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Canal-Top and Reservoir Solar Panels: An Approach to Integrate Renewable Energy and Water Conservation

Dipti Ghatak[1], Roumi Bhattacharya[2]
[1]*Civil Engineering Department, OmDayal Group of Institutions*
[2]*Civil Engineering Department, Indian Institute of Technology*

Abstract: Canals and water reservoirs are essential hydrological structures that serves purposes such as flood control, seasonal water storage for irrigation, fishing, hydropower generation, and energy storage. At present, solar photovoltaics have emerged as a key renewable energy solution and floating Photovoltaic systems (FPVs), particularly installed on canals and reservoirs, offer an integration of renewable energy with water resource management. They present a synergistic strategy to simultaneously expand renewable energy generation and conserve freshwater resources. This review explores the concept of canal-top and reservoir-based FPVs for their dual role in sustainable energy production and water conservation by reducing evaporation. Results indicate that canal-top installations can reduce evaporation by 20 – 40% depending on coverage percent and local meteorology, while reservoir coverage yields comparable reductions with additional benefits for algal bloom suppression and water quality stabilization. The multipurpose advantages of this photovoltaics are explored in this study emphasizing on the cooling effect of water surfaces towards increasing its performance efficiency and lifespan. Energy analyses show that water-adjacent cooling can increase module efficiency by 3 – 7%, translating to higher annual energy output per unit area compared with equivalent land-based arrays. The potential integration of FPV with hydropower and pumped storage systems to optimize energy-water nexus solutions is also discussed. Environmental and ecological impacts, such as habitat alteration, and aquatic ecosystem interactions, are critically assessed in this study. The research gaps in areas such as long-term performance monitoring, ecological risk assessment, and techno-economic optimization for large-scale deployment are highlighted. Key barriers of this technology include permitting complexity, initial capital intensity, mitigation strategies include modular designs, adaptive coverage ratios, and monitoring protocols to protect aquatic habitats. The review underscores canal-top and reservoir solar panels as a promising strategy to simultaneously advance renewable energy goals and water conservation imperatives.

***Keywords**: Renewable Energy; Floating Solar Photovoltaics; Evaporation; Sustainable Electricity; Canal Top Solar Plant; Solar Panels on Reservoirs.*

I. INTRODUCTION

Solar photovoltaics (SPVs) are considered one of the most decarbonized electricity generation systems, offering a promising solution to mitigate climate change and enhance energy security. By reducing greenhouse gas (GHG) emissions and providing a scalable and reliable energy source, solar PV plays a key role in addressing global sustainability challenges [1]. Globally, there has been a steady growth of SPVs, recently which has increased from 1.2 TW in 2022 to 1.6 TW in 2023 and 2.2 TW in 2024 [2]. In 2025, 597 GW of SPV was installed worldwide, in which Asia-Pacific region was responsible for over 70% with China contributing to 329 GW of new capacity [3]. SPV systems have usually been widely installed on land, either as ground mounted arrays or rooftop systems. However, SPVs are more area-intensive as compared to conventional energy sources which results in land-use conflicts particularly in regions that are densely populated and space-limited and may have larger environmental impacts including deforestation, biodiversity loss, and water depletion [4]. A study by Ritchie and Roser [5] reports that SPVs has 10-15 times higher land use per unit electricity generation than natural gas. Furthermore, these SPV systems also incur performance losses due to high operating temperatures, and dust accumulation, reducing overall energy yield [6]. This have led to the popularization of photovoltaic (FPV) systems installed over larger water bodies like lakes, canals, lagoons, coastal waters and reservoirs.

