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Article

Toward sustainable power with floating solar at Near East University Lake, Northern Cyprus

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ABSTRACT

Floating solar photovoltaic (FPV) systems have become a desirable research topic for optimization and development. The primary objective of the current study is to optimize an FPV at Near East University Lake in Northern Cyprus, aiming to enhance energy production and mitigate negative environmental impacts. Besides, the potential for energy generation and economic feasibility of various design configurations related to fixed and tracked PV systems and coverage area (45, 60, 75, and 90%) were investigated. The results demonstrated that the increase in coverage area indeed increased energy yield due to the increase in the number of panels. The 90% coverage area, for instance, reduces the cost of energy production to 0.0176 USD/kWh and produces a very respectable increase in energy yield. According to the techno-economic analysis, the reduction of GHG emissions can range from 330 to 659 tCO2/year, depending on the coverage area. The value of NPV demonstrates the system's long-term sustainability and profitability, while the basic payback period remains relatively consistent across all coverage percentages, ranging from 3.19 to 3.20 years. Thus, this research provides valuable insights into how floating solar technology can be integrated with water conservation and sustainable energy production, which can greatly aid in achieving renewable energy targets and reducing water evaporation losses.

1. Introduction

The global transition to renewable energy sources is increasing as countries attempt to meet the Sustainable Development Goals (SDGs) and the Paris Agreement's carbon emission reduction and energy sustainability targets [1]. Renewable energy sources, including solar power, offer a practical and sustainable alternative to conventional power generation systems [2]. Solar energy has the potential to be used as an alternative source of power to traditional power sources [3]. The use of solar photovoltaic (PV) technology is gaining pace around the world as many nations believe it plays a vital role in meeting challenging renewable energy goals and national net-zero emissions targets [4,5]. General, ground-mounted, and floating solar PV systems are two of the principal ways of harnessing solar power [6]. The ground-mounted systems are widely used due to the ease of installation on land surfaces. They typically require a substantial land area, which can be a constraint in regions with limited land availability. However, floating solar photovoltaic (FPV) systems are seen as a novel solution to the land availability restriction. FPV technology involves mounting solar panels on buoyant structures designed to withstand water conditions. These platforms, anchored or moored for stability, use conventional photovoltaic cells to convert sunlight into electricity [7]. In general, the major components of the FPV system are PV arrays, inverters, lightning arresters, combiner boxes, and metal frames that secure the entire set according to Lee et al. [8]. The authors provide more details about the components of the FPV system. Moreover, the materials used to construct these pontoons or floats are typically high-density polyethylene (HDPE) or fiber-reinforced plastic (FRP) [9,10]. These materials are chosen for their excellent durability, lightweight properties, and resistance to environmental stresses, such as

UV radiation and water exposure. According to Claus and López [11] and Ghigo et al. [12], one of the most critical aspects of FPV system design is the anchoring and mooring system. This system ensures the floating platform remains stable and retains its intended orientation, even in the face of wind, waves, and other environmental forces.

Abbreviations

AIIP	Albedo Irradiance on Inclined Plane
AT	Ambient temperature
DHI	Diffuse Horizontal Irradiance
DIIP	Diffuse Irradiance on Inclined Plane
FPV	Floating solar photovoltaic
FRP	Fiber-reinforced plastic
GHI	Global Horizontal Irradiance
GIIP	Global Irradiance on Inclined Plane
HDPE	High-density polyethylene
KIB-TEK	KibrisTürkElektrikKurumu
NEU	Near East University
PR	Performance Ratios
PV	Photovoltaic
RH	Relative humidity
SDGs	Sustainable Development Goals
SGEE	Summation of grid exported energy
STS	Sun-tracking system
WS	Wind speed

Without this stability, the efficiency and safety of the solar panels would be compromised. Anchoring and mooring systems are meticulously engineered, taking into account site-specific conditions such as water depth, wave dynamics, and wind loads [13]. The design and structure of floating photovoltaic (FPV) systems play a critical role in their efficiency, durability, and adaptability to different water bodies. FPV systems utilize floating modules connected in a cascaded manner to create a stable foundation for PV panels while maximizing coverage of the water surface [14]. However, designing an optimal FPV structure involves addressing several key considerations to account for site-specific challenges and operational requirements [11]. According to Santafé et al. [15], several factors need to be evaluated during the installation of FPV systems on water bodies, as follows:

- In-Situ Construction and Operation: The design should accommodate on-site assembly, construction, and maintenance with minimal disruptions to the surrounding environment.
- Varying Water Levels: The system must adapt to fluctuating water levels, whether due to seasonal changes, reservoir management, or climatic conditions.
- Reservoir Layout and Internal Geometry: Water bodies vary significantly in shape, depth, and layout, making it challenging to create a universally adaptable floating structure.
- Floating Platform Design: The platform must be robust enough to support the PV modules and ancillary equipment while providing stability against environmental forces.

FPV systems are designed to simplify operation and maintenance [16]. This is often achieved through the use of access platforms or pathways that are at least 0.5 meters wide [17]. The distance between frames is carefully calculated to avoid shading and ensure optimal solar exposure for the PV modules [18,19]. According to the previous studies [20-22], the main types of FPV systems are pontoon structure (Type 1), superficial rigid structure (Type 2), and superficial flexible structure (Type 3). Kim et al. [20], Kumar et al. [21], and Silvério et al. [22] provide more details about these types. Moreover, FPV maximizes underutilized water surfaces, making it appealing in land-scarce areas based on the previous studies [23-27]. According to Kumar et al. [23], the water surface cools panels, improving efficiency, while evaporation helps mitigate heating. This approach offers environmental benefits by reducing water evaporation, conserving resources, minimizing impact on land ecosystems, preserving habitats, and reducing land use conflicts [24]. Utilizing water bodies, including lakes, ponds, and reservoirs, provides FPV advantages over ground-mounted systems [25]. These advantages of the FPV system are (a) increasing the solar panels' efficiency and output power by the cooling effect of the water, which lowers operating temperatures [26], and (b) saving water resources by reducing water evaporation [27]. Therefore, FPV systems are an alternative solution to reduce the water and energy crisis, especially in regions where land resources are limited and water bodies are abundant.

