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Floating Solar Plants and Relevant Environmental, Health, and Safety Challenges

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Abstract: An Environmental Impact Assessment (EIA) was conducted for 2 × 150 MW Floating Photovoltaic (FPV) plants, based on the World Bank's new Environmental and Social Framework (ESF). The project was the first of its kind financed by the World Bank in Pakistan and was geared towards renewable energy development in the country. Key components of the project included the installation of high-density polyethylene floats, Photovoltaic (PV) panels, underwater transmission cables to floating or shoreline inverters and transformers, and overhead transmission lines to existing or new substations. The EIA was commissioned to identify all environmental, health, and safety challenges associated with the construction and operation of the FPV plants. A risk screening criterion based on the World Bank ESF was employed to identify these challenges, while a mitigation hierarchy and hierarchy of control were used in providing measures to address these challenges. The environmental challenges identified were pollution of surface water and degradation of aquatic habitat from bird droppings on the floating panels; changes to the thermal structure and evaporation rate of the water body as a result of decreased sunlight access; direct impacts of shading on fish and aquatic algae; impacts on migratory birds and their habitats; and impacts on fish movements due to the anchoring and cabling of the floats. Likewise, the project-specific occupational health and safety challenges identified were the risk of falling and drowning in the water during the installation and maintenance of the panels over the water. Mitigation measures were provided for the identified challenges. In conclusion, the construction and operation of FPV plants have environmental, health, and safety issues. It is therefore recommended that the mitigation measures provided should be incorporated into the earlier stages of the design and operation of future similar FPV plants around the world.

Key words: Photovoltaic, floating solar, impacts, occupational health and safety, mitigation hierarchy, hierarchy of control.

1. Introduction

With the increasing energy demand, fast depletion of expensive fossil fuels, and the threat of climate change, alternative energy generation technologies are becoming a necessity. Floating Solar Photovoltaic is a technology being used by many countries to combat this issue [1]. Compared to traditional, land-based PV plants, there are fewer FPVs around the world. The first floating PV system was built in 2007 in Aichi, Japan, followed by several other countries, including France, Italy, the Republic of Korea, Spain, and the United States, all of which have tested small-scale systems for research and demonstration purposes [2]. The first commercial installation was a 175 kWp system built at the Far Niente Winery in California in 2008. The system was floated atop a water reservoir to avoid occupying land better used for growing grapes. Medium-to-large floating installations (larger than 1 MWp) began to emerge in 2013. The majority of the FPV plants are currently located in North America, Europe, and East and Southeast Asia [1]. After an initial wave of deployment concentrated in Japan, Korea, and the United States, the floating solar market spread to China (now the largest player), Australia, Brazil, Canada, France, India, Indonesia, Israel, Italy, Malaysia, Maldives, the Netherlands, Norway, Panama, Portugal, Singapore, Spain, Sweden, Sri Lanka, Switzerland, Taiwan, Thailand, Tunisia, Turkey, the United Kingdom, and Vietnam. Projects are under

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consideration or development in Afghanistan, Azerbaijan, Colombia, Ghana, and the Kyrgyz Republic, as well as other countries. FPV is a relatively new form of renewable energy, especially, in South Asia, with the majority of the existing ones located in India [2, 3]. South and East Asian countries are some of the regions in the world that will benefit the most from this technology. FPV technology will not only provide renewable energy for these regions with limited stable energy supply, but it will also help to decrease the water evaporation rate of the water body [1, 4, 5]. This is especially beneficial for South Asian countries as many of them have limited sources of potable water [6]. The limited number of freshwater bodies and the excessive water evaporation from reservoirs during high temperatures is a big challenge in this region. Therefore, with the ability to decrease water evaporation, an FPV plant will provide a renewable source of energy and also help conserve water.