At present, there is a serious concern regarding water scarcity and depletion of freshwater resources worldwide, where evaporation losses have a major contribution. A study on evaporation data across various waterbodies in Tehran reported that cumulative evaporation between 1994 to 2023 was recorded as 2356.37 mm. This evaporation loss was supported by SPEI index confirming increased draught over the period [7]. Several studies have reported water losses due to evaporation at different regions of the world, including more than 8% of water available for irrigation in Segura Basin, as high as 40% of open reservoirs water in Australia, and more than 20% from the lakes and dams in Turkey [8]. Considering energy generation through SPVs, one major concern about implementing large scale solar energy development projects is the significant land requirement, often affecting agriculture and conservation of natural habitat. High temperatures negatively affect SPVs, particularly the crystalline silicon module inside the cells, which, after continuous use results in the loss of efficiency. To maintain a sustained and prolonged usability with high performance, it is necessary to maintain a constant and low temperature in the module [9]. As a result, alternative solutions have emerged including floating photovoltaics (FPVs), SPVs on building rooftops, partial shading on agricultures and installing solar panels on degraded lands [10]. Installing SPVs on larger waterbodies, particular canals and reservoirs, has emerged as a potential energy-water-food nexus offering benefits for both water resource conservation and renewable energy generation. This has shown positive effects for controlling evaporation, particularly in hot and dry areas [11]. Also known as floating photovoltaics (FPVs), these solar panels are installed in enclosed waterbodies such as reservoirs, lakes, ponds, and canals. These photovoltaic systems consist of a racking assembly mounted on floating plastic or high-density polyethylene platforms, known as rafts or pontoons, that are held in place by anchoring systems [12]. A lab-scale study has demonstrated that floating covers can reduce evaporation by 70–80% [13]. Compared to FPVs installed over saltwater bodies, the ones over fresh water like canals and reservoirs offers multiple advantages including less corrosion, reduced impact of tides and limited algal growth [9].

FPVs on canals and reservoirs offer multiple environmental advantages including higher efficiency due to cooling effect of the surrounding water, reduced evaporation losses, increased incident light on the solar panels due to absence of obstruction in the open surroundings, lower dust deposition and easy cleaning being in close proximity with water, and reduction in algae concentration on the water surface [12,14]. They can simultaneously increase solar output, ranging about 3 – 7% module efficiency from water cooling, with 20–40% evaporation reduction under partial coverage, making them especially attractive for water-stressed regions [15]. Additional advantages include reduced dust deposition, easier cleaning due to direct access to water, and the avoidance of land acquisition, making FPVs particularly attractive in densely populated or agriculturally intensive regions. Moreover, reduced soiling, easier cleaning logistics, and potential suppression of surface algal growth have been observed, enhancing water quality and lowering maintenance costs related to canal and reservoir water. Despite of these advantages, FPVs over canals and reservoirs are often faced with concerns regarding structural anchoring and electrical safety in water, corrosion and maintenance complexity. Potential ecological impacts include altered thermal stratification, changes in dissolved oxygen levels, and habitat disturbance, necessitating site specific environmental assessments.

The growing recognition of these technical and environmental advantages has accelerated interest in FPV systems beyond local or regional applications. The global FPV market is expanding rapidly, and its installations on reservoirs, lakes, and irrigation canals becoming increasingly common to explore the dual benefit of energy expansion and water conservation. FPVs on canals and reservoirs have long been in use in different parts of India, particularly in Gujarat, followed by followed by projects in Punjab, Karnataka, and Andhra Pradesh [16]. As of now, several countries with extensive canal systems, including the United States, China, Europe, and parts of the Middle East, have explored canal top FPVs to address land scarcity, with water conservation due to reduced evaporation, and improve the net efficiency of electricity generation through natural waterbased cooling. A study on solar panels in Spain concludes that covering only 10% of waterbodies of the country can meet 31% of the total electricity demand [17]. Large FPV systems on reservoirs have been widely installed in countries like China, Japan, South Korea, Singapore, and the United States. These FPVs demonstrate strong performance stability, reduced algae growth, and compatibility with existing hydropower infrastructure. FPVs on reservoirs also avoid the complexities associated with anchoring in flowing water, making them structurally simpler than canal top systems. At present, Indian policy push towards increasing renewable energy production with minimizing land use conflicts has further strengthens the use of FPVs. The very first canal-top solar panel was in fact installed in India, rapidly followed by other extensive projects. One of India's most notable FPV installations is on the Ramagundam reservoir in Telangana, where thousands of floating panels generate clean power while conserving water. Considering all the works done on this field, the objective of this review is to critically evaluate canal-top and reservoir-based floating photovoltaic (FPV) systems as integrated solutions for renewable energy generation and water conservation. The paper aims to synthesize current knowledge on their dual benefits of reducing evaporation losses while enhancing photovoltaic efficiency through water-surface cooling.