1.1 Energy situation in Northern Cyprus

Energy demand has increased in Northern Cyprus as a result of expanding educational institutions and economic growth [28, 29]. This increased demand creates challenges for the energy sector due to a lack of local resources. According to Akçaba and Eminer [30], energy shortages are most severe in the summer, when demand is at its peak. They found that the residential sector uses around 20% of energy, while the commercial sector uses the remaining 30%. Moreover, according to the Cyprus Turkish Electricity Authority, Kibris Türk Elektrik Kurumu (KIB-TEK), 6% of Northern Cyprus' electricity is currently produced by renewable sources, with the remaining 94% coming from fossil fuels in 2023. In addition to raising expenses, the dependence on imported fuel significantly increases greenhouse gas emissions, putting pressure on the economy and the environment. Therefore, the development of affordable, sustainable, and clean energy has been the primary goal for Northern Cyprus. Implementing energy-saving measures and concentrating on the growth of renewable energy sources, especially solar energy, are two aspects of the government's strategy. According to the Global Solar Atlas, Northern Cyprus has excellent potential for solar energy use, with 320 sunny days annually and an average daily solar radiation of 5.6–6.13 kWh/m^2. Moreover, solar resource in Northern Cyprus can be categorized as "good to excellent," according to Prăvălie et al. [31], with the value of energy production from solar systems ranging between 4.5kWh/kWp/day and 4.8 kWh/kWp/day according to the Global Solar Atlas.

To encourage solar power system implementation, KIB-TEK has implemented a net metering system [32-34]. Presently, customers can generate and export extra energy from their photovoltaic systems to the grid. This initiative has encountered challenges due to the grid system's isolation, which limits its capacity to handle expanding PV installations.

The Renewable Energy Board (Yek-Kurulu) currently permits single-phase grid-connected customers to install up to 5 kW of PV systems, while three-phase customers are permitted to install up to 8 kW [35]. Solar power systems in Northern Cyprus have generated approximately 74.3 MW of electricity despite these limitations. Numerous studies have explored the solar energy potential and economic feasibility of photovoltaic systems in various regions of Northern Cyprus [36-54]. Based on these studies, it can be concluded that installing solar power plants could solve the country's energy crisis and significantly reduce its reliance on fossil fuels. According to the authors' review, two studies [53, 54] evaluated the performance of the FPV system in the country. Ünlükuş [53] assessed the financial and technical aspects of constructing a 1 MW floating PV system at Girne's Geçitköy Dam and a 1 MW land-based PV system at Middle East Technical University. The results demonstrated that the installation of the FPV plant has the potential to produce electricity, in contrast to the photovoltaic systems based on silicon. Kassem et al. [54] investigated the techno-economic feasibility of FPV systems at 15 water reservoirs in Northern Cyprus. The results show that a floating structure with bifacial panels and a north-facing tilt of 6° performs best. Furthermore, 10.19–47.21% less electricity could be produced using fossil fuels at 75% FPV coverage.

1.2 Importance of the study

According to previous studies, FPV systems can lower surface evaporation from bodies of water and provide a sustainable alternative to traditional energy generation methods. Also, the use and potential benefits of FPV systems in Northern Cyprus remain relatively unexplored. Examining the relationships between FPV technology and the region's high solar energy potential and growing water scarcity concerns has not received much attention from scholars in Northern Cyprus. This highlights an urgent requirement for particular studies to bridge this gap and reveal the enormous potential of FPV systems in the region. Moreover, numerous studies have evaluated the techno-economic feasibility of FPV systems at various water bodies, but one study has examined the feasibility of achieving FPV systems at a university campus for achieving SDGs [3], according to the authors' review. Therefore, the present study aims to design an efficient and sustainable FPV system at the artificial lake within the Near East University (NEU) campus in Northern Cyprus. The study attempts to determine the feasibility and performance of FPV systems based on different water surface coverage ratios, evaluating their influence on energy generation, system efficiency, and interactions with the water body. Besides, fixed-tilt systems with different sun-tracking technologies are then compared, including single-axis and dual-axis ones, to estimate which configuration may have the most promising output regarding energy generation, structural feasibility, and cost efficiency. In terms of modeling and assessment, technical and economic parameters are evaluated for each scenario.

2. Materials and methods

2.1 Study area

The study is conducted at NEU, which is located in Lefkoşa (Nicosia), the capital city of Northern Cyprus. NEU is located at approximately 35.2295° N latitude and 33.3785 °E longitude, and it falls under the Mediterranean climate zone that is characterized by hot, dry summers and mild, wet winters. Lake NEU (Figure 1) is an artificial water body on the university campus. The lake is primarily an aesthetic environmental consideration for microclimatic cooling and recreation. As shown in Figure 1, these channels help prevent flooding by safely diverting overflow to other places. The drainage system keeps stable water levels in winter, making NEU Lake a suitable place for sustainable water management and FPV applications.

2.2 Climate parameters

The estimation of water losses from climate parameters was conducted during the period of 2010 to 2023 using data from the NASA power dataset. Monthly evaporation from Lake of NEU from 2010 to 2023 was calculated using mean monthly temperature, relative humidity, and wind speed data that are available at (https://power.larc.nasa.gov/data-access-viewer/). (accessed on March 5, 2025). Figure 2 illustrates the variation of weather parameters, including Horizontal Irradiance (GHI), ambient temperature (AT), and wind speed (WS). It is found that the GHI peaks in May (217.2 kWh/m^2) and June (238.9 kWh/m^2). This certainly has a good energy generation potential. The lowest irradiance is recorded in December (68.4 kWh/m^2), indicating a noticeable decrease in irradiance during the winter months. It has been found that AT increased steadily through the months of measurement and attained a maximum in July at 30.19°C and slowly declined toward winter. Besides, the WS, on a moderate scale of solitarily surpassing that range, varied with a minimum of 2.0 m/s in December and a maximum of 3.1 m/s in April, helping cool the system and thus ensuring efficient performance during the hottest months. Moreover, the maximum and lowest value of RH is recorded in January and July, with values of 77.0% and 46.5%, respectively.

Figure 1. Location map

2.3 Sun-tracking designs for FPV Systems

According to Paudel et al. [55], the orientation angles are one of the important factors that are directly related to the system's performance. Therefore, the performance of different sun-tracking systems (see Table 1) is evaluated according to performance ratios (PR) for selecting the optimum design for the proposed system. PR is defined as the ratio of the yield factor to the reference yield as given in Eq. (1) [20].

$$PR = \frac{Yield\ factor}{Reference\ yield} \tag{1}$$

In this study, Jinko Tiger Neo N-type 72HL4-(V) was selected as the recommended grid-connected photovoltaic system. It was chosen for this study since it is one of the best PV modules available. Furthermore, a 250kW three-phase string inverter with 12 MPPTs with 99% efficiency is used.

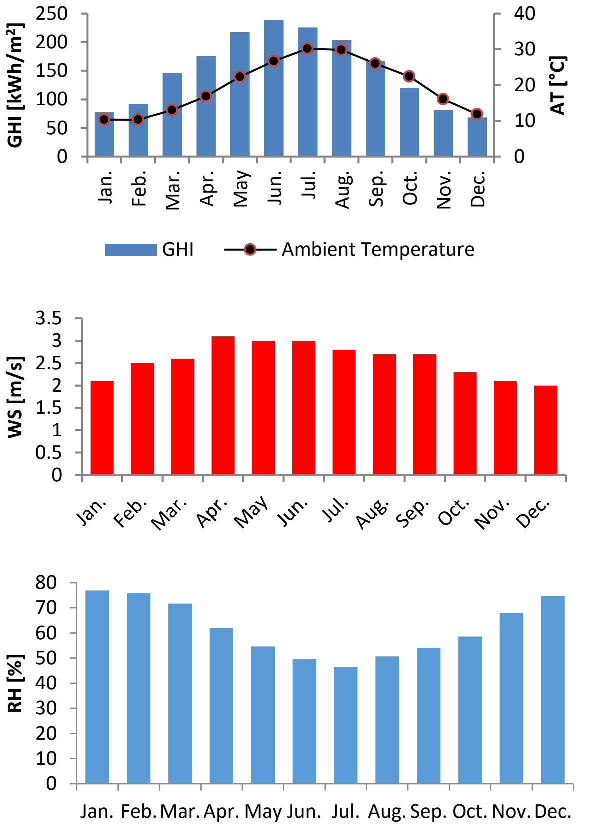

Figure 2. Monthly variation of climate parameters

Table 1. Description of the sun-tracking system (STS) used in the study

Sun-tracking system	**Description**
STS#1	Fixed Plane (30°/0°): Panels fixed at 30° tilt, facing 0° (south
STS#2	Seasonal Tilt Adjustment: Adjust tilt (20° in summer, 50° in winter) every season, azimuth = 0°
STS#3	Tracking Sun-Shields (Facade Orientation 30°): Panels mounted vertically (like sun-shields) tilted at 30°
STS#4	Tracking Two Axis (Frame E-W): Dual-axis tracking, E-W frame alignment
STS#5	Tracking Two Axis (Frame N-S): Dual-axis tracking, N-S frame alignment
STS#6	Tracking Plane, Two Axis: Standard dual-axis tracking (both tilt and rotation)
STS#7	Tracking Plane, Horizontal N-S Axis: Single-axis tracking (rotating horizontally N-S)
STS#8	Tracking Plane, Vertical Axis (30° tilt): Vertical axis tracking with panel tilt 30°

2.4 Simulation software

In general, computer simulation software such as PVSyst, HOMER, and RETscreen is useful for the optimal design of solar PV projects [54]. It contains meteorological data of most locations and suitable algorithms capable of simulating the user's data and suggesting various configurations. In this study, the PVsyst simulation tool is used. A PVsyst simulation tool, designed initially in Geneva, helps in estimating the performance of PV systems [56]. The software assists in creating a design configuration for the system and also allows for the calculation of energy generation. The output is based on the simulation of the sizing system, further depending primarily on the geographical site location. The results might involve various simulations that can be shown in monthly, daily, or hourly volumes. The "Loss Diagram" predicts the weaknesses in the system design [56,57].

2.5 Evaporation estimation and annual water-saving

The floating photovoltaic structure reduces evaporation over the water's surface, not only beneath the panels. The main contributors to this decrease are twofold: (a) a reduction in air-water interaction beneath the covered area and (b) a change in the lake's thermal balance that results in lower surface temperatures and reduced evaporation. There are several different ways to calculate the evaporation of water on free surfaces in the literature [54]. Additionally, the Penman-Monteith method is used to calculate the evaporation rate (E). It can be expressed as Eq. (2).

$$E = \frac{0.047 \cdot \Delta \cdot R_n + \gamma \cdot \frac{900}{T+273} \cdot U_2 (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot U_2)} \tag{2}$$

$$e_s = \frac{1}{2} \cdot \left[0.6108 \cdot exp\left(\frac{17.27 T_{max}}{T_{max}+237.3}\right) + 0.6108 \cdot exp\left(\frac{17.27 T_{min}}{T_{min}+237.3}\right)\right] \tag{3}$$

$$e_a = \frac{RH}{100} \cdot e_s \tag{4}$$

Where R_n is the net radiation [W/m²], U_2 is the wind speed at 2m height [m/s], Δ is the slope of the saturated vapor pressure–air temperature curve [kPa/ °C], γ: Psychrometric "constant" (depends on temperature and atmospheric pressure) [Pa °C^{-1}], e_s: saturated vapor pressure at the temperature of the air [kPa]; e_a is the vapor pressure at the temperature and relative humidity of the air and RH is relative humidity [%].

Moreover, the water saving (w-s) from installing the proposed system can be determined using Eq. (5) [54].

$$w - s = E_{monthly} \times A \times 0.70 \tag{5}$$

where $E_{monthly}$ is the monthly evaporation, A is the box's surface area that prevents water evaporation [m²], which is equal to 2470 m².

3. Results and discussion

3.1 Best sun-tracking system for FPV system

As mentioned previously, different sun-tracking systems are compared according to their PR as shown in Figure 3. It was found that a fixed-tilt system with a 30° tilt and a 0° azimuth achieved an 83.64% PR. By including seasonal tilt changes (20° in the summer and 50° in the winter), the PR was slightly raised to 83.66%. Tracking systems were also evaluated. While monitoring sunshields with a facade angle of 30° gave a PR of 83.61%, dual-axis tracking systems produced somewhat higher PR values, ranging from 83.69% to 83.72%, depending on the frame orientation (E-W or N-S). With the highest PR of 84.11% among all the options, the tracking plane with a horizontal N-S single axis was the most efficient configuration. Numerous studies concluded that a single-axis tracking configuration is one of the best orientations for optimizing the annual energy yield in PV systems [58, 59]. Moreover, single-axis trackers can increase the energy production over fixed systems [59, 60], which can be important for maximizing energy output on water surfaces in FPV installations [61, 62].

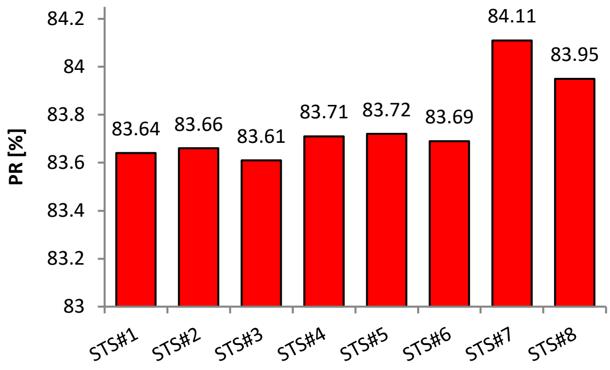

Figure 3. PR value for various sun-tracking systems

To maximize the efficiency of FPV systems, it is important to understand the solar irradiance parameters [63,64]. Figure 4 illustrates the monthly variation of Diffuse Horizontal Irradiance (DHI), Global Irradiance on Inclined Plane (GIIP), Diffuse Irradiance on Inclined Plane (DIIP), and Albedo Irradiance on Inclined Plane (AIIP) for the best-performing sun-tracking system. It is found that the maximum DHI is recorded in April (74.72 kWh/m^2) and May (77.29 kWh/m^2), giving enough scattered sunlight to be efficiently utilized by the system. Moreover, it is observed that the highest value for the GIIP is recorded in June (326.1 kWh/m^2), followed by May (293.6 kWh/m^2), which indicates that these months have the greatest solar energy potential. Furthermore, DIIP follows the general trend of global irradiance, with the highest value in May (36.99 kWh/m^2) and low values during the winter months, particularly December. Additionally, AIIP, which represents the amount of radiation reflected by the surface, shows high values during the summer months, particularly in June (4.561 kWh/m^2), which complements the overall system energy generation potential.

3.2 Monthly variation of evaporation at various sun-tracking systems

The monthly and annual evaporation data are estimated based on the global inclined solar irradiation. Figure 5 illustrates the monthly and annual evaporation for various sun-tracking systems. It is found that January has the lowest evaporation, whereas July consistently has the highest evaporation rates in all systems. Additionally, the results show that STS#1 1 has the lowest yearly evaporation at 2642.96 mm, whereas STS#2 and STS#3 show a slight increase in evaporation to 2715.58 mm and 2786.03 mm, respectively, as a result of their superior solar capture. Furthermore, STS#4, STS#5, and STS#6 systems have the highest evaporation rates, exceeding 3400 mm/year due to the full two-axis tracking continuously optimizing panel orientation to maximize solar exposure on the water's surface.

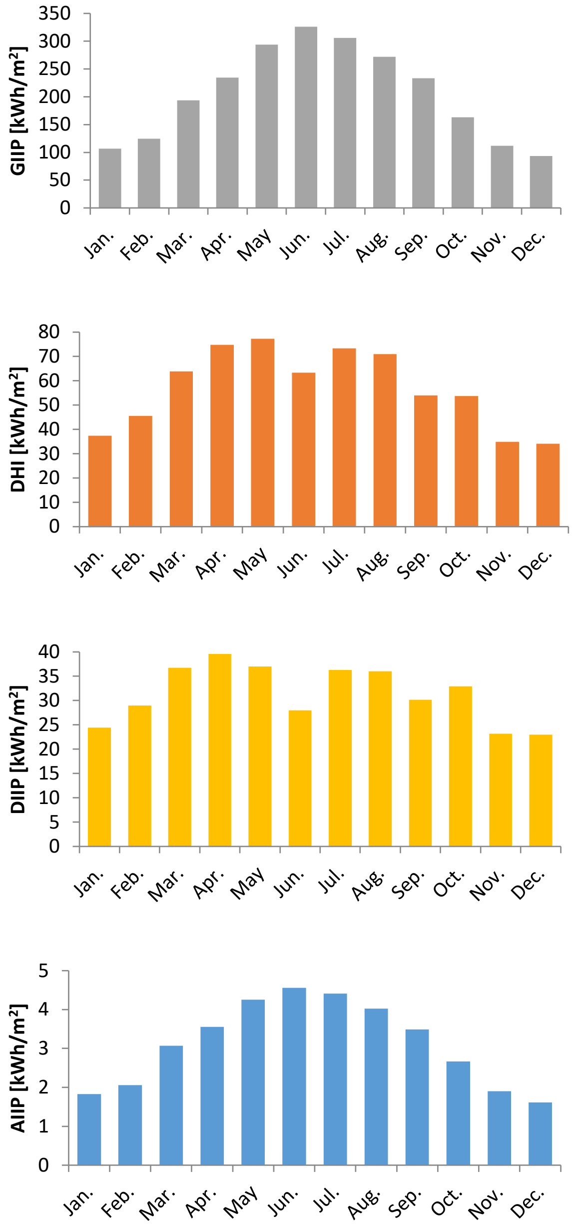

Figure 4. Monthly variation of climate parameters

Furthermore, at roughly 3180 mm/year, STS#7 and STS#8 show intermediate rates of evaporation. These systems achieve a better balance without the severe evaporation that comes with full two-axis tracking by increasing solar output compared to fixed systems. Moreover, the estimated w-s for different configurations of the PV system at various coverage percentages (45%, 60%, 75%, and 90%) over an integrated water surface area of 2470 m^2 is shown in Figure 5. The results show that increasing the covering area significantly improves water conservation by reducing evaporation. Furthermore, it is found that the water savings at 45% coverage range from 2056.35 m^3 (Seasonal Tilt Adjustment) to 2669.93 m^3 (Tracking Plane, Horizontal N-S Axis).

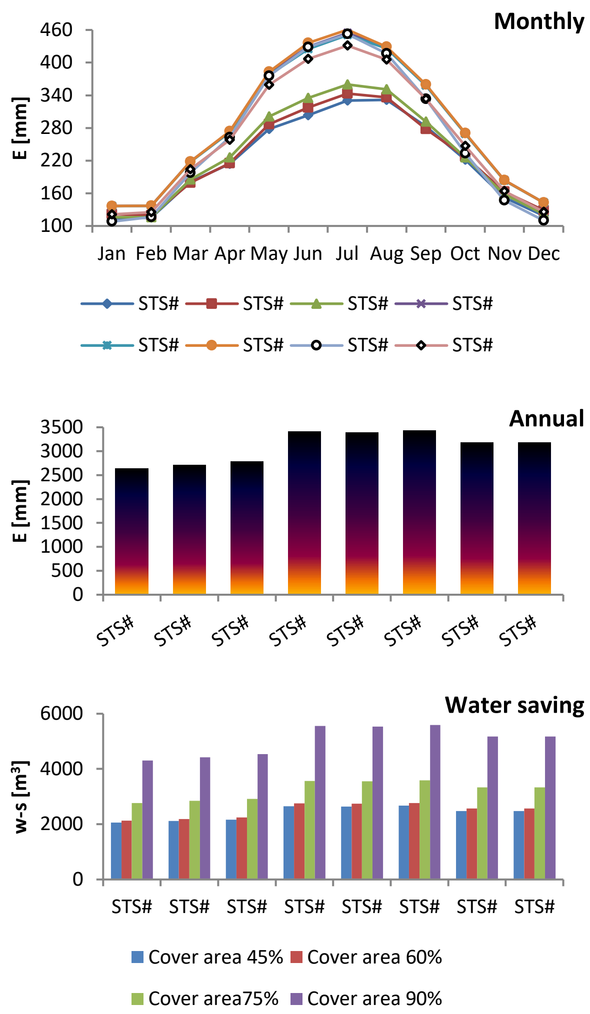

Figure 5. Estimation of the value of evaporation and water saving for different sun-tracking systems

The savings gradually increase with an increase in the covered area to 60%, 75%, and finally 90%. At 90% coverage, the highest water-saving capacity is observed for the Tracking Plane, Horizontal N-S Axis system, with 5589.08 m^3, and the Seasonal Tilt Adjustment system recorded less water savings of 4304.64 m^3. Besides, two-axis tracking systems, including frame and plane kinds, exhibit the greatest potential for water savings at higher coverage levels among the systems studied due to their superior capacity to inhibit evaporation. This analysis shows that increased coverage offers substantial water-saving benefits in addition to increasing solar energy output. This is particularly important for reservoirs that are located in dry or drought-prone regions.

The findings reveal that water savings increase significantly as the coverage percentage rises from 0% to 90%, highlighting the system's effectiveness in reducing evaporation. For instance, annual water savings at 90% coverage can reach as high as 5589.08m^3, compared to zero savings when no photovoltaic panels are used. These results align with previous research. For example, Abd-Elhamid et al. [65] reported water savings ranging from 2.1 × 10^9 m^3/year at 25% coverage to 8.4 × 109 m^3/year at 100% coverage. Similarly, Ilgen et al. [66] estimated that at 90% FPV coverage, water savings could reach up to 5.9 billion m^3/year, with a corresponding 49.7% reduction in evaporation

3.3 Energy production analysis for optimal FPV tracking system

The monthly hourly summation of grid exported energy (SGEE) shows the entire electrical energy that is expected to be delivered by the PV system to the grid each month. The main objective of these results is to measure the energy performance of the configured PV system over time, considering site-specific solar conditions, system configurations, and losses. As mentioned previously, a variety of coverage percentages, including 45%, 60%, 75%, and 90%, were used in its computation. The results show that by increasing the number of panels, the covering area significantly increases annual energy output, as shown in Figure 6.

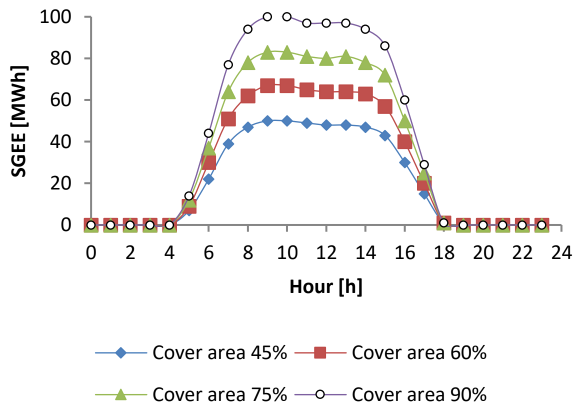

Figure 6. Annual hourly value of SGEE with various coverage areas

Moreover, Figure 7 illustrates the monthly hourly SGEE for the cover area of 45% as an example. Figure 7 demonstrates:

- For the summer months (June, July, and August), energy generation is relatively high, reflecting the increased solar radiation during those months.
- The winter months (December, January, and February) have low energy due to the shorter daylight hours, along with a lower amount of solar irradiation.
- Peak power is typically achieved in most months, specifically in summer, between the periods of 9h and 15h. This peak corresponds to the time of day when the solar radiation is at its highest.
- It's quite obvious that energy output tends to uniformly increase over the hours from morning (6h) to afternoon (15h), before declining towards evening and night (17h to 23h), just like any solar-generating system will show.
- The peak energy export is recorded between the hours of 10h and 15h, coinciding with a peak incident during the day when solar radiation is at its maximum.

The loss diagram for a cover area of 45% as an example, shows each loss that occurs in the system step-by-step (Figure 8), where a drop of 1812kWh/m² is caused by the PV system. It's a good thing. Because of IAM and soiling losses, the system's overall energy generation is 579 MWh, with an efficiency of 21.4%. Last but not least, 579Mwh and the remaining energy are lost due to LID, mismatch loss, inverter loss during operation, and Ohmic loss.

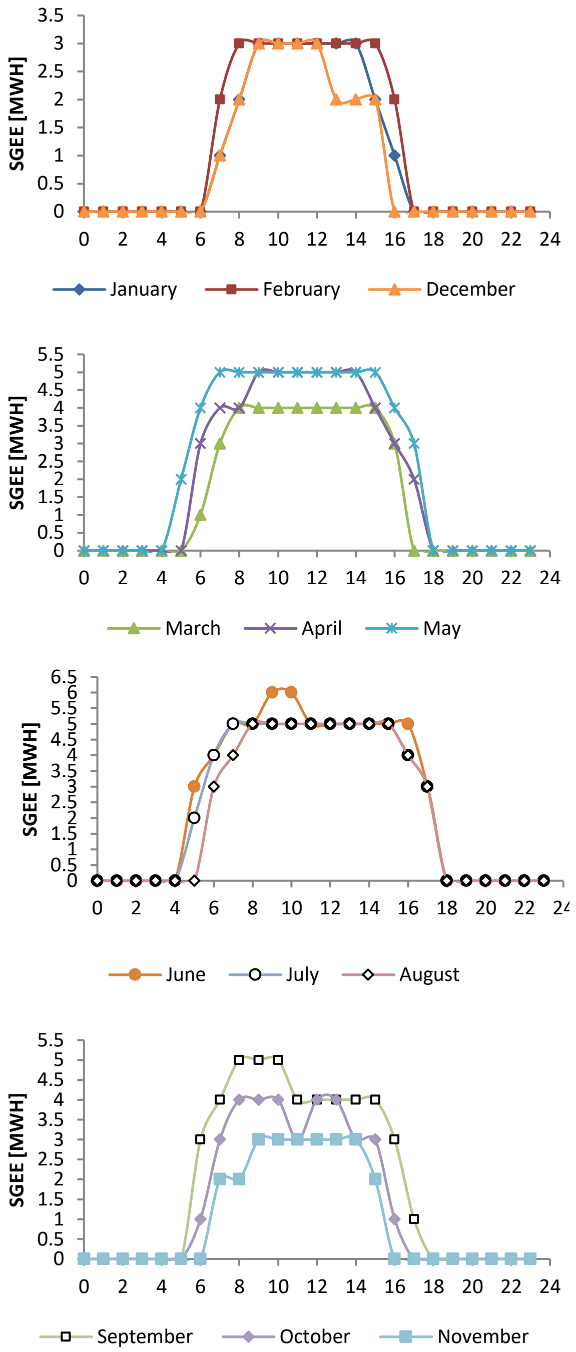

Figure 7. Annual hourly value of SGEE for covering an area of 45%

3.4 Economic analysis of PV system performance at various coverage areas

This study conducted a techno-economic assessment of the FPV system under several assumptions. The system is expected to generate the most energy and return on investment over a 25-year period. The discount rate is assumed to rise from 0% to 11% in 3% increments to account for the time value of money. Moreover, a 2% to 10% inflation rate with 2% increments is assumed for anticipated cost escalation over time. Furthermore, it is assumed that: (a) engineering is expected to cost 2% of the initial cost, (b) civil work could cost 5%, (c) technical and structural aspects can cost 8%, and (d) transportation and electrical connection costs would cost 2% and 7% of the initial cost, respectively. Furthermore, miscellaneous costs (including those that were perhaps unexpected or just small) were given an account of 1%. These assumptions set the basis for the estimate and the financial evaluation of the PV system throughout its expected lifetime. The economic analysis covers financial and environmental implications for various coverage areas of FPV systems. There's a clear increase in GHG annual emission reduction with increased coverage area, from 67 tCO_2/year at 45% to 105 tCO2/year at 90%, as shown in Figure 9. Besides, the simple and equity payback periods are within the range of 3.8-4.4 years and 1.2-1.4 years, respectively, as shown in Figure 10. The results indicate that the initial investment gets recovered in quite a short period. The results demonstrate that the payback period can be influenced by the reservoir area covered by solar panels according to previous studies [54, 67, 68].

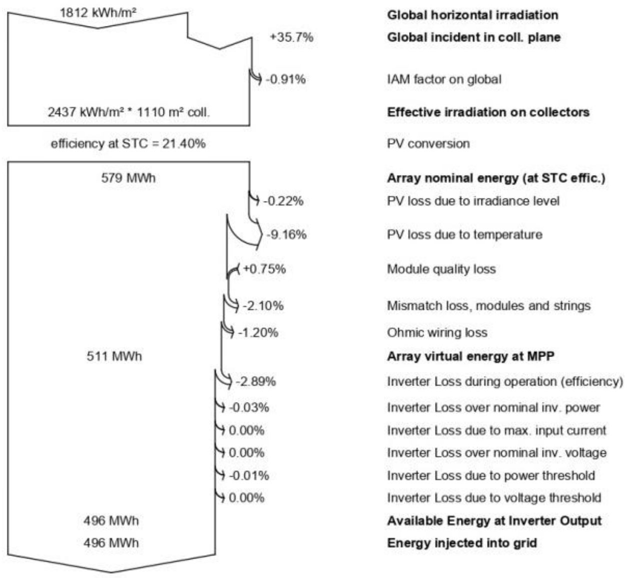

Figure 8. Loss diagram for covering an area of 45%

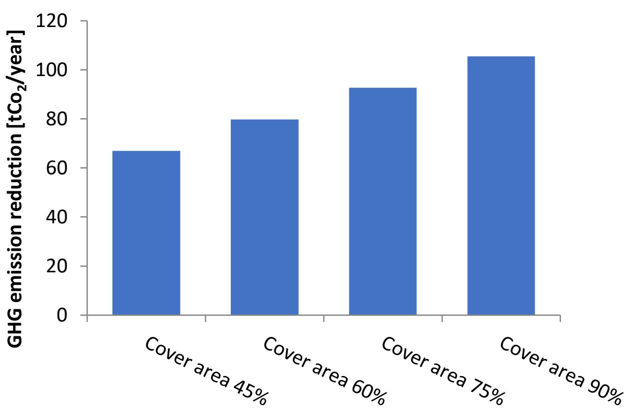

Figure 9. GHG annual emission reduction for the percentage of various cover areas

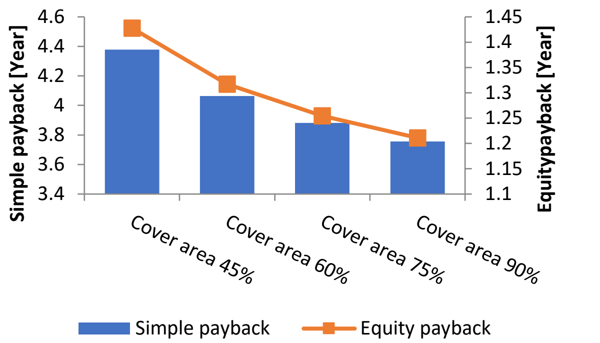

Figure 10. Simple and equity payback value for various percentages of the covered area

Figure 11 shows the relationship between the Net Present Value (NPV) of the FPV system and various discount rates (DR) and inflation rates. As mentioned previously, it was assumed that the discount rate would range from 0% to 11% in 3% increments to account for the time value of money, while the inflation rate was adjusted from 2% to 10% in 2% increments to reflect anticipated cost escalation over the project's lifetime. The negative consequences of increased cost escalation are illustrated by the fact that, for all discount rates, NPV falls as inflation increases. Similarly, higher discount rates reduce the present value of future cash flows, which in turn reduces the project's overall profitability [69]. The combination of an 8% inflation rate and a 6% discount rate was found to be the most effective among scenarios. This choice strikes a balance between favorable project returns and the region's actual economic conditions. An 8% inflation rate accounts for the higher-than-global-average price growth anticipated in the local economy, while a 6% discount rate is a reasonable assumption for the cost of capital and project risk in renewable energy investments. In spite of moderate cost escalation and capital costs, the FPV system maintains a high enough net present value (NPV) under these circumstances, suggesting strong financial feasibility. According to Kassem et al [54], the optimal combination of a 6% discount rate and an 8% inflation rate was found among the examined scenarios. This choice impacts a balance between favorable project returns and feasible regional economic conditions.

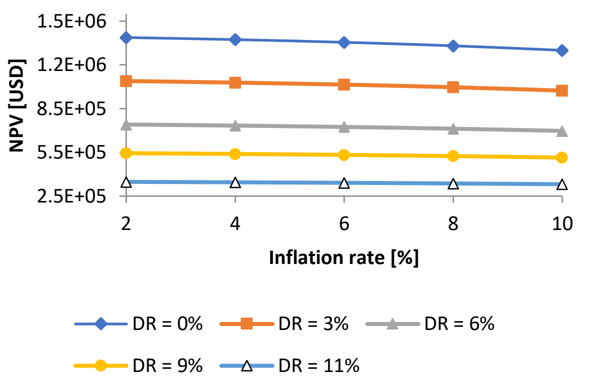

Figure 11. Relationship between the NPV of the FPV system and various discount and inflation rates for covering an area of 45%

Long-term profitability increases with coverage, as demonstrated by the Net Present Value, which rises from 712518.59 USD at 45% to 1519930.53 USD at 90% as shown in Figure 12. The annual life cycle savings (ALCS) for a year are also going with this, producing savings of 62120.62 USD at 45% coverage and 132514.47 USD at 90%. Moreover, the energy production cost remains very low and almost constant in all coverage areas, which indicates efficient generation of energy irrespective of the coverage size. Being a cost incurred in giving one unit of electricity over the life cycle of the PV system, energy production cost is quite an important metric in techno-economic analysis. In this study, energy production cost was calculated by dividing the total cost of the system by the total energy generated over the 25-year lifetime of the system. The results indicate that the energy production cost is 0.0524USD/kWh, 0.0451 USD/kWh, 0.0405 USD/kWh, and 0.0372 USD/kWh for cover areas of 45%, 60%, 75% and 90%, respectively, as shown in Figure 12. Previous studies [3,54,70] demonstrated that increasing the coverage area of FPV has led to a decrease in the cost of energy, primarily due to the higher electricity generation achieved from larger installations.

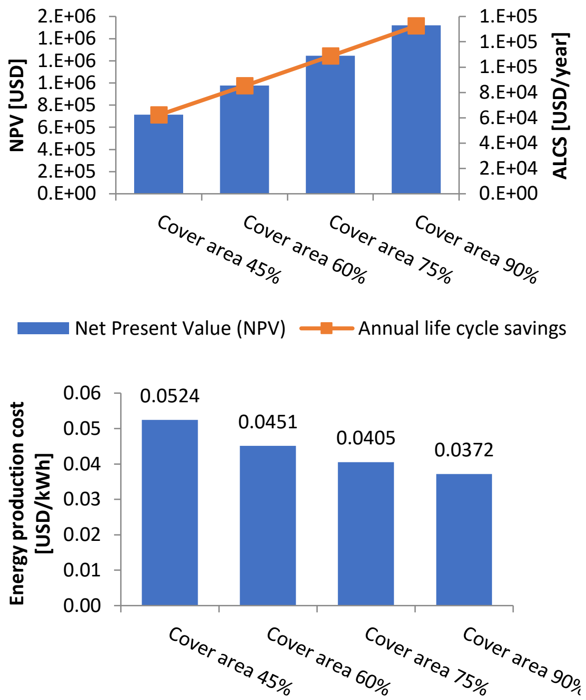

Figure 12. Simple and equity payback value for various percentages of the covered area

4. Conclusion

FPV systems provide a viable way to produce clean, renewable energy that can satisfy this growing demand and support sustainable development objectives. FPV systems for reservoirs are an emerging technology that holds significant potential for reducing evaporation. Based on the findings, it is found that evaporation is highest in July and lowest in January across all systems. The evaporation values were within the range of 2642.96-3400 mm/year. Additionally, various scenarios involving the coverage of the lake surface with the FPV system were explored. Additionally, the economic study indicates that increasing the floating PV system's coverage area significantly improves both its financial and environmental outcomes. The yearly GHG emission reductions rise from 330 to 659 tCO_2/year, yet the simple payback period remains brief and stable at roughly 3.2 years. Increased coverage indicates higher long-term profitability since it dramatically increases NPV and annual life cycle savings. The benefit-to-cost ratio is still quite favorable in all circumstances. The system's cost of energy production remains relatively low and nearly constant, ranging from 0.0175 to 0.0176 USD/kWh, even with larger coverage areas, proving its sustainability and economic effectiveness. In the end, expanding the coverage area of floating solar designs is highly beneficial for achieving sustainability and energy-generating goals. The economic and technological potential of floating solar systems over bodies of water, such as the NEU Lake, is demonstrated by this study. Future research needs to be performed to confirm the simulated results for energy generation and evaporation decrease by experimental measurements, therefore enhancing the accuracy of the results. Additionally, further research into the required infrastructure, grid compatibility, and regulatory framework for integrating FPV-generated electricity into the Northern Cyprus grid is recommended in order to assure realistic adoption.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The authors declare no potential conflict of interest.

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