There are various other benefits of FPV systems compared to traditional PV systems. The main advantage that FPV has over a traditional land-based PV system is the land requirement [6, 7]. The land is a valuable and limited commodity. Land-based PV systems need to compete with other land uses. In South and East Asian countries unutilized land is scarce. PV systems are difficult to build. Another advantage that FPV systems have over traditional PV systems is their efficiency as solar panels become less efficient once they overheat [1, 8, 9]. The land-based systems require cooling systems to ensure the panels continue to function. However, for FPV, the natural cooling from the water increases the energy yield by up to 10% [9]. Similarly, in the study conducted by Choi [10], analysis of an FPV system installed in Korea showed that FPV systems have a lower module temperature compared to land-based PV systems and this leads to an 11% efficiency increase in power generation. Other benefits of FPV include the decrease in algae formation in the water bodies due to the reduced rate of photosynthesis in the water [2].

An FPV system may consist of the following structures (Fig. 1): Floats/Pontoons System: a floating body, such as a pontoon, is used for supporting the heavy load that floats on water. Pontoons have high buoyancy and are designed to hold several panels; Mooring System: these are permanent structures to which a floating structure is secured. A mooring system can either be on-shore or have an anchor mooring line that fixes the floating structure to a fixed point on the bottom of the waterbody; PV modules: this system consists of multiple solar modules, a solar inverter, wires, and sometimes batteries. A single solar module can only produce a limited amount of power so the greater the number of panels, the greater the generation potential; Cable system: this consists of a select number of cables whose purpose is to transfer the energy generated from the panels to a transformer and transmission lines on-land.

The Water and Power Development Authority (WAPDA) of Pakistan, is considering the installation of 2 × 150 MW FPV systems at the Ghazi Barrage Headpond and Ghazi Barotha Forebays, as a hybrid scheme with the already established hydropower facilities. The Project will be partially funded by the World Bank. This project is the first of its kind in Pakistan and will join one of the large FPV systems in Asia. The Project has three components, (a) floating solar subprojects and their short connections to existing transmission infrastructures, (b) project management, and technical assistance, and (c) environmental and social management, to meet the project development objectives.

The impacts and risks outlined in this paper are from the Independent Environmental and Social Impact Assessment (ESIA) of the Project. The paper also presents an assessment of impact and risk based on the World Bank's Environmental and Social Framework (ESF) and Environmental and Social (ESS) guidelines, and standard mitigation and preventive measures using the mitigation hierarchy of ESS1, which can be utilized in utility-scale FPV projects. This paper will guide