Furthermore, the environmental and ecological implications, and potential synergies with hydropower and pumped storage systems to strengthen the energy–water nexus is also evaluated. By comparing canal-top and reservoir applications, the study highlights operational advantages, barriers to deployment, and mitigation strategies for ecological risks. Furthermore, the paper identifies research gaps in long-term monitoring, ecological impact assessment, and optimization frameworks for large-scale adoption.

II. CONCEPT AND PRINCIPLES

Large artificial freshwater structures are highly preferred as a site for FPV installation provided there are associated roads and urban settlements aiding in easy transport, installation and management of the panels [18]. Hydraulic canals involve huge financial investment, requiring large land area, which when integrated with solar panels makes an attractive multipurpose system. The FPV built on canals has a fixed gap between the top surface of the water and PVs. Solar panels on canals can be designed either following steel-truss canal-spanning design or a suspension-cable canal-spanning design [10]. Apart from these, sometimes ground mounted SPVs are also placed alongside canals and reservoirs, which are not classified under FPVs and are thus not included in this review. Pure water, a strong absorber of light, offers maximum absorption for wavelengths between 350 and 550 mm. in case of which the absorption depends on solar wavelength. The PV technology is mainly based within this wavelength region of solar incident light. FPVs have also been reported to generate higher power because of the reflection of light from the surface of the water [19]. However, the reflectivity varies daily with the intensity of sunlight as well as with solar altitude angle. Thus, the surface of the waterbodies such as canals and reservoirs is partially covered by floating PV modules that intercept the solar wavelength to generate power and are held together by articulated couplings, also providing structural integrity [8]. The accessories associated with an FPV consist of:

1) A floating platform (raft or pontoon), generally made of medium density polyethylene (MDPE) providing buoyancy and stability
2) PV module support structure (metal frames) that supports the weight of the PV panels and transmit the wind forces across the floating platform to the anchoring system
Reinforced concrete piles that forms a rigid anchoring system to resist the lateral forces to anchor the floating platform
3) Articulated metal couplings, chains or cables linking the platforms together allowing vertical and horizontal displacements adapting to the flow profile
4) Flexible rubber or MDPE couplings or straps that allows stretching until a maximum displacement depending on the water levels
5) Polyester or nylon nautical ropes for tying the floating cover to the sides of the reservoir

In case of canal-top FPV systems, reflectors in inter array spacing increases the amount of radiation reaching the solar panels, thereby enhancing the power output. These inter-array spacing increases the shading and helps with the servicing and maintenance of the setup and should be placed with a minimum distance so as to avoid shading on the panels. Often, a minimum access way of 0.5 m is kept between the rows throughout the grid. The angle and length of the reflectors are designed for maximum reflection, which often provides sufficient inter array spacing [16]. The PV modules are installed on rafts offering sufficient buoyancy to remain in floating condition even adverse environmental conditions [9]. Designing a FPV requires considering the inclination and orientation of the modules along with dimensions of the solar panels. In general, the efficiency and performance of SPVs depend on several factors including irradiation, operating temperature, shading, orientation and tilt angle; the last two of which depends on the latitude of the site [20]. Along with these, the design characteristics of the floating deck should also be considered including the angle of elevation of the solar modules that will impact the action of wind over the surface, geometry and topography of the reservoir. Geometry and material properties of the floating platforms also play an important role in FPV design, that should be flexible enough to adapt according to the requirement at an affordable cost [8].

However, it is important to note that the structures built for FPVs must be strong enough to withstand the effects of winds, air currents, and dust storms with careful insulation of the electrical wiring to prevent corrosion and electricity losses [21]. Wind loads on the panels are dependent on the tilt angle and the angle of incidence of the wind and can directly impact power generation and CO_2 emission [19]. Lightweight materials, waterproof connectors and sensor-based remote monitoring systems are now being used for optimized design of FPVs [22]. Another benefit of installing FPVs on reservoirs is the additional power generation to increase the net electricity production of associated hydropower plants [23]. The location of FPV on reservoirs with hydropower stations nearby enhances grid stability and reduces transmission losses by generating power close to demand centres. The primary objective of installing FPVs on canals and reservoirs is to improve the water-energy balance.

III. PERFORMANCE AND EFFICIENCY

A. *Performance of Canal-top and reservoir-based FPVs*

A global analysis estimates that FPVs installed on suitable reservoirs worldwide could generate up to 9,434 TWh annually, representing a significant share of global electricity demand [15]. This large-scale potential is complemented by performance data from operational FPVs built on reservoirs. The performance analysis of an FPV system installed on the Mettur Dam reservoir in India demonstrated stable generation and operational reliability, confirming the feasibility of integrating FPVs with existing hydropower infrastructure [24]. Solar panels next to large waterbodies show increased performance efficiency due to the cooling effect of water. Apart from reduced evaporation losses, FPVs have been reported to mitigate weed growth [10]. Cadmium telluride (CdTe) SPV panels have been shown to improve panel efficiency because of the cooler surrounding microclimate [25]. FPVs on canals are thus associated with increased electricity generation, and non-interruption with natural land area, thereby resulting in financial advantages [26]. Canal-top FPVs, while more spatially constrained, also contribute meaningfully to electricity production. Their linear deployment along canal corridors allows energy generation without land acquisition, making them particularly valuable in densely populated or agriculturally intensive regions. Although there is no data, it is hypothesized that reservoir-based FPVs will generally outperform canal-top systems in terms of scalability and cooling efficiency. Their large surface areas allow deployment of multi-megawatt arrays, while canal-top systems are limited by canal width and structural constraints. However, canal-top FPVs offer unique advantages of eliminating land use, reducing canal evaporation, and can be integrated with irrigation and water-conveyance infrastructure. Reservoir-based FPVs benefit from stable water bodies, whereas canal-top systems must account for flow dynamics and structural loading. Despite these challenges, both systems demonstrate strong performance potential when designed with site-specific considerations.

B. *Comparison with Ground-mounted solar panels*

Studies comparing ground-mounted solar panels with FPVs highlight that the latter can outperform conventional PVs due to reduced thermal stress and improved irradiance capture [6]. Studies show around 3 – 7% improvement in efficiency compared to ground-mounted PV due to passive cooling from water surfaces, translating to translates into higher annual energy yield per unit area [27]. Quantitative performance evaluations show that FPVs generate 5–15% more annual energy than ground-mounted SPVs, depending on water body characteristics and local climate. A comparative study reported that FPVs produced higher specific yield (kWh/kWp) than fixed ground-mounted systems [28]. Reservoir-based FPVs often exhibit even greater gains because of direct water adjacency and reduced heat accumulation, making them particularly effective in hot climates where land-based SPV suffers from thermal degradation. The cooling effect of surrounding water in case of FPVs results in greater electricity output as compared to ground mounted systems [29]. One major limitation for ground mounted SPVs is the necessity of open land stretch, which might limit its application in remote areas with fewer inhabitations. Shifting the SPVs in remote areas require additional infrastructure costs and loses [30]. Compared to ground-mounted SPVs, FPVs over canals are more compatible with distributed generation and electricity grid, and generation points can be close to the land targeted for use [10]. This lessens the distance and associated costs of transmission and distribution lines.

