Table 6, the actual or predicted values in the evaporation pond were multiplied by this coefficient and the amount of water evaporated per square meter in the dam lake was calculated in mm. In addition, since Keban Dam has a reservoir area of 408.28 km^2 at a minimum water elevation of 820.00 m and a reservoir area of 676.14 km^2 at a normal water elevation of 845.00 m, the annual total evaporation values in the dam were also calculated for these reservoir areas.

Table 5 Comparison between the calculated and measured evaporation (mm).

		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
AĞIN	Linacre	1595	1513	1493	1541	1574	1478	1529	1524	1532	1499
	LSTM	1276	1311	1446	1457	1414	1381	1320	1456	1460	1225
ELAZIĞ CENTER	Linacre	1508	1467	1470	1493	1549	1464	1504	1522	1496	1473
	Penman	820	755	879	1457	1477	1465	1446	1627	1514	913
	LSTM	1467	1375	1442	1438	1512	1406	1328	1487	1433	1250
	Measured (MGM)	1377	1450	1478	1470	1440	1434	1427	1544	1611	
ELAZIĞ -HARPUT	Linacre	1797	1627	1397	1441	1400	1309	1362	1353	1341	1309
	Penman								343	743	521
	LSTM	1036	1285	1307	1122	1202	1118	1196	1336	1297	1103
KOVANCILAR-YARIMCA	Linacre	1490	1452	1469	1463	1534	1435	1469	1516	1489	1441
	LSTM	1460	1418	1300	1340	1480	1420	1308	1496	1429	1251
ELAZIĞ -ÇÖTELİ KÖYÜ	Linacre	136	1430	1423	1454	1499	1437	1486	1474	1465	1429
ARAPGİR	Linacre	1395	1361	1337	1395	1414	1351	1404	1383	1409	1350
	LSTM	1450	1355	1382	1425	1459	1370	1292	1446	1269	1197
ÇEMİŞGEZEK	Linacre	1537	1479	1442	1410	1550	1471	1504	1519	1512	1451
	LSTM	1506	1219	1398	1316	1466	1399	1330	1483	1456	1229
TUNCELİ	Linacre	1453	1393	1366	1399	1475	1373	1426	1463	1427	1373
	Penman	519	660	892	840	1277	1235	1283	1352	1301	716
	LSTM	1478	1380	1412	1413	1533	1393	1466	1499	1462	1371
	Measured (MGM)	1272	1231	1244	1261	1331	1313	1356	1455	1484	1284
PERTEK-AŞAĞIGÜLBAHÇE KÖYÜ	Linacre	142	1478	1455	1488	1534	1458	1525	1506	1490	1442
ELAZIĞ -YURTBAŞI	Linacre			504	1486	1532	1449	1535	1569	1485	1463
	LSTM								1305	1356	1183
PERTEK-ELMAKAŞI KÖYÜ	Linacre			543	1353	1382	1339	1401	1367	1355	1330
KOVANCILAR-KOLLUCA KÖYÜ	Linacre					1522	1443	1532	1470	1498	1480
PERTEK-KOÇPINAR KÖYÜ	Linacre					1460	1387	1441	1459	1434	1393

Table 6. The estimated annual evaporation of the Keban Dam Lake.

	Evaporation Gage (mm)	Keban Dam Lake (mm)	Keban Dam Lake Minimum Water Level (m^3)	Keban Dam Lake Normal Water Level (m^3)
Linacre	1.415	991	404.605.480	670.054.740
Penman	1.290	903	368.676.840	610.554.420
LSTM	1.441	1.009	411.954.520	682.225.260
Measured (MGM)	1.323	926	378.067.280	626.105.640

It has been observed that if the water surface is covered with solar energy panels in natural lakes and ponds, evaporation decreases by 33%, and in artificial lakes and dams by 50% [42].

Keban Dam has a reservoir area of 408.28 km^2 and a water volume of 15.820.000 m^3 at a minimum water elevation of 820 m, and a reservoir area of 676.14 km^2 and a water volume of 29.414.669 m^3 at a normal water elevation of 845 meters. How much evaporation will be prevented and how much energy can be produced with this water prevented from evaporating in case a floating solar power plant is installed to cover 3%, 5% and 10% of the surface area of Keban Dam at minimum and normal water elevation is calculated in Table 7.

The amounts of water used and energy obtained in the Keban Dam Lake in Elazığ for the year 2023 are given in Figs. 10 and 11, respectively.

Table 7. The total annual water saving.

	Total Surface Area of Dam Reservoir Covered with PV Panels					
	3%	5%	10%	3%	5%	10%
	The estimated annual total evaporation of the Keban Dam Lake Minimum Water Level (m^3)			The estimated annual total evaporation of the Keban Dam Lake Normal Water Level (m^3)		
Linacre	6.069.082	10.115.137	20.230.274	10.050.821	16.751.369	33.502.737
Penman	5.530.153	9.216.921	18.433.842	9.158.316	15.263.861	30.527.721
LSTM	6.179.318	10.298.863	20.597.726	10.233.379	17.055.632	34.111.263
Measured (MGM)	5.671.009	9.451.682	18.903.364	9.391.585	15.652.641	31.305.282

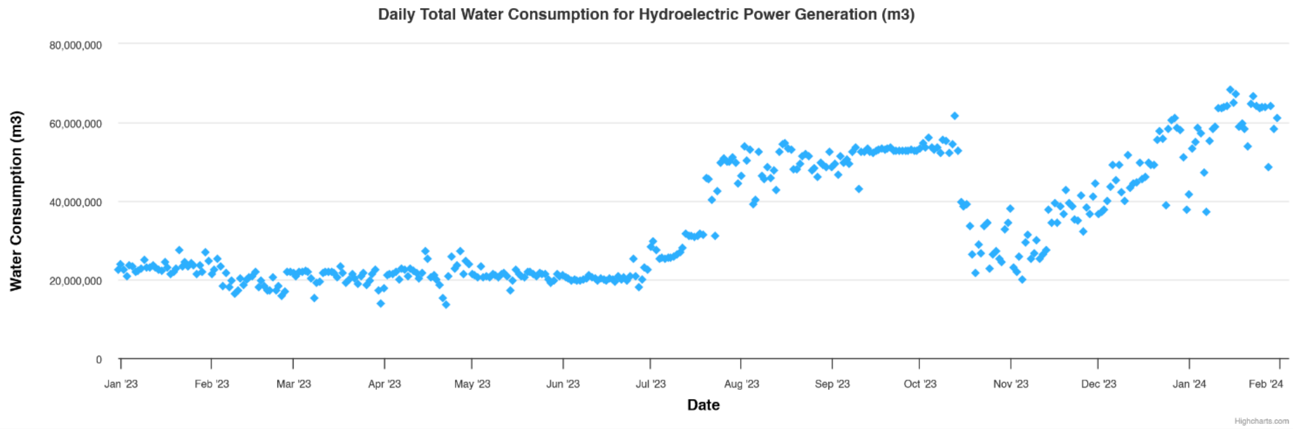

Figure 10. Daily total water consumption for hydroelectric power generation from Keban Dam Lake (Jan 2023 – Feb 2024).

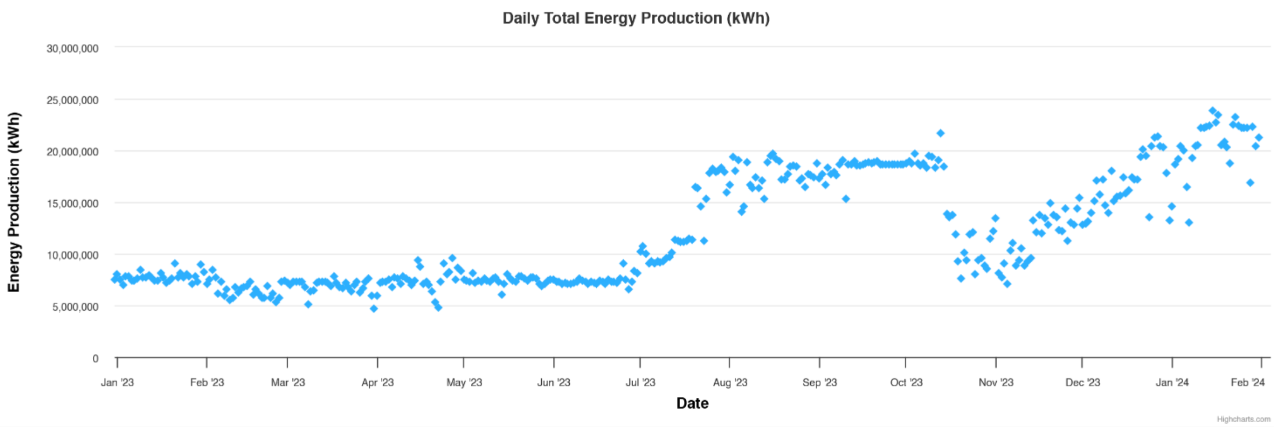

Figure 11. Daily total electrical energy produced from Keban Dam Lake (Jan 2023 – Feb 2024).

Keban Dam meets the electrical energy needs of 1.750.733 people in their daily lives with an average electricity production of 5.794.927,279 kWh. It has been calculated that a total of 31.305.282 m^3 of water in normal water code will be prevented from evaporating annually, thanks to a FSPP that will cover 10% of the dam lake. It has been analyzed that thanks to this water, energy benefit will be provided by the power plant with an installed power (10% floating solar power installed capacity) of 6.624,84 MWe, and 11.297.018 kWh of electricity can be produced from the dam turbines with the water prevented from evaporating thanks to FSPP.

Approximately 72.39 MWe energy is needed for the Ağın, Pertek, Serince, Palu-Kovancılar, Uluova, Kuzova irrigation projects around the Keban Dam lake. Thanks to this study, it has been determined that the amount of water and energy needed for irrigation of these plains can be obtained thanks to FSPP.

4 Results

Türkiye's average annual rainfall is 643 mm. Approximately 501 billion m^3 of this amount of precipitation corresponds to water. 274 billion m^3 of this precipitation returns to the atmosphere through evaporation from rivers, lakes, streams and seas, and from plants. 158 billion m^3 of the water that falls to the ground through precipitation is carried to lakes or seas by streams. The remaining 69 billion m^3 consists of groundwater [43]

With the amount of water per capita of 1.519 m^3, Türkiye is classified as a country suffering from water shortage. Turkish Statistical Institute (TUIK) estimates that Türkiye's population will reach 100 million in 2030. In other words, the amount of water per capita is estimated to be 1.120 m^3/year. Our country is facing the situation of being "water poor" with its increasing population, growing cities and developing economy. Additionally, it has been determined that precipitation in the Mediterranean basin has decreased by 20% in the last 25 years due to global climate change [44].

Floating solar power plants are a structure consisting of solar panel systems mounted on the water surface. These systems are usually built on artificial water reservoirs such as dams, ponds or irrigation ducts.

Solar panels used in floating GES are mounted on platforms floating on the water surface. These systems are usually made of light and water -resistant materials such as HDPE (high density polyethylene). The panels contain photovoltaic cells to capture sunlight and convert them into electricity. The generated electricity is then moved to the land by cable and is either used for direct energy needs or transferred to the electricity network.

Floating GESs, first, the cooling effect of water increases the efficiency of the panels. Secondly, these systems; It reduces the evaporation of water by covering the water surface and contributes to the protection of water resources. Thirdly, floating GESs are beneficial for land use and are especially preferred in areas with land shortage.

For irrigation projects, these irrigation needs to be made with the pumping system, that is with an energy, in terms of the elevation between the buildings to be irrigated with water from dam reservoir. This means an additional cost of about 40 percent.

In addition to providing energy from renewable energy sources for economic development, Türkiye must use water resources effectively, economically and efficiently. In this study, thanks to the FSPP to be built on the Keban Dam lake, overheating of photovoltaic panels will be prevented and electrical energy will be obtained with higher efficiency. Thanks to FSPP, water evaporation in the dam lake is reduced, how much water is prevented from evaporating by using artificial intelligence methods, and thanks to this water, more energy will be obtained from the turbines in the power plant, and thanks to the non-evaporated water, the water needs of the plains around the dam lake and the promoted irrigation systems will be met. determinations were made.

Thanks to a FSPP that will cover 10% of the Keban Dam lake, which is the subject of the study, it has been calculated that a total of 33.502.737 m^3, 30.527.721 m^3 and 34.111.263 m^3 of water in normal water code will be prevented from evaporating annually using Linacre, Penman and LSTM methods, respectively. It was calculated that the evaporation of the measured 31.305.282 m^3 of water was prevented and thanks to this water, energy benefit was provided by the Solar Power Plant with an installed power of 6.624,84 MWe. Additionally, it has been analyzed that 11.297.018 kWh of electricity can be produced from the dam turbines with the water prevented from evaporating thanks to FSPP.

There are 968 dams in Türkiye. In this study, using artificial neural networks and Penman and Linacre methods, which are widely used in evaporation calculations, it has been seen that the amount of water evaporation in the Keban Dam lake with FSPP and the benefit of energy production thanks to water will be significant. In addition, it has been determined that much more energy will be obtained by passing the water flowing after these turbines through the turbines in Karakaya Dam, Atatürk Dam, Birecik Dam and Karkamış Dam. It is thought that this study will create a model for FSPPs to be built on all dams in Türkiye.

Declaration

Ethics committee approval is not required.

References

[1] Exley, G., Armstrong, A., Trevor, P., Page, T., & Jones, I. D. (2021). Floating photovoltaics could mitigate climate change impacts on water body temperature and stratification. *Solar Energy, 219*, 24–33.

[2] Dörenkämper, M., Wahed, A., Kumar, A., Jong, M., Kroon, J., & Reindl, T. (2021). The cooling effect of floating PV in two different climate zones: A comparison of field test data from the Netherlands and Singapore. *Solar Energy, 214*, 239–247.

[3] Melvin, G. K. X. (2015). *Experimental study of the effect of floating solar panels on reducing evaporation in Singapore reservoirs* (Master's dissertation, National University of Singapore).

[4] Redón Santafé, M., Torregrosa Soler, J. B., Sánchez Romero, F. J., Ferrer Gisbert, P. S., Ferrán Gozálvez, J. J., & Ferrer Gisbert, C. M. (2014). Theoretical and experimental analysis of a floating photovoltaic cover for water irrigation reservoirs. *Energy, 67*, 246–255.

[5] Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy Policy, 33*(3), 289–296.

[6] Farfan, J., & Breyer, C. (2018). Combining floating solar photovoltaic power plants and hydropower reservoirs: A virtual battery of great global potential. *Energy Procedia, 155*, 403–411.

[7] Reindl, T., et al. (2019). *Where sun meets water: Floating solar market report*. Retrieved April 10, 2020, from https://esmap.org/where_sun_meets_water_floating_solar_market_report

[8] Intersolar Europe. (2022). *Floating PV: On the rise in Europe*. Retrieved January 1, 2022, from https://www.intersolar.de/market-trends/floating-pv-europe

[9] Farrar, L. W., Bahaj, A. S., James, P., Anwar, A., & Amdar, N. (2022). Floating solar PV to reduce water evaporation in water stressed regions and powering water pumping: Case study Jordan. *Energy Conversion and Management, 260*, 115598.

[10] Işık, A. H., Arıcı, B., & Alhelali, S. *Floating solar power plants technical guide*. Clean Creative Technologies Consultancy and Engineering Inc.

[11] Bulut, M., Kaplanoğlu, İ., & Geylani, V. (2018). Development of world hydro-floating SPP projects and their potential in Turkey. *Power Systems Conference*, Ankara, Turkey.

[12] Huzaifa, R., Gull, M. S., & Arshad, N. (2019). Integrating floating solar PV with hydroelectric power plant: Analysis of Ghazi Barotha reservoir in Pakistan. *Energy Procedia, 158*, 816–821.

[13] World Bank Group, ESMAP, & SERIS. (2019). *Where sun meets water: Floating solar market report*. Retrieved April 10, 2020, from https://www.worldbank.org/en/topic/energy/publication/where-sun-meets-water

[14] Trapani, K., & Santafé, M. R. (2014). A review of floating photovoltaic installations: 2007–2013. *Progress in Photovoltaics: Research and Applications, 22*(4), 689–716.

[15] Jeong, H. S., Choi, J., Lee, H. H., & Jo, H. S. (2020). A study on the power generation prediction model considering environmental characteristics of floating photovoltaic system. *Applied Sciences, 10*(13), 4527.

[16] Aquilina, M., Mule` Stagno, L., Grech, M., & Sant, T. (2016). Determining the optimum shape and size of a platform for an offshore floating photovoltaic system. In *3rd Offshore Energy & Storage Symposium (OSES)*, Valletta, Malta.

[17] Kajari-Schröder, S., Kunze, I., Eitner, U., & Köntges, M. (2011). Spatial and directional distribution of cracks in silicon PV modules after uniform mechanical loads. In *Proceedings of the 37th IEEE Photovoltaic Specialists Conference*, Seattle, WA, USA.

[18] Bellini, E. (2019). Japan's largest floating PV plant catches fire after Typhoon Faxai impact. *PV Magazine International*. Retrieved September 9, 2019, from https://www.pv-magazine.com/2019/09/09/japanslargest-floating-pv-plant-catches-fire-aftertyphoon-faxai-impact/

[19] Alcan, Y., Demir, M., & Duman, S. (2018). Examination of Sinop Province's electricity production potential from solar energy in comparison with our country and Germany. *El-Cezeri Journal of Science and Engineering, 5*(1), 35–44.

[20] Bolat, B. (2022). *Investigation of the energy production potential of hydroelectric power plants and dam lakes with floating solar power plants* (Master's dissertation, Yıldız Technical University)

[21] Güner, S., & Özgür, A. E. (n.d.). Investigating the applicability of Eğridir Lake Solar Power Plant. *Süleyman Demirel University YEKARYUM e-Journal, 8*(2), 80–93.

[22] TRT Haber. (2024). Türkiye yüzer GES'lerden elektrik alacak. Retrieved May 14, 2024, from https://www.trthaber.com/haber/ekonomi/turkiye-yuzer-geslerden-elektrik-alacak-857398.html

[23] ASKİ. (2024). Türkiye'de ilk: ASKİ, baraj üzerinde yüzer GES kurarak elektrik üretecek. Retrieved March 14, 2024, from https://www.aski.gov.tr/tr/HABER/Turk%C4%B1yede-Ilk-Ask%C4%B1-Baraj-Uzer%C4%B1nde-Yuzer-Ges-Kurarak-Elektr%C4%B1k-Uretecek/569

[24] Kaymak, M. K. (2021). *Design and application of adaptive floating solar power plant to weather-environmental conditions* (Doctoral dissertation, Istanbul Technical University, Graduate Education Institute).

[25] State Hydraulic Works (DSİ). (2024). Both clean energy and water savings with floating GES. Retrieved March 10, 2025, from https://www.dsi.gov.tr/Haber/Detay/12128

[26] Ministry of Environment, Urbanisation and Climate Change & Turkish State Meteorological Service. (n.d.). [Institutional source – no specific title available].

[27] Turkish State Meteorological Service. *Official web site: Forecast cities*. Retrieved January 9, 2025, from https://www.mgm.gov.tr/eng/forecast-cities.aspx

[28] PyET Project. *Estimation of potential evaporation*. Retrieved from https://pypi.org/project/pyet/

[29] Terzi, Ö. (2004). *Development and application of evaporation models for Lake Eğirdir* (Unpublished doctoral thesis, Süleyman Demirel University, Institute of Science and Technology, Isparta).

[30] Efthimiou, N., Alexandris, S., Karavitis, C., & Mamassis, N. Comparative analysis of reference evapotranspiration estimation between various methods and the FAO56 Penman–Monteith procedure. [Conference or journal info not provided].

[31] Hiroyuki, M., & Kazzutoshi, O. (2023). Alternative net longwave radiation equation for the FAO Penman–Monteith evaporation equation and the Penman evaporation equation. *Theoretical and Applied Climatology, 153*, 1355–1360.

[32] Emerine, C. N., Isagba, E. S., & Idehen, O. F. (2018). Linacre derived potential evapotranspiration method and effect on supplementary irrigation water needs of tomato, cabbage, and carrot. *Nigerian Journal of Environmental Sciences and Technology, 2*(1), 108–117.

[33] Karaatlı, M., Helvacıoğlu, Ö., Ömürberk, N., & Tokgöz, G. (2012). Automobile sales forecasting with artificial neural networks method. *International Journal of Management Economics and Business, 8*(17), 87–100.

[34] Esen, H., & İnallı, M. (2009). Modelling of a vertical ground coupled heat pump system by using artificial neural networks. *Expert Systems with Applications, 36*(7), 10229–10238.

[35] Wikipedia. Neural network (machine learning). Retrieved June 23, 2025, from https://en.wikipedia.org/wiki/Neural_network_(machine_learning)

[36] Çakmak, E., & Selvi, İ. H. (2022). Protein secondary structure prediction using deep learning (CNN, RNN, LSTM, GRU). *Acta Infologica, 6*(1), 43–52.

[37] Esen, H., İnallı, M., Sengur, A., & Esen, M. (2008). Performance prediction of a ground-coupled heat pump system using artificial neural networks. *Expert Systems with Applications, 35*(4), 1940–1948.

[38] Hochreiter, S., & Schmidhuber, J. (1997). Long short-term memory. *Neural Computation, 9*(8), 1735–1780.
[39] Akın, E., & Şahin, M. E. (2024). A review on deep learning and artificial neural network models. *EMO Scientific Journal: Scientific Refereed Journal of Electrical, Electronics, Computer, Biomedical, Control Engineering, 14*(1), 27–38.
[40] Medium.LSTM cells in PyTorch. Retrieved June 23, 2025, from https://medium.com/@andre.holzner/lstm-cells-in-pytorch-fab924a78b1c
[41] Yıldız, F. E., & Güler, İ. (2014). Comparison of evaporation methods for Sultan Sazlığı wetland. *Gazi University Journal of Science and Technology Part C: Design and Technology, 2*(3), 247–254.
[42] Alok, S., Neha, Y., & Sudhakar, K. (2016). Floating photovoltaic power plant: A review. *Renewable and Sustainable Energy Reviews, 66*, 815–824.
[43] Tokuşlu, A. (2022). Assessing the impact of climate change on Turkish basins. *International Journal of Environment and Geoinformatics, 9*(1), 103.
[44] Devlet Su İşleri. Toprak ve su kaynakları. Retrieved April 3, 2015, from http://www.dsi.gov.tr/toprak-ve-su-kaynaklari
[45]WWF–Türkiye.Türkiye'de su kaynaklarının güncel durumu raporu. Retrieved April 10, 2025, from https://www.wwf.org.tr/kesfet/tatli_su/turkiyede_su_kaynaklarinin_guncel_durumu/

.