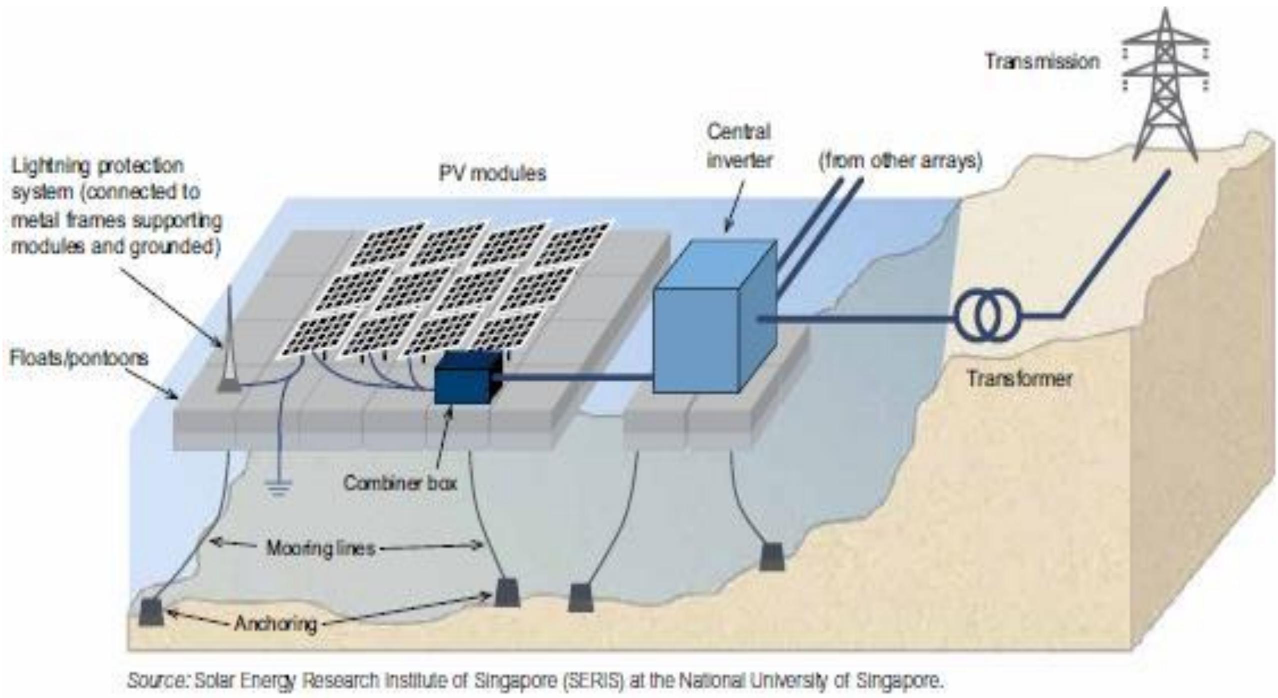

Fig. 1 Schematic representation of a typical large-scale FPV system with its key components.

other developers to identify the impacts and risks, quantify them, and accordingly develop action plans to address them.

2. Methodology

2.1 Project Locations

The Project comprises two sites, each of which is a body of water. These sites are Ghazi Barrage Headpond and Ghazi Barotha Forebay (Fig. 2). Floating arrays of photovoltaic panels will be placed on each body of water. Key components of this installation will be high-density polyethylene floats, PV panels, underwater transmission cables to floating or shoreline inverters, transformers, and overhead transmission lines to existing or new substations. The floats will be tethered to the bottom of the water body using a cable and concrete block. A pontoon will be created to facilitate boat access to the floating units. During the construction phase, a 2-ha laydown and assembly area and connecting access road will be required near each body of water for the assembly of the panels on floating units before they are floated into place on the water. All worker accommodation will be in existing facilities away from the project site. Suitable locations and right of way for the interconnection infrastructure (switchgear, transformers, and transmission line) will require land.

The summary of the anticipated installed capacity, area of coverage of the waterbody, and the nearest settlements with distance from the FPV sites are presented in Table 1.

2.2 Area of Influence (AoI)

The AoI covers land and water, directly or indirectly impacted by the Project. This includes communities along the access road, WAPDA colonies, and areas adjacent to the AoI that may experience impacts during the construction or operation of the Project, despite being located outside of the area in which the Project will be located (e.g., traffic safety risk, visual or noise impacts).

Table 2 presents three distinct areas of influence which are considered in the baseline and impact assessment. All areas include a core and buffer area, the extent of the buffer is determined by the reach of impacts such as noise and air pollution.

The background information, which was used to determine the risks for the risk analysis, was obtained from project design documents, related agencies' websites, literature reviews, consultations, and meetings with various stakeholders. Information on the baseline was collected through primary surveys and secondary data for the physical, biological, and socioeconomic environment.