IV. WATER RESOURCE ENGINEERING BENEFITS

A. *Enhanced Water Conservation*

Large water bodies in arid and semi-arid regions experience substantial evaporation losses, often exceeding several thousand m^3 annually. Given the challenges faced worldwide related to water conservation and management, particularly in dry areas prone to draught, FPVs are also seen as an effective way for controlling evaporation from waterbodies with large surface area [31]. By blocking direct solar radiation, FPVs on canals and reservoirs decrease the energy available for evaporation. Additionally, the panels and floating platforms reduces wind-driven turbulence at the water surface, further suppressing evaporative flux. A review by Mane and Punyarthi [32] highlights that reservoirs in India encounters vast quantities of water loss annually due to direct solar exposure, making evaporation control a national priority. Literature consistently shows that FPVs can mitigate these losses by providing shading, reducing wind-driven evaporation, and stabilizing water temperature profiles. Studies estimate that reservoir FPVs can reduce evaporation by 30 – 60%, depending on coverage percentage, climatic conditions, and reservoir geometry. This reduction is particularly valuable in regions facing seasonal droughts, where stored water is essential for irrigation, drinking supply, and hydropower operations. Even partial coverage can meaningfully reduce surface heat flux, thereby lowering evaporation rates. It is estimated that covering only 25% of the total surface area of reservoirs alone can host 5700 GW of FPV power plants generating around 8200 TWh of electricity [33]. This can lead to conservation of 74 billion m^3 of water from evaporation, thereby addressing both hydropower production, water conservation and increased water availability. Another study by Hashemi and Shahraki [34] reported a reduction of 175 million m^3 of evaporation loss by FPV along with achieving strong financial benefits. FPV on a Portuguese reservoir with 6 – 10% of surface area reduced evaporation by 20 – 30% [9]. Engineering analyses also show that full-width canal coverage can reduce evaporation by up to 70% under peak summer conditions. Beyond evaporation control, these systems also reduce algal growth by limiting sunlight penetration, thereby improving water quality and reducing maintenance requirements for irrigation infrastructure. This synergy between energy generation and water management underscores the strategic value of canal-top and reservoir-based FPVs in water-stressed regions.

B. Greenhouse-gas emissions

Apart from conserving water losses, SPVs on waterbodies have been effective in reducing greenhouse gas (GHG) emissions, thereby having an impact on climate change [35]. Both canal-top and reservoir-based FPVs not only contribute to climate mitigation by reducing reliance on fossil fuels, but also directly lowers greenhouse gas emissions. They support national commitments to decarbonization and global frameworks including the Paris Agreement. Additionally, these systems minimize ecological disturbance relative to land-based SPVs, which often require vegetation clearing, soil compaction, and habitat alteration. By contrast, FPVs preserve terrestrial biodiversity and reduce the environmental footprint of renewable energy expansion. An extensive study conducted around Tehran showed that at 20% coverage, CO_2 reductions amounted in the range of 63,738 tonnes/yr and 350,455 tonnes/yr [7]. In India, a 20 MW canal-top project by the Ministry of New & Renewable Energy (MNRE), Govt. of India, have reduced CO_2 emissions by 7500 tonnes/yr along with saving 100 acres of land [19]. Installing FPVs on reservoirs restrict methane and CO_2 emissions from organic matter decomposition form hydropower reservoirs thereby reducing the effective carbon intensity of electricity generation [36]. Limited algal growth and lower temperatures further decrease biogenic methane production in stagnant waterbodies. Similar to FPVs installed on reservoirs, canal-top solar panels also have the potential to mitigate GHG emissions and carbon footprint by similar approach, however, studies regarding that are quite limited. Furthermore, GHG emissions associated with land clearing for ground mounted solar panels are also effectively avoided in FPVs. However, extensive studies related to quantification of GHG emissions and life cycle assessments for canal-top and reservoir based solar panels are essential to completely characterize the climate mitigation potential of FPVs.

C. Integration with irrigation systems and hydropower

Canal-top and reservoir-based FPVs offer unique solution to co-optimize renewable energy generation, water conveyance efficiency, and hydropower operations. On the global scale, hydropower plants are one of the largest sources of electricity generation although they are often subjected to multiple challenges including covering large surfaces, GHG (CO_2 and CH_4) emissions from the associated water reservoirs and lower albedo of water reservoir compared to soils [23]. Reservoir-based FPVs offer even greater potential when integrated with hydropower plants. Literature increasingly highlights these systems as multipurpose infrastructure capable of supporting irrigation pumping, stabilizing hydropower output, and improving overall water-resource management. The existing power lines for previously built hydropower plants and capacity to store the excess energy from FPV also are the advantages offered by integrating FPVs at hydropower generating reservoirs. The reduction in evaporation losses by canal-top and reservoir-based FPVs especially beneficial in irrigation networks where water must travel long distances before reaching agricultural fields. Reduced evaporation translates directly into higher conveyance efficiency, allowing more water to reach end-users without additional pumping or storage infrastructure. For example, canal-top FPV projects in Gujarat, India, have demonstrated measurable reductions in water loss along irrigation canals while simultaneously generating electricity for nearby villages and pumping stations. An integrated approach for hydropower plants with FPV, covering less than 15% of reservoir surface produced 50% of hydropower output [37]. Hydropower plants can also provide ancillary service as virtual batteries for reservoir-based FPVs, and with 25% surface coverage, power generation from solar panels can significantly outgrow that from hydropower [23]. Hydropower reservoirs provide large, stable water surfaces suitable for FPV installation, and the location of solar and hydropower enables hybrid energy generation. This hybridization addresses the challenge faced due to intermittency of solar power by leveraging flexibility of hydropower to balance fluctuations in solar output. When solar output is high, hydropower plants can conserve water by reducing turbine discharge, effectively storing energy in the form of retained water. Conversely, during low solar periods, hydropower can compensate for reduced PV generation, ensuring stable power supply. This synergy is particularly valuable in regions with seasonal hydropower variability.

For example, during dry seasons when reservoir levels drop, FPVs continue to generate electricity, reducing pressure on hydropower operations. Conversely, during monsoon seasons, hydropower output increases while FPVs contribute additional generation, maximizing total energy production. However, the most prominent advantage of combining FPV on reservoirs for hydropower is in the case of pumped storage power systems. For a pumped storage with 1 GW capacity and a reservoir-based FPV plant with 2 GW, benefits regarding reduced energy disbalance, higher electricity generation and reduced annual water evaporation by 19 million m^3 has been observed [38].

V. ENVIRONMENTAL AND ECOLOGICAL IMPACTS

Despite of these advantages, studies have demonstrated the effects of water surface coverage on aquatic ecosystems. FPVs are proven to impact penetration of light, surface temperature, and gas exchange in the waterbodies, which is also influenced by the surface coverage percentage [14]. Most studies in this regard, reported a decreased water surface temperature with reduced evaporation after installation of FPVs [39]. It is, thus, essential to select the coverage of SPV considering the ecological balance of the aquatic ecosystem. Reservoir FPVs with coverage >50% may achieve greater evaporation reduction but may cause habitat disruption [15]. Several studies have strongly reported the reduction of chlorophyll-a and phytoplankton growth in the water bodies after the installation of FPVs [12]. However, Exley et al. [40] observed a slight increase in chlorophyll-a with 30% coverage at slower-flowing areas of a reservoir. A stark decrease in primary producers has been observed in aquatic ecosystems with more than 20% FPV coverage [14]. Several other factors such as the flowing speed of water below the panels and water temperature needs to be considered in analysing the difference [40]. FPV can reduce the growth rate of cultured algae growing under semi-transparent panels with photoinhibition increasing their photosynthetic activities. A study by Yamamichi et al. [41] reported that decreased light reduction can increase phytoplankton by supressing macrophytes and reducing the competition between them for nutrients. Apart from these, construction activities including structural debris, installation noise, and maintenance activities may interfere with the aquatic life [19].

Apart from these, FPVs can also be paired with aquaculture for potential benefit across water–energy–food nexus [4]. As of now, there is no consistent data regarding the effect of FPVs on fish and crustacean health although both morphology and physiology of these animals have been noted to be influenced by solar panels on waterbodies. The bacterial community inhabiting under the panels have shown to aid the growth of shrimps and restrict algal cultures [42]. Both body weight and size of fishes have been reported to increase with FPV installed waterbodies although there is a discrepancy between the effect on production and growth rate [14]. Similar to fishes, body size of both crab and shrimp has been observed to increase along with overall production rate [43]. However, a negative effect has been observed on fish feeding habits with reduced heat stress at high temperatures and shortened spawning period for fishes due to temperature variation. For crabs cultivated under SPV panels, a change in tissue colour, muscles and organs have been noted [44].

VI. CASE STUDIES

Countries with particularly shortage of water and conventional electricity source is diverting their attention towards FPVs with multipurpose utilization of canals and reservoirs. The first canal-top FPV in India was installed in 2012 on the network of Narmada canals that targeted 1 MW electricity over a length of 750 m [16]. On Vadodara Branch Canal, a 3.6 km long 10MW PV plant was built which is reported to annually conserve 95.54 million litres by reducing evaporation losses [25]. FPV system covering 30% of the surface area of Vaigai Reservoir in India annually saves 42,731.56 m^3 of water, generating 1.9 GWh electricity and reducing carbon emissions by 44,734.62 tonnes [45]. A study covering the FPVs on artificial reservoirs in India has shown to yield 160 GWh electricity, with a decrease in carbon emission by 3.3 million tonnes annually, saving 1.4 million m^3 of water per day [24].Considering the gap between supply and demand through conventional electricity generation methods, particularly in rural India, the dry weather conditions of Western India makes the installation of FPVs over canals and reservoirs an attractive choice for water conservation.

FPVs have now been installed worldwide over reservoirs and canals. Research on the solar panels installed in reservoirs in Brazil showed that FPVs on Passaúna Reservoir in southeastern Brazil can reduce evaporation by 60.2% over a surface area of 1265.14 m^2 [46]. Simulations in the study indicated that with an electricity production capacity of 5 MW/s. and 100% coverage of the reservoir surface, there can be a potential saving of 2.69 million m^3 of water annually. Hydropower reservoirs in the European Union have a potential to produce 42.31 TWh electricity with reduction in water loss by 557 million m^3 [37]. FPVs on Tajo-Segura canal in Spain has reduced annual PV losses by 6.57 GWh saving 226 k € [47].

Simulation studies on FPVs on an 8 km long irrigation canal at Minab city in Tehran shows that a coverage of 60% of the canal length, 5 MW electricity can be generated along with saving 6000 m^3 of water from evaporation [11]. Another simulation based on FPVs on a 6350 km canal in California showed a reduction in average annual evaporation by 39±13 thousand m^3 of water /km, Furthermore, the net value of canal top solar was evaluated to be 20-50% more than that of overground solar [10]. In Afghanistan's Qush-Tepa irrigation canal FPVs installed with an annual electricity production capacity of 1,465 GWh reduces evaporation loss by 20% saving approximately 445 million m^3 of water [21].

VII. CHALLENGES AND FUTURE DIRECTIONS

Although widely implemented, solar panels, including FPVs, are associated with high initial investment costs, and disposal and recycling of FPV materials [33]. A canal-top PV project at central Arizona on a 336-mile-long canal was predicted to cost 24% higher than ground-mounted solar panels near the canal [19]. As of now, several countries are not equipped with integrating FPVs into existing grid infrastructures at a reasonable cost. Corrosion of the materials from long-term exposure to water should be taken into consideration [9]. Problems associate with dust are also prominent due to the installation of these FVPs are mainly in the hot and dry regions. Thus, regular cleaning is essential, and precautions are to be taken to not mix the cleaning water with the canal-top or reservoir water to reduce its adverse impact on the vulnerable part of the native ecosystem. Concern arises from the leachate from FPVs contaminating waterbodies, particularly in case of canals and reservoirs, that are directly used as water sources for drinking. These leachates also affect the aquatic ecosystem, and it largely depends on the panel material. Aluminium and zinc leaching has been detected from several FPV components made of polyethylene only after 2 weeks of installation [48]. Crystalline silicon, one of the widely used materials for SPVs, cause heavy metal leaching [49] resulting in deformities and lower survival rates among Daphnia magna and toxicities in Danio rerio [14]. FPV setups have also been noted to act as a substrate for different microbial species that attracts larger organisms, often leading to the growth of fouling fauna attached to these setups. These organisms belong to several different groups including Annelida, Arthropoda, Bryozoa, Chlorophyta, Chordata, Cnidaria, Entoprocta, Nemertea, Ochrophyta, Platyhelminthes and Rhodophyta. Around 11% of these are found to be non-native, negatively impacting the native aquatic ecosystem [50].

Most of the research conducted on ecological assessment of FPVs are short term and does not consider the factors like thermal stratification in the waterbody, the water quality, dissolved oxygen variation, and nutrient recycling over seasons or multiple years and nutrient recycling [39]. One of the fundamental aspect of discrepancies in data comparison in this regard is the wide variation of reported outcomes which stems from differences in climatic conditions across regions, types and scales of reservoirs and canals, and evaporation measurement approaches [7].

Studies often are based on different performance assumptions, bringing uncertainty in data comparison and analysis. This makes the study of FPVs highly region-specific and context dependent. There is a prominent gap in research regarding the impact of FPVs on biochemical and ecological processes in the native aquatic ecosystem along with the interactions involving organisms at different trophic levels. This results in ineffective understanding of the biodiversity and conservation of the ecosystem. Furthermore, detailed studies regarding economic, environmental and social impact along these large waterbodies is still an area that requires research to completely understand the large-scale benefits of installing FPVs beyond water conservation. As of now, there are no standard ecological monitoring frameworks which can be investigated through sensor deployment and integration of long-term data. Considering the effect of canal-top and reservoir-based FPVs on irrigation, the actual data regarding the effect of reduced evaporation on irrigation along with its downstream effects on cropping intensity, irrigation scheduling, and drought resilience is scarce [8]. Despite of the extensive research and development in this area, policy support is essential to efficiently implement the technology with reduced costs and ensure its integration into mainstream energy markets. The quantification of FPVs and its impact with integration of irrigation, hydropower and aquaculture is an area which is not thoroughly investigated. FPVs offer a promising potential to be integrated with hydroelectricity in reservoirs that already is a part of the energy grid. Furthermore, intensive studies exploring the effects of FPVs on ecological interactions should be undertaken as a step to preserve the native and commercial biodiversity of canals and reservoirs. It has been observed that invasive species might inhabit along the FPV structures although the effect of FPV on dispersal of these species is yet to be investigated. The effect of FPVs on different canal conditions including water flow, engineered banks, sediment transport and impact on canal-dependent aquatic life is an area that remains largely unexplored.

VIII. CONCLUSIONS

Due to the constant increasing population globally, challenges related to demand for water, land, energy and food has been prominent over the past few decades. In the context of renewable or green energy, installing SPVs directly aligns with the 7th Sustainable Development Goal (SDG) of United Nation, by increasing access to affordable, reliable and sustainable energy. There is a steep increase in solar energy demand which can be efficiently addressed by installing solar panels in waterbodies like canals and reservoirs. The integration of SPV systems with existing water infrastructure such as canal-top and reservoirbased installations presents a transformative pathway for addressing energy demands along with water resource challenges. This review demonstrates that canal-top and reservoir-based solar technologies are not just alternatives to conventional groundmounted PV systems, rather, they can reshape the renewable energy landscape. A major advantage of these FPVs is to utilize pre-existing linear water infrastructure without requiring additional land acquisition. In regions where land availability is constrained and land-use conflicts are prominent; these generate clean electricity while preserving native ecosystems and agricultural zones. Comparison and analysis of evaporation rates, insolation and associated water cost savings is challenging in most cases due to the diverse climatic and environmental conditions along these waterbodies. This synergy between energy generation and water conservation positions canal-top and reservoir-based FPVs as a high-impact solution for countries where extensive canal networks intersect with rising energy demand and water stress. Moreover, these FPV systems can be integrated with existing hydropower infrastructure, enabling hybrid generation models that optimize grid stability, reduce intermittency, and maximize the use of transmission assets. Economically, they offer long-term benefits through improved energy generation efficiency, reduced water loss, and optimized land use. While initial capital costs may be higher, lifecycle analyses indicate that the combined water and energy savings can offset these expenses. Often, adaptive coverage strategies like modular arrays, and partial shading are recommended to balance energy output, water savings, and ecosystem health. FPVs on canals and reservoirs also aligns with global decarbonization goals, as it is a scalable technology capable of contributing meaningfully to national renewable energy.

IX. ACKNOWLEDGMENT

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