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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

Mohamed Abdelgaied [1], Abd Elnaby Kabeel [1,2], Martina Zeleňáková [3,*] and Hany F. Abd-Elhamid [4,5]

1 Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Tanta 31521, Egypt
2 Faculty of Engineering, Delta University for Science and Technology, Gamasa 35712, Egypt
3 Institute of Circular and Sustainable Construction, Faculty of Civil Engineering, Technical University of Košice, 040 01 Košice, Slovakia
4 Department of Water and Water Structures Engineering, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
5 Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, 040 01 Košice, Slovakia
* Correspondence: martina.zelenakova@tuke.sk

Abstract: Water resources are considered one of the most critical and indispensable elements to ensure the survival of all living organisms on the planet. Since there is a close relationship between water, energy, and food security, this interdependence presents a major global societal challenge. While Egypt is one of the countries that suffers the most from water poverty, it has Lake Nasser which is considered one of the largest artificial lakes in the world, with an estimated area of about 5250 km^2. Hence, this work aims to conserve such water resources while addressing two critical issues related to water and energy. To achieve this goal, this study proposed the use of partial coverage technology on Lake Nasser with floating photovoltaic (FPV) panels. The results of the study showed that the partial coverage of Lake Nasser with FPV panels represents a very effective proposal to preserve the water resources of Egypt, which suffers from water poverty. The savings in water evaporation in Lake Nasser reached 61.71% (9,074,081,000 m^3/year) and the annual rate of electricity production was 467.99 TWh/year when 50% of the area of Lake Nasser was covered with FPV panels.

Keywords: water scarcity; floating photovoltaic; water evaporation reduction; electricity generation; Lake Nasser; Egypt

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1. Introduction

In the twenty-first century, water scarcity has become one of the main problems facing all countries in the world, as nearly two-thirds of the world's population suffers from water stress for at least a month each year, in addition to about half a billion people who suffer daily from severe water shortages [1,2]. Water is not only used for humans, but is also used in agriculture and food production. In many regions around the world, the extraction of water resources and their delivery to consumers or agricultural land depends largely on energy. Hence, there is a close interdependence between water resources, food, and energy, for which reason the Food and Agriculture Organization of the United Nations (FAO) was established [3,4]. Ensuring the continuity of food supplies for the global population requires the preservation of water resources as well as the availability of energy, and this represents a significant challenge for the global community [5,6]. A recent study indicated that agricultural land irrigation is the world's largest consumer of fresh water, as it consumes about 70% of water resources. This percentage rises to 90% in developing countries compared to 60% in developed countries [7]. Hence, for developing countries that suffer from water poverty, any approach that can conserve water resources, especially in areas with hot and dry weather, will be a fundamental solution not only from the point of view of food security, but also an effective case in terms of economic development. Globally, basins are used for drinking and irrigating crops. As there are approximately 277,400,000 small-scale irrigation basins (<10,000 square meters) and 24,120,000 large-scale irrigation basins (10,000–100,000 square meters), these basins represent more than 90% of the standing water used in irrigation of crops globally [8,9].

The surface evaporation of water in ponds, lakes, and reservoirs is an important factor in water loss due to its exposure to direct sunlight. Therefore, surface evaporation of water represents one of the factors of the water scarcity problem in many countries of the world, especially remote areas. Creating a shadow on the surface of the water is one of the ways to reduce the rates of surface evaporation of water in ponds, lakes, and reservoirs [10]. This shade can be achieved by placing floating photovoltaic cells on the surface of the water [11]. The floating photovoltaic cells on the surface of the water are characterized by reducing surface evaporation rates and improving the efficiency of photovoltaic cells [12]. The installation of photovoltaic panels on water bodies is an effective alternative to traditional methods where photovoltaic panels are installed on the ground [13]. Japan was the first country to build floating photovoltaic systems on water bodies and to compare its performance with that of conventional photovoltaic systems for research purposes [14]. Floating photovoltaic panels are installed on natural water bodies such as lakes, reservoirs, dams, and ponds [15]. The technology of floating photovoltaic panels on natural water bodies has attracted worldwide attention since 2007, when a limited number of medium and large-capacity floating photovoltaic power stations were established in many American and Asian countries [16]. The floating photovoltaic panels effectively shade the water surface and thus, help reduce surface evaporation rates and reduce water loss [17]. Photovoltaic panels can be installed on the surface of the water in different ways. It should be noted that the main motive behind the use of floating photovoltaic (PV) systems is to avoid the purchase or lease of land and, most importantly, to improve the efficiency of PV panels.

Floating photovoltaic panels on water bodies are characterized by a higher level of electrical efficiency due to their cooling by water vapor [18,19]. Since floating photovoltaic panels are characterized by their ability to reduce surface evaporation rates from water bodies as well as generate electricity, floating photovoltaic systems can contribute to the stability of the agricultural and electricity generating sectors [20,21]. Many researchers have studied the effect of photovoltaic systems on the relationship between water, food, and energy [22–24]. Padilha et al. [25] studied the possibility of using photovoltaic plants in arid regions of Brazil to increase water security and power generation. They mentioned that the surface evaporation of water in dam reservoirs represents one of the main obstacles to achieving water stability in the arid regions of Brazil, and they found that the use of floating photovoltaic systems reduced the rates of surface evaporation and electricity generation in these areas [26]. They also conducted an economic feasibility study for the use of such projects [27,28].

By reviewing the previous studies, it was found that the use of floating photovoltaic panels to reduce water evaporation rates in water bodies, whether lakes, ponds, or water reservoirs, has a positive effect in terms of reducing water losses and electricity production. Hence, the use of floating photovoltaic panels conserves water resources while addressing the two important issues of water and energy, thus achieving the United Nations Sustainable Development Goals. Egypt is one of the first countries to suffer from water poverty and thus, contains Lake Nasser, one of the largest artificial lakes in the world with an estimated area of about 5250 km^2. This work aims to conserve such water resources while addressing the two important issues of water and energy, thus striving for achievement of the United Nations Sustainable Development Goals. To achieve this, the study proposed the use of partial coverage technology for Lake Nasser with floating photovoltaic panels to reduce the rates of surface evaporation of water and generate electricity, while at the same time preserving fish wealth. This study dealt with four proposals to cover Lake Nasser with floating photovoltaic (FPV) panels at different coverage rates: 50%, 40%, 30%, and 20%.

2. Data and Methods

The freshwater limitation represents one of the most important and most dangerous problems facing the Arab Republic of Egypt, and since Egypt lies below the water poverty line, this research aimed to reduce water evaporation rates from water bodies. This research examined the effect of floating photovoltaic panels on surface water evaporation rates in Lake Nasser, Aswan, Egypt. Given the results of this study, they fall into the category of applied research.

First, the location of Lake Nasser was determined and data about the lake collected. Second, the surface water evaporation rates were calculated for open water surface with and without FPV panels. Third, the volume of evaporation water savings was calculated. Lastly, the amount of electrical power that could be produced from the FPV panels was determined. All the above data was calculated using climate and radiation data for the location of Lake Nasser.

2.1. Reservoir Area Determination of Lake Nasser

Lake Nasser, or the High Dam Lake, is one of the largest artificial lakes in the world, located in southern Egypt, south of Aswan (22°25′ N 31°45′ E), and in northern Sudan. The name Lake Nasser is given to the largest part that lies within the borders of Egypt and represents 83% of the total area of the lake, while the remaining part located within the borders of Sudan is called Lake Nuba. It was formed as a result of the water accumulated behind the High Dam after its construction (which lasted from 1958 to 1970), with a length of 500 km, an area of about 5250 km^2, and a depth of 180 m with a total storage capacity of 162 billion cubic meters, making it the largest artificial lake in the world and the second largest lake by area (Figures 1 and 2).

Figure 1. Location of Lake Nasser, Egpt.

Figure 2. Image of Lake Nasser, south of Aswan, Egypt (22°25′ N 31°45′ E).

2.2. Estimation Method of Surface Water Evaporation Rates

This section presents the method used to estimate surface water evaporation rates with and without floating photovoltaic panels.

2.2.1. Evaporation Estimation for Open Water Surface without Floating Photovoltaic Panels

Water evaporation from the open water surface of Lake Nasser without a floating photovoltaic structure was estimated by using the Penman-Monteith equation [6,29]:

$$E' = \frac{0.408\,\Delta\,(Q - G) + \gamma\,\frac{900}{T_a + 273}\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34)\,u_2} \tag{1}$$

where E' is the average evaporation per day (mm/day); G is the heat flux in soil, which is zero for water; Q is the daily average irradiation balance (MJ/m^2/day); Δ is the slope of saturation vapor pressure curve; γ is the psychrometric constant (kPa/°C); u_2 is the wind speed on a height of 2 m (m/s); T_a is the average ambient air temperature (°C); e_s is the saturated vapor pressure (kPa); e_a is the actual vapor pressure (kPa). The values of γ, Δ, e_s, and e_a are calculated as follows [29–31]:

$$\gamma = 0.665 \times 10^{-3} \times P_{atm} \tag{2}$$

$$\Delta = \frac{4098\,e_s}{(T_a + 273)^2} \tag{3}$$

$$e_s = 0.6108\,e^{\left(\frac{17.27\,T_a}{T_a + 273}\right)} \tag{4}$$

$$e_a = \frac{e_s\,RH}{100} \tag{5}$$

2.2.2. Evaporation Estimation for Incorporating Floating Photovoltaic Panels

Water evaporation from Lake Nasser covered by the floating photovoltaic structure depended on the PV panel configurations.

The total irradiation from Lake Nasser covered by the floating photovoltaic panels (Q_{tot}) consisted of the surface area covered by floating photovoltaic panels and the irradiation underneath the area covered by the floating photovoltaic panels (Q_{under}), calculated as [29–31]:

$$Q_{tot} = Q\,(1 - x) + (x\,Q_{under}) \tag{6}$$

The irradiation underneath the area covered by floating photovoltaic panels (Q_{under}) depended on the long-wave and shortwave radiation, calculated as:

$$Q_{under} = 0.1\,\sigma\,{T_w}^4\,(0.56 - 0.0092\,\sqrt{e_a}) \tag{7}$$

Finally, the water evaporation from Lake Nasser covered by the FPV structure (E'_{FPV}) was calculated as follows [29–31]:

$$E'_{FPV} = (1 - x)\ E'_{tot} \tag{8}$$

$$E'_{tot} = \frac{0.408\ \Delta\ (Q_{tot} - G) + \gamma\ \frac{900}{T_a+273}\ u_2\ (e_s - e_a)}{\Delta + \gamma\ (1 + 0.34)\ u_2} \tag{9}$$

where x is the ratio between the water surface covered by the FPV structure to the total Lake Nasser flooded area; T_w is the water temperature (K); and σ is the Stefan-Boltzmann constant (4.903×10^{-9} MJ/m^2 K^4 day).

2.2.3. Volume of Evaporation Water Savings

The volume of evaporation water savings, EWS (m^3/year), was calculated as follows [29]:

$$EWS = \left(E' - E'_{FPV}\right)\ A_{res} \times 10^3 \times 365 \tag{10}$$

where A_{res} is total Lake Nasser flooded area (km^2).

2.3. Design of the Floating Photovoltaic (FPV) System

The objectives for covering Lake Nasser with an FPV system were to reduce evaporation from the water surface by placing the units on a floating platform with polyethylene, and to increase the efficiency of electricity generation by directing them towards the south at an angle of inclination equal to the latitude angle of the city of Aswan (Figure 3).

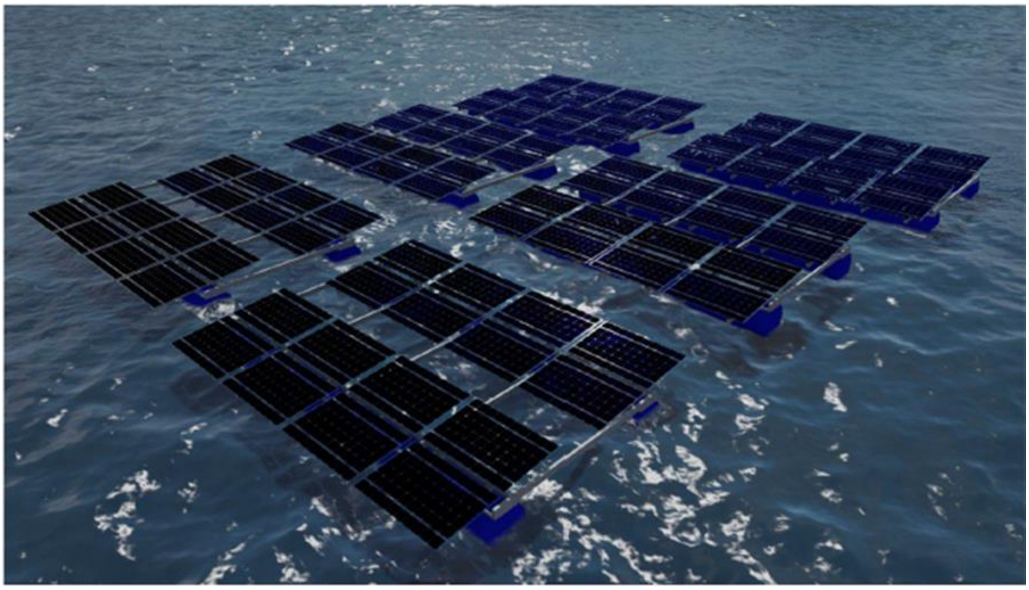

Figure 3. Photo of floating photovoltaic (FPV) panels.

The floating platform consisted of several photovoltaic panels of the type (AE HM400M6-72) 400 W monocrystalline modules. The number of FPV panels utilized in this study depended on the area proposed to be covered. These FPV panels were connected in series and placed in multiple rows, with each series connected to the MPPT input of the inverter. These inverters were connected to a transformer fixed on the ground and connected to a high-voltage transmission network. The platform area of each FPV panel utilized in this study was 1.979 m × 1.002 m and 1.983 m^2.

Solar radiation and cell temperature are the two most important factors affecting the output power of a photovoltaic unit. Therefore, it was necessary to calculate the cell temperature first in order to calculate the output power of the PV modules. To calculate the output power of the PV modules, it was necessary to know the optical and thermal properties of all materials used in the manufacture of PV modules, and this data was obtained from the PV module manufacturer. The cell temperature (T_m) and module output power (P_m) were calculated as follows [29,32]:

$$T_m = T_a + \left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{9.5}{5.7 + 3.8\ u}\right)(T_{NOCT} - T_{a,\ NOCT})\left[1 - \frac{\eta_m}{\tau\alpha}\right] \quad (11)$$

$$P_m = P_{Peak}\left(\frac{G_T}{G_{St}}\right)[1 - \alpha_T(T_m - T_{St})] \quad (12)$$

where T_a is the temperature of ambient air (°C); G_T is the intensity of total irradiance on module surface (W/m^2); $G_{T,NOCT}$ = 800 W/m^2; u is the wind speed (m/s); T_{NOCT} is the nominal operating cell temperature T_{NOCT} = 45 °C; $T_{a,NOCT}$ = 20 °C; η_m is the module efficiency and is given by 21.2%; τ_α is the coefficient of transmittance absorptance which can be estimated as 0.9; P_{Peak} is the peak power of module (400 W given by manufacturer); G_{St} = 1000 W/m^2; α_T = −0.38% °C; and T_{St} = 25 °C.

After calculating the output power for each module, it was multiplied by the total number of the modules, which depended on the percentage of water surface coverage with FPV panels, to calculate the power produced from all modules. The overall system efficiency (η_{sys}) was calculated by giving the cable efficiency (η_{cable} = 99.4%), inverter efficiency (η_{inv} = 97.5%), and transformer efficiency (η_T = 97%). The AC power at the output of the transformer and at entering the transmission line was calculated as:

$$\eta_{sys} = \eta_{cable}\ \eta_{inv}\ \eta_T \quad (13)$$

The output AC power supplied to transmission line was calculated as:

$$P_{output,\ AC} = P_m\ \ \eta_{sys} \quad (14)$$

3. Results

To explore the best way to use the FPV panels technique, four different cases were studied:

- Case study 1: 50% of the total submerged area was covered by FPV panels.
- Case study 2: 40% of the total submerged area was covered by FPV panels.
- Case study 3: 30% of the total submerged area was covered by FPV panels.
- Case study 4: 20% of the total submerged area was covered by FPV panels.

Figure 4 shows the data of average daily solar irradiation and average daily ambient temperature that were imported from the Egyptian Surface Meteorology and Solar Energy Database of the city of Aswan, Egypt (22°25′ N 31°45′ E).

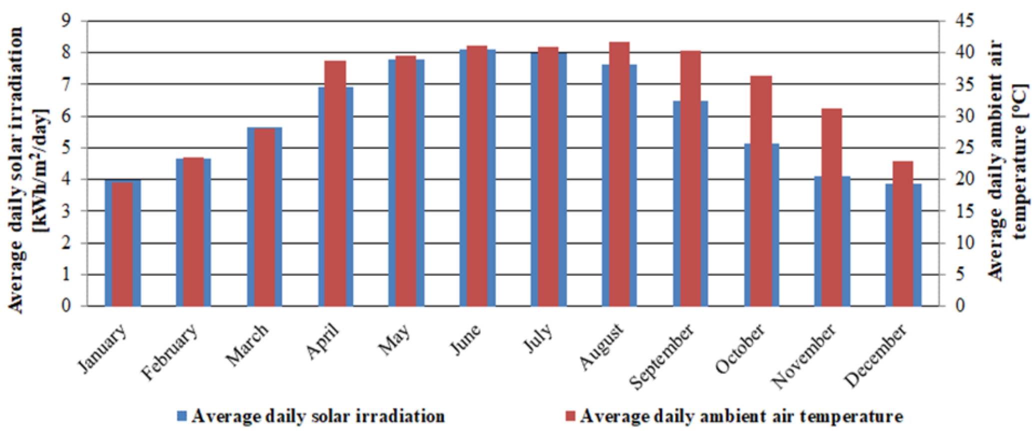

Figure 4. Average daily solar irradiation and daily ambient temperature of the city of Aswan, Egypt (22°25′ N 31°45′ E).

3.1. Evaporation Savings

This section presents the effect of partial coverage of Lake Nasser with FPV panels on water surface evaporation rates. This study dealt with four proposals for partial coverage of Lake Nasser with FPV panels to show the effect of these four proposals on the results of evaporation water savings.

The collected parameter values, as well as the estimated values of the variables that do not depend on the FPV panels proposed in this study, are summarized in Table 1. In addition, the values of the collected parameters and the calculated values of the variables for the four cases proposed with different coverage rates of 50% (Case study 1), 40% (Case study 2), 30% (Case study 3), and 20% (Case study 4), are summarized in Tables 2 and 3.

Table 1. Parameters and variables calculated for Lake Nasser, city of Aswan, Egypt (22° 25′ N 31°45′ E).

Months	A_{res} (km^2)	Q (MJ/m^2/Day)	T_a (°C)	E' (mm/Day)
January	5250	14.309	19.5	3.933
February	5250	16.779	23.5	4.853
March	5250	20.347	28	6.146
April	5250	24.934	38.6	9.026
May	5250	27.992	39.5	9.844
June	5250	29.207	41.1	10.447
July	5250	28.697	40.9	10.294
August	5250	27.521	41.7	10.215
September	5250	23.287	40.2	9.002
October	5250	18.465	36.3	7.303
November	5250	14.819	31.2	5.780
December	5250	13.917	22.8	4.356

Table 2. Water evaporation savings results (Case Study 1 and Case Study 2).

Months	Case Study 1					Case Study 2				
	x	Q_{tot} (MJ/m^2/Day)	E'_{FPV} (mm/Day)	$EWS \times 10^6$ (m^3/Month)	$EWS \times 10^6$ (m^3/Year)	x	Q_{tot} (MJ/m^2/Day)	E'_{FPV} (mm/Day)	$EWS \times 10^6$ (m^3/Month)	$EWS \times 10^6$ (m^3/Year)
January	0.5	8.106	1.591	381.297	-	0.4	9.3465	1.999	314.833	-
February	0.5	9.384	1.916	431.768	-	0.4	10.8633	2.422	357.422	-
March	0.5	11.219	2.354	617.196	-	0.4	13.0443	2.997	512.487	-
April	0.5	13.638	3.361	892.274	-	0.4	15.897	4.309	742.856	-
May	0.5	15.178	3.590	1017.769	-	0.4	17.7406	4.628	848.894	-
June	0.5	15.805	3.785	1049.224	-	0.4	18.4858	4.887	875.624	-
July	0.5	15.548	3.742	1066.47	-	0.4	18.178	4.827	889.78	-
August	0.5	14.970	3.743	1052.758	-	0.4	17.4803	4.819	877.695	-
September	0.5	12.834	3.399	882.455	-	0.4	14.9249	4.343	733.733	-
October	0.5	10.375	2.867	722.022	-	0.4	11.9933	3.628	598.058	-
November	0.5	8.492	2.347	540.74	-	0.4	9.7572	2.947	446.279	-
December	0.5	7.946	1.775	420.11	-	0.4	9.1399	2.226	346.591	-
					9074.081					7544.251

Table 3. Water evaporation savings results (Case Study 3 and Case Study 4).

Months	Case Study 3					Case Study 4				
	x	Q_{tot} (MJ/m^2/Day)	E'_{FPV} (mm/Day)	$EWS \times 10^6$ (m^3/Month)	$EWS \times 10^6$ (m^3/Year)	x	Q_{tot} (MJ/m^2/Day)	E'_{FPV} (mm/Day)	$EWS \times 10^6$ (m^3/Month)	$EWS \times 10^6$ (m^3/Year)
January	0.3	10.587	2.437	243.472	-	0.2	11.828	2.906	167.212	-
February	0.3	12.342	2.969	277.072	-	0.2	13.821	3.556	190.718	-
March	0.3	14.87	3.698	398.413	-	0.2	16.696	4.456	274.974	-
April	0.3	18.156	5.350	578.919	-	0.2	20.415	6.483	400.465	-
May	0.3	20.303	5.772	662.68	-	0.2	22.866	7.023	459.126	-
June	0.3	21.166	6.105	683.902	-	0.2	23.846	7.437	474.057	-
July	0.3	20.808	6.025	694.788	-	0.2	23.438	7.336	481.494	-
August	0.3	19.991	6.003	684.887	-	0.2	22.501	7.297	474.335	-
September	0.3	17.015	5.376	571.127	-	0.2	19.106	6.496	394.636	-
October	0.3	13.611	4.453	463.873	-	0.2	15.229	5.3399	319.469	-
November	0.3	11.023	3.5899	344.974	-	0.2	12.288	4.277	236.827	-
December	0.3	10.334	2.710	267.821	-	0.2	11.529	3.227	183.799	-
					5871.927					4057.111

Figure 5 presents the average daily evaporation in each month for Lake Nasser, Aswan, Egypt (22°25′ N 31°45′ E) for the cases with and without FPV panels. As is evident in Figure 5, as well as in Table 1, if Lake Nasser was not covered by floating photovoltaic panels, the average daily evaporation during the months of the year ranged between 3.933 and 10.447 mm/day. This large discrepancy in the average daily evaporation during the months of the year is mainly due to the effect of climatic changes throughout the year. As shown in Figure 5 as well as Tables 2 and 3, when 50% of the Lake Nasser surface area was covered with floating photovoltaic panels, the average daily evaporation from Lake Nasser was reduced and ranged between 1.591 and 3.785 mm/day. Furthermore, when 40% of the Lake Nasser surface area was covered with floating photovoltaic panels, the average daily evaporation from Lake Nasser was reduced and ranged between 1.999 and 4.887 mm/day. When 30% of the Lake Nasser surface area was covered with floating photovoltaic panels, the average daily evaporation from Lake Nasser was reduced and ranged between 2.437 and 6.105 mm/day. Finally, when 20% of the Lake Nasser surface area was covered with floating photovoltaic panels, the average daily evaporation from Lake Nasser was reduced and ranged between 2.906 and 7.437 mm/day.

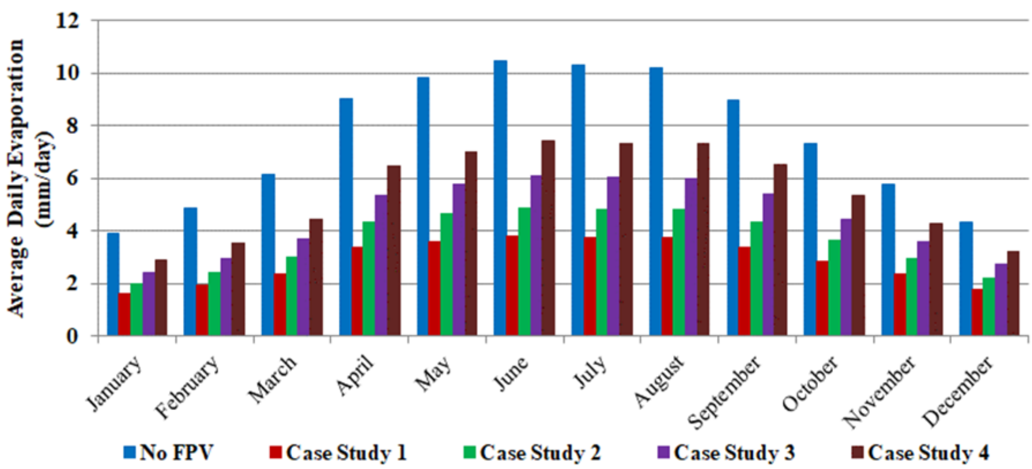

Figure 5. Average daily evaporation for each month throughout the year for the cases with and without FPV panels.

Figures 6 and 7 show the savings in surface evaporation (mm/day) and volume of evaporation water savings (m^3/day) that resulted from the installation of floating PV panels in Lake Nasser during the months of the year. The rates of savings in surface evaporation depended on the percentage of the area covered by the FPV panels. It is clear from the results presented in Figures 6 and 7 that for the case of covering 50% of the area of Lake Nasser with floating photovoltaic panels (Case Study 1), the savings in surface evaporation ranged between 2.343 and 6.662 mm/day (12,299,915–34,974,125 m^3/day) throughout the year; for the case of covering 40% of the area of Lake Nasser (Case Study 2), the savings in surface evaporation ranged between 1.934 and 5.56 mm/day (10,155,915–29,187,464 m^3/day) throughout the year; for the case of covering 30% of the area of Lake Nasser (Case Study 3), the savings in surface evaporation ranged between 1.496 and 4.342 mm/day (7,853,921–22,796,718 m^3/day) throughout the year; and for the case of covering 20% of the area of Lake Nasser (Case Study 4), the savings in surface evaporation ranged between 1.027 and 2.958 mm/day (5,393,939–15,801,891 m^3/day) throughout the year. These discrepancies in the savings values in surface evaporation for each of the four cases proposed were due to changes in weather conditions throughout the year.

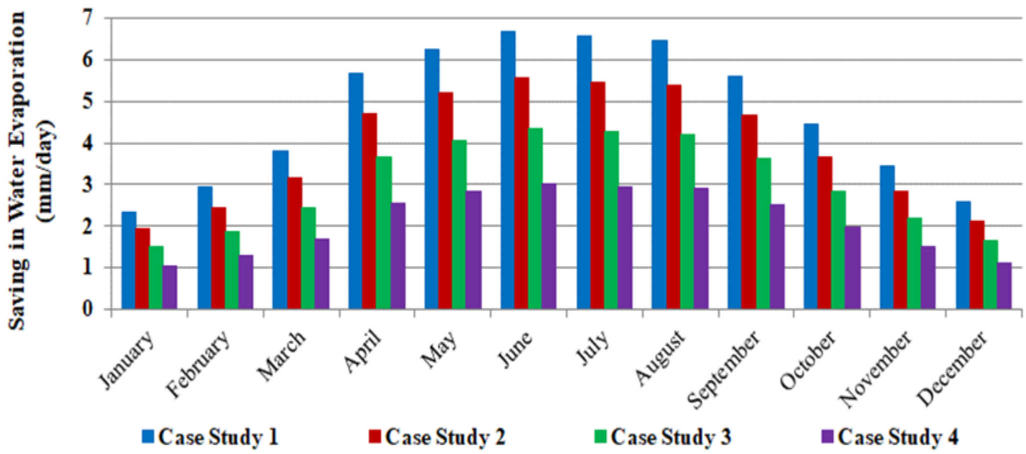

Figure 6. Average daily evaporation savings for each month of the year during the installation of FPV panels on Lake Nasser.

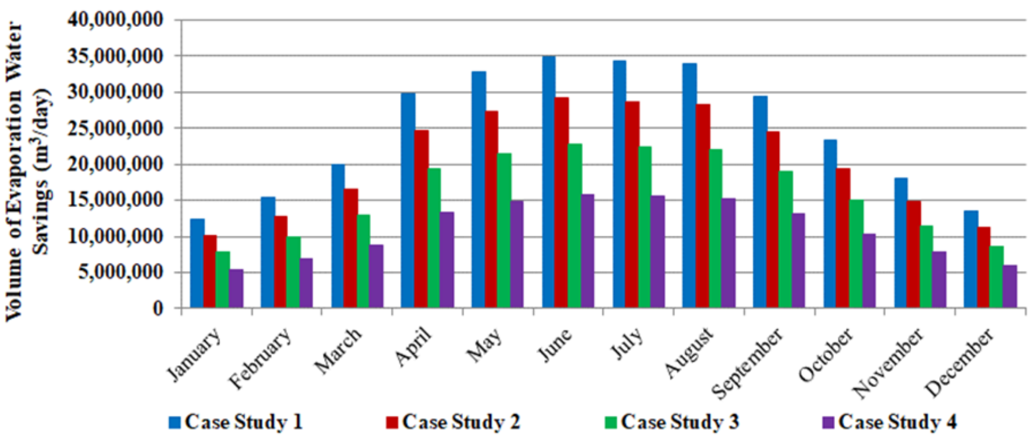

Figure 7. Average volume of daily water evaporation savings for each month of the year during the installation of FPV panels on Lake Nasser.

The results presented in Figures 5–7 and Tables 1–3 concluded that the installation of FPV panels in Lake Nasser represents a very effective proposal, especially for Egypt which suffers from water poverty for agriculture, domestic use and drinking. In addition, the construction of the Renaissance Dam currently being built in Ethiopia has caused tensions between Egypt, Sudan, and Ethiopia. The rate of water evaporation savings in Lake Nasser reached 61.71% (9,074,081,000 m^3/year) when covering 50% of the area of Lake Nasser with floating photovoltaic panels (Case Study 1). When covering 40% of the area of Lake Nasser (Case Study 2), the savings in water evaporation in Lake Nasser reached 51.24% (7,544,251,000 m^3/year). The rate of water evaporation savings in Lake Nasser reached 39.83% (5,871,927,000 m^3/year) when covering 30% of the area of Lake Nasser (Case Study 3), and the rate of water evaporation savings in Lake Nasser reached 27.49% (4,057,111,000 m^3/year) when covering 20% of the Lake Nasser area with floating photovoltaic panels (Case Study 4).

3.2. Installed Capacity and Electricity Output of FPV Array

Figure 8 and Table 4 show the daily and annual electricity rates expected to be generated from the FPV panels system on the surface of Lake Nasser for the four cases proposed in this study, according to the climatic conditions of Aswan, Egypt. As shown in Figure 8, the daily rates of electricity expected to be generated from the FPV panels system for the four cases proposed in this study changed throughout the year as a result of changing climatic conditions. The daily rates of electricity production ranged between 877.9 and 1666.5 GWh/day when covering 50% of Lake Nasser with floating photovoltaic panels (Case Study 1). With 40% of Lake Nasser covered by floating photovoltaic panels (Case Study 2), the daily rates of electricity production range between 702.3 and 1333.2 GWh/day. The daily rates of electricity production ranged between 526.8 and 999.9 GWh/day when covering 30% of Lake Nasser with floating photovoltaic panels (Case Study 3). Lastly, with 20% of Lake Nasser covered with floating photovoltaic panels (Case Study 4), the daily rates of electricity production ranged between 351.2 and 666.6 GWh/day.

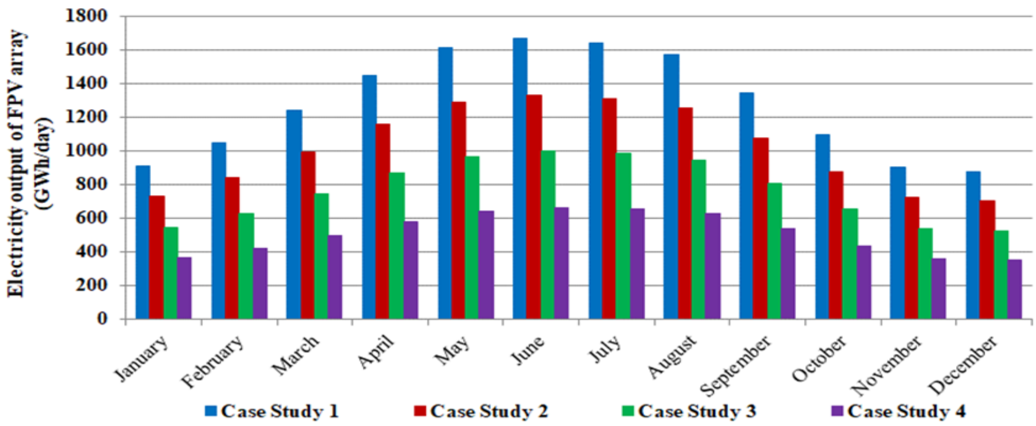

Figure 8. Daily electricity generation of a floating photovoltaic array installed on Lake Nasser.

The results presented previously showed that covering Lake Nasser with floating photovoltaic panels represents a very effective solution for Egypt, which suffers from water poverty in addition to electric power. As shown in Table 4, the annual rates of electricity production from the floating photovoltaic system of Lake Nasser depended on the percentage of the area covered by the floating photovoltaic panels. The annual rate of electricity production from the FPV panels system for Lake Nasser reached 467.99 TWh/year, 374.41 TWh/year, 280.787 TWh/year, and 187.21 TWh/year when covering 50% (Case Study 1), 40% (Case Study 2), 30% (Case Study 3), and 20% (Case Study 4) of Lake Nasser with FPV panels, respectively.

Table 4. Floating photovoltaic (FPV) panels generation results.

Months	A_{res} (km^2)	Case Study 1			Case Study 2			Case Study 3			Case Study 4		
		x	FPVep (TWh/Month)	FPVep (TWh/Year)	x	FPVep (TWh/Month)	FPVep (TWh/Year)	x	FPVep (TWh/Month)	FPVep (TWh/Year)	x	FPVep (TWh/Month)	FPVep (TWh/Year)
January	5250	0.5	28.32	-	0.4	22.67	-	0.3	16.99	-	0.2	11.33	-
February	5250	0.5	29.42	-	0.4	23.53	-	0.3	17.65	-	0.2	11.77	-
March	5250	0.5	38.57	-	0.4	30.86	-	0.3	23.14	-	0.2	15.43	-
April	5250	0.5	43.46	-	0.4	34.77	-	0.3	26.08	-	0.2	17.39	-
May	5250	0.5	49.96	-	0.4	39.97	-	0.3	29.97	-	0.2	19.98	-
June	5250	0.5	50	-	0.4	40	-	0.3	30	-	0.2	20	-
July	5250	0.5	50.85	-	0.4	40.68	-	0.3	30.51	-	0.2	20.34	-
August	5250	0.5	48.7	-	0.4	38.96	-	0.3	29.22	-	0.2	19.48	-
September	5250	0.5	40.44	-	0.4	32.35	-	0.3	24.26	-	0.2	16.18	-
October	5250	0.5	33.96	-	0.4	27.17	-	0.3	20.377	-	0.2	13.58	-
November	5250	0.5	27.09	-	0.4	21.68	-	0.3	16.26	-	0.2	10.84	-
December	5250	0.5	27.22	-	0.4	21.77	-	0.3	16.33	-	0.2	10.89	-
				467.99			374.41			280.787			187.21

4. Conclusions

Floating solar photovoltaic panels are an advanced technology that aims to reduce the rates of water evaporation from water bodies to reduce the problem of water shortages that most countries of the world suffer from, in addition to generating electricity while at the same time eliminating the need to use valuable land. At the global level, we find that irrigation ponds contain nearly 70% of freshwater resources, and this percentage rises to 90% for remote areas. Lake Nasser (the lake of the High Dam) is considered one of the largest artificial lakes in the world, and it is located in southern Egypt, south of Aswan (22°25′ N 31°45′ E), with an estimated area of about 5250 square kilometers. Egypt is among the countries that suffer from water poverty and this problem will be exacerbated in the future due to Ethiopia's construction of the Renaissance Dam, which has led to strained relations between Egypt, Sudan, and Ethiopia. Therefore, the current study proposed the use of floating photovoltaic technology to partially cover Lake Nasser to reduce water evaporation rates and produce electricity. Covering Lake Nasser with floating photovoltaic cells can reduce water evaporation rates, helping to solve the problem of water poverty that Egypt suffers from. This paper dealt with four proposals to partially cover Lake Nasser with floating photovoltaic panels. In the first proposal, 50% of the area of Lake Nasser was covered by floating photovoltaic panels. In the second proposal, 40% of the area of Lake Nasser was covered by floating photovoltaic panels. In the third proposal, 30% of the area of Lake Nasser was covered by floating photovoltaic panels. In the fourth proposal, 20% of the area of Lake Nasser was covered with floating photovoltaic panels. Among the most important results reached are the following:

- The installation of FPV panels on Lake Nasser is a very effective solution for Egypt which suffers from water poverty, as the rate of water evaporation savings in Lake Nasser reached 61.71% (9,074 081, 000 m^3/year) when covering 50% of Lake Nasser area with floating photovoltaic panels.
- The rate of water evaporation savings in Lake Nasser depends on the percentage of the area covered by the floating photovoltaic panels, which reached 61.71%, 51.24%, 39.83%, and 27.49% for covering 50%, 40%, 30%, and 20% of the area of Lake Nasser with FPV panels, respectively, as compared to the conventional case without FPV panels.
- The annual rate of electricity production from the FPV panels system for Lake Nasser reached 467.99 TWh/year, 374.41 TWh/year, 280.787 TWh/year, and 187.21 TWh/year for covering 50%, 40%, 30%, and 20% of Lake Nasser with FPV panels, respectively.

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