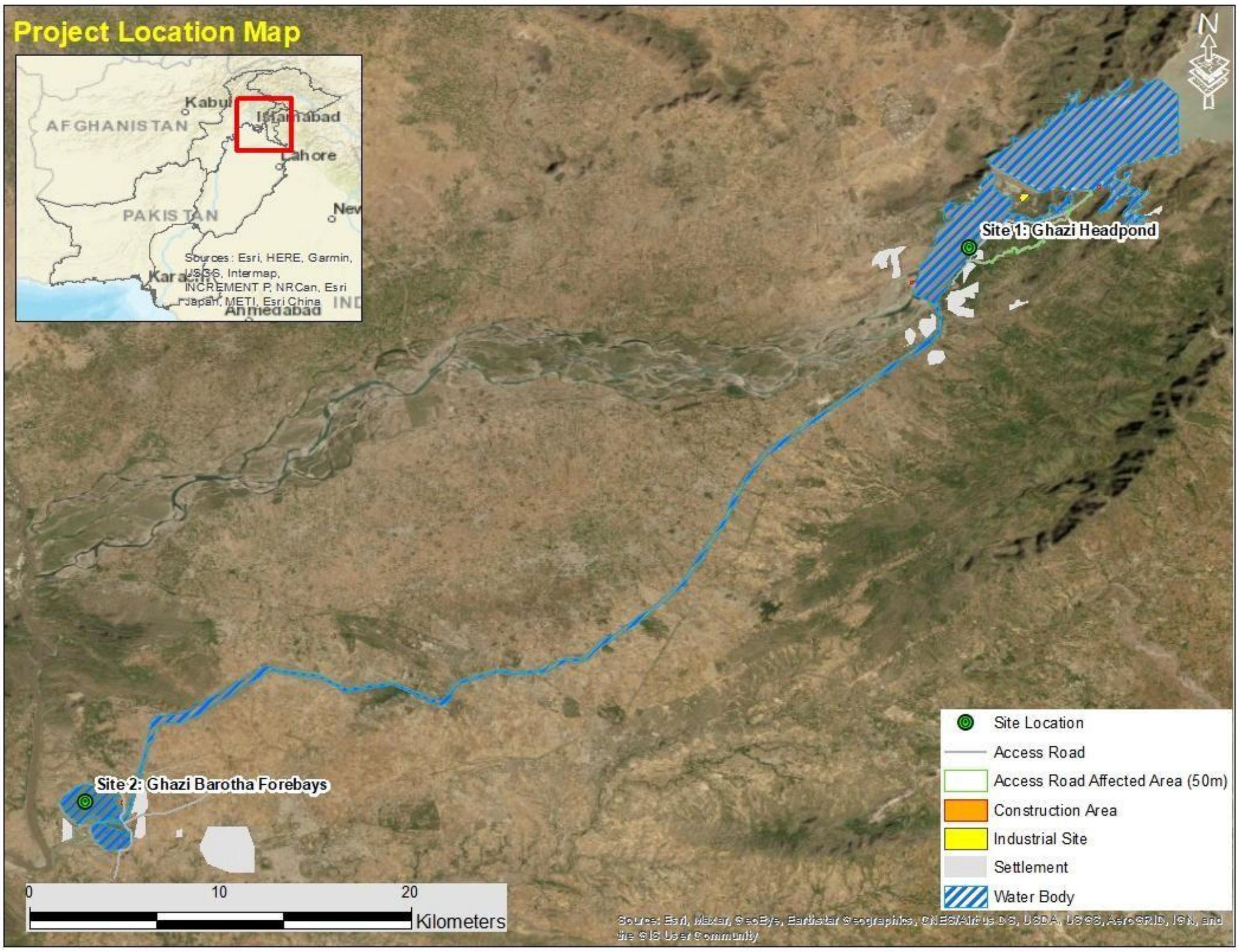

Fig. 2 Project locations in the two waterbodies.

Table 1 Summary of the description of the project sites.

Name of site	Capacity (MW)	Area of water (ha)	Area of panel (ha)	Coverage	Nearest settlement to the construction site
Site 1: Ghazi Barrage Headpond	150	800	165	21%	Galla (1 km north)
Site 2: Ghazi Barotha Forebay	150	400	165	41%	Barotha (1 km east) Dhair, Jabba (1 km east)

Table 2 Project areas of influence.

Areas of influence	Description	Buffer (m)
Construction/laydown area	Approximately 1 ha site for materials laydown and assembly of the FPV units and 1 ha for access road connecting the laydown area. A 500 m buffer around each site to account for potential noise, dust, and waste.	500
Water bodies	Area covered by the water bodies at the full supply level. Plus 100 m buffer on the land around each to account for potential land-water interaction.	100
Access roads	Roads that will experience an increase in traffic during the project. A 50 m buffer on each side of the roads to account for potential noise, dust, and safety risk.	50

Table 3 Risk screening criteria.

Risk Category	Screening Criteria
High	The resource/receptor would likely experience a large magnitude impact that would last for a long time, extend over a large area, exceed national/international standards, endanger public health and safety, threaten a species or habitat of national or international significance, and/or exceed a community's resilience and ability to adapt to change. The Project may have difficulty in complying with the applicable ESF requirement, and significant mitigation would likely be required.
Substantial	The resource/receptor would experience a clearly evident change from baseline conditions and would approach but not exceed applicable standards. The Project would comply with the applicable ESF requirement, but mitigation would be required.
Moderate	The resource/receptor would experience a noticeable effect, but the magnitude of the impact is sufficiently small (with or without mitigation) that the overall effect would remain well within applicable standards. The Project would comply with the applicable ESF requirement, but mitigation may be required.
Low	The resource/receptor will either not be affected or the likely effect would be imperceptible or indistinguishable from natural background variation. The Project would comply with the applicable ESF requirement and mitigation would typically not be required.

2.3 Risk Screening

Using the results from the baseline and stakeholder information gathering, environmental and social impacts and risks were conducted. Risk screening criteria based on World Bank ESF were employed as shown in Table 3. Please note that only the environmental and social related risks that were determined to be substantial and higher are presented in this paper.

2.4 Mitigation Hierarchy

The mitigation hierarchy avoid, minimize, mitigate/control, compensate/offset was used to provide mitigation measures for the evaluated environmental, health, and safety risks associated with the FPV plants. Impacts and risks assessed as moderate and low were not addressed as they could be mitigated through the Environment Code of Practices (ECPs). The residual risks, which are risks after mitigation, were provided for each of the impacts, with rationale provided for residual risks of moderate ranking and higher.

3. Results and Discussion

3.1 Environmental, Health, and Safety Risks

Based on the risk screening that was carried out on the 2 × 150 MW Floating Solar Plants, the following environmental, health, and safety risks were identified

3.1.1 Risk of Falling in the Water and Drowning During Installation of Panels over Water

The installation of panels on the surface of the water will require many workers to be working on floating platforms, rafts, and pontoons. If the workers are not trained and skilled swimmers, there is a chance of drowning, if they fall into the water. During the construction stage, this risk is rated substantial, while it is rated low during the operation stage since the operation crew will be exposed to the floating panel less frequently and they will be highly trained in maintenance work.

3.1.2 Pollution of Surface Water Due to the Cleaning of Accumulated Bird Droppings

At the operation stage, panels may attract birds, and their droppings might require periodic cleaning and can pollute the water. Also, bird droppings on the panel by the migratory birds can reduce the surface area of the solar panels thus reducing their generation efficiency. Therefore, it is crucial to implement barriers or a similar approach to prevent waste material or debris from accumulating and covering the solar panels. The risk of the pollution of surface water from bird droppings is rated low during construction, and substantial during operation of the FPV plant. Labile nutrients in feces dissolve rapidly in water, increasing the nutrient content. Fecal fragments can persist in water for over 21 days, acting as a nutrient source. Microbes in the water and sediment microcosms were disturbed by 5.0 g of feces.

Table 4 Environmental, health, and safety risks and impacts associated with the 2 × 150 MW floating solar plants

Environmental, Health and Safety Risks, and Impacts	Risk Ratings before Mitigation and Control	
	Construction Stage	Operation Stage
Risk of falling in the water and drowning during installation of panels over water	Substantial	Low
Pollution of surface water due to the cleaning of accumulated bird droppings	Low	Substantial (Site 2)
Changes to water quality, thermal structure, and evaporation rate as a result of shading	Low	Substantial (Site 2)
Impacts on fish from shading and anchoring and cabling	Moderate	Substantial (Site 2)
Impact on migratory birds and their habitats	Moderate	Substantial (Site 2)
Aquatic habitat degradation as a result of altered quantity of bird droppings	Low	Substantial (Site 2) Low (Site 1)

3.1.3 Changes to Water Quality, Thermal Structure, and Evaporation Rate as a Result of Shading

Covering water bodies with FPV installations can increase stratification and limit water mixing below and in the vicinity of the panel installation. This can result in lower dissolved oxygen levels and lower temperatures at depth. The magnitude of increased stratification is site-specific and dependent upon the scale of the project and the water retention time. If the ratio is high, the FPV array will block the influx of solar radiation at the water's surface resulting in an impact on water quality if the retention time is also high. If stratification occurs and a layer of low dissolved oxygen develops at depth, there could be anaerobic decomposition of organic materials and metals from bottom sediments. It is estimated that 165 ha (21%) in the Headpond and 165 ha (41%) in the Forebay waterbodies will be shaded by the panels, respectively. The presence of PV on the water surface may disrupt the process of top-layer wind mixing, which has an important role in the nutrient dynamics of water bodies and the transfer of heating/cooling. Coverage of the water surface can lead to reduced rates of water evaporation, further changing the aquatic environment. The risk rating for this parameter is low during construction, and substantial during operation of the FPV plant.

In a study by Exley et al. [5], the authors found that it is possible to have an annual evaporation loss reduction of 1,395 cubic meters per MWp when an FPV plant covers 25% of the total submergence area (6,052 ha). This study was conducted at Rajghat dam located in southern Uttar Pradesh, India. The findings about this impact are also consistent with those of Sahu et al. [9]. In their research, they found that FPV plants have the potential to impact water quality negatively. In the study by de Lima et al. [11], the authors found the overall differences in the measured key water quality parameters below the solar panels compared to the reference locations were little. The maximum detected temperature at the reference location reached 26.6 °C while the maximum under the solar park was 25.3 °C. The minimum temperatures recorded were 6.1 °C at the reference location and 6.3 °C under the floating solar park. Overall, under the solar panels, the temperature was lower at the upper layers of the water compared to the reference location. The authors also reported a decrease in temperature fluctuations under the solar panels as they observed a delay in the heating of the water under the solar park and a reduction in peak values. Similar effects were observed regarding cooling effects. These effects are likely the result of the shading effect, the sheltering effect from wind and currents, or the reduced impact of raindrops on the water surface but further studies are required for conclusive results. The authors also found that electrical conductivity was similar in both the solar park and reference location, with slightly higher values observed at the reference point. Dissolved oxygen was another parameter of interest. de Lima et al. [11] found that dissolved oxygen levels remained at healthy levels throughout the monitoring period but the dissolved oxygen concentrations were lower under the floating solar park (reached 4.6 mg/L) than in open water (minimum 6 mg/L). It is important to note that the study by de Lima et al. [11] was carried out in the Bomhofsplas Lake in the Dutch city of Zwolle. Their study location is therefore in a very different geographical location from the one being presented in this paper.

Another study that looks at the impact of FPV on temperature and water quality is the study by Yang et al. [12] and the study area is located at the Tengeh and Poyan Reservoirs in Singapore. The authors obtained similar [11] study in some of the parameters; the area of the reservoir where the panels were placed experienced both limited light and reduced wind stress conditions [12]. The dissolved oxygen concentration under the solar panel was also lower. The lower dissolved oxygen level was observed throughout the water column. However, when it comes to temperature, the study by Yang et al. [12] found the average water temperature beneath the panels to be significantly higher than the temperature in the open water. The authors observed an average increase of 0.32 ℃ in the daily mean water surface temperature under the panels compared to open water conditions. This increase in water temperature under the FPV is related to the increase in the temperature of the air between the PV panels and the water surface. The authors also recorded a reduction in net radiation at the water surface beneath the panels. If the surface water temperature was based on radiation only, the temperature should decrease. However, due to impacts from wind and heat transferred from the panels via the airspace, the overall temperature was higher. The differences between the studies by de Lima et al. [11] and Yang et al. [12] could therefore be due to wind, geographical differences, various meteorological factors, differences in the depth of the water bodies, and/or design factors. The study design also differs between the two studies, making it difficult to make concrete comparisons. As such, similar or different effects to those observed in the two studies may be observed at our study location but it is not certain without further assessments.

3.1.4 Impacts on Fish from Shading and Anchoring and Cabling

Impacts on aquatic flora and/or fauna that rely on light for photosynthesis, seeking prey, and food production could occur from shading caused by the FPV installation (41% in Forebays and 21% in Headpond). There could also be degradation of littoral zone plant growth due to reduced sunlight. This could change the overall ecosystem dynamics of the water body. While structures that create cover and shade may provide habitat, this simple habitat is different from the natural habitat, in that it lacks structural complexity, which some prey species rely on for cover. Therefore, overwater structures may alter predators' success rates. Shading also reduces aquatic vegetation and phytoplankton abundance, reducing habitat and primary production.

While shading by FPV and related structures may provide cover from some predators, the structures often lack the complexity to function as suitable prey refuge habitats and may increase the success rate of other predators in some cases. Additionally, increased shading can alter fish behavior (studies conducted on the impact of piers show reduced fish numbers under piers). Reduced primary productivity and changes in aquatic habitat may decrease habitat suitability and resources for fish. The impact is likely to be of greater magnitude at Site 2, where 41% waterbody coverage is proposed, compared to Site 1.

The installation of FPV components within the littoral or benthic zone can cause direct disturbance and mortality due to subsurface penetration from mooring systems and disturbance from the placement or movement of underwater electrical cables. The placement or movement of underwater electric cables and anchors due to wind or changes in reservoir levels can impact the aquatic habitat and shading which can decrease the oxygen level thus endangering the aquatic species. Cables that run across the floor of a water body can affect habitat due to movement caused by wind and/or a change in reservoir levelsthis is relevant at

Sites 1 and 2 where the proposed design includes AC cables running along the bed of the water body to shore.

Anchoring at the bottom of the waterbody (proposed at Sites 1 and 2) and mooring systems directly anchored to the bottom/substrate (Site 2) can further impact benthic habitats, with an increase in water turbidity caused by sediment turnover during installation. While the impact is most relevant during the construction phase, when infrastructure is being put in place, it may result in some long-term changes from the presence of cables and anchors, especially if movement is caused.

Sahu et al. [9] opined that the presence of FPV plants on waterbodies not only affects fish communities via shading but also has the potential to reduce algae populations and impact aquatic biodiversity. It is important to note that even though the decrease in algae may result in an improvement in water quality, it may have negative impacts on the aquatic ecosystem if they rely on it for food and the decrease is significant. In another study by Exley et al. [3], the authors used modeling to determine the impact of floating solar on phytoplankton populations. The results showed that FPV coverage significantly impacted the thermal properties of the water, resulting in changes to phytoplankton species composition and a decrease in phytoplankton biomass. However, the biomass reduction was highly dependent on whether the FPV was located in faster-flowing, central, or slower-flowing areas. There was a greater reduction in biomass in the faster-flowing areas due to the flushing from the water cumulating with the impacts of the FPV. As such, a smaller coverage by FPV can achieve similar biomass reduction when placed in fast-flowing areas vs a larger coverage placed in slow-flowing areas. This study outlines the complexity of FPV's impact on the ecosystem. If biomass reduction is the goal, this can be considered a positive impact. However, if biomass is reduced in a healthy lake, it can have negative impacts instead [3]. Other changes to water bodies that occur due to FPV include reduced air-water interface, shading effect, changes in wind action, effect on hydrodynamics, impact on water quality, and presence of objects on the water surface [11]. The positive impact of a reduced air-water interface is the reduction in evaporation but it may instead lead to lower dissolved oxygen levels. Similarly, the shading effect can help control algae glooms but it can affect water temperature and phototropic organisms. Furthermore, the presence of the FPV on the water can act as a habitat for different organisms and improve biodiversity but it can also be a potential source of leaching and habitat invasive species.

3.1.5 Impact on Migratory Birds and their Habitats

Baseline conditions show that migratory/winter birds identified in the project area (in Headpond and Forebay area) mostly consist of predominantly aquatic species (such as waterfowl) and they require large water bodies with good visibility, shallow margins, fresh water, and high macrophyte abundance. The migratory birds consist of various species of waterfowl and cranes, including common teal, pintail, mallard, gadwall, white-headed duck, houbara bustard, and Siberian crane. Moreover, a total of 89 bird species were recorded in field surveys and the common pochard was listed as Vulnerable on the IUCN Red List. The common pochard is omnivorous and requires wide areas of open water and abundant vegetation.

After construction is completed, the solar panels that would be placed on the water surface would significantly reduce the surface area available for migratory birds. The risk ratings associated with this impact are moderate for the construction stage and substantial for the operation stage of the project.

3.1.6 Aquatic Habitat Degradation as a Result of Altered Quantity of Bird Droppings

Accumulation of bird droppings on the panels due to the panels acting as barriers to the free-fall of bird droppings and periodic cleaning can degrade water quality, especially in the north pond of the Forebays site. When cleaning is undertaken, the accumulated bird droppings will be dumped into the water all at once. These occurrences and construction activities could result in habitat degradation due to changes in water quality in the water bodies. This can result in biodiversity impacts, including Reduction in the habitat availability for fish, macroinvertebrates, and macrophytes forcing species to leave the affected area; Causing direct fish and invertebrate deaths; Having complex impacts on the physiological and biological processes of fish; Mortality of algae and phytoplankton to primary production with negative consequences on the waterbody food chain [13]. The presence of FPV plants on water bodies also impacts aquatic biodiversity, among others [9]. The risk rating for this impact is low during construction and substantial during the operation of the plant.

3.2 Mitigation Measures for the Environmental, Health, and Safety Risks

Mitigation measures following the mitigation hierarchy for the substantial to higher risk rating evaluated in table 4 are presented in this section. The residual risks, which are risks after mitigation, are provided for each of the impacts, with rationale provided for residual risks of moderate ranking and higher.

3.2.1 Mitigating the Risk of Falling in the Water and Drowning During the Installation of Panels over Water

The Project work involves the installation of panels on the surface of the water and many workers will be working on floating platforms, rafts, and pontoons. There is a substantial risk of falling into the water and drowning. The mitigation hierarchy for this risk is presented in Table 5.

3.2.2 Mitigating the Impact of Pollution of Surface Water Due to the Cleaning of Accumulated Bird Droppings

The bird droppings on the FPV will be cleaned regularly to maximum output efficiency. The mitigation measures for the impact of the droppings on the surface water are presented in Table 6.

3.2.3 Mitigating the Impact of Changes to Water Quality as a Result of Shading

There are potential changes to water quality, thermal structure, and evaporation as a result of shading, especially Site 1: Headpond and Site 2: Forebays, impacting aquatic algae and plankton, fish, and birds (including waders and waterfowl). Mitigation measures are presented in Table 7.

3.2.4 Mitigating the Impacts of Shading on Fish, Aquatic Algae, and Plankton

Shading will cause direct impacts on the fish, aquatic algae, and plankton. Mitigation measures are presented in Table 8.

3.2.5 Mitigating the Impacts on Migratory Birds and Bird Habitats Due to Panel Installation

Currently, the entire waterbodies are used as staging grounds by migratory birds. After the installation of solar panels, the habitats will be reduced, especially in Headpond (21%) and Forebays (41%) sites. Mitigation measures for this impact are presented in Table 9.

Table 5 Mitigation measures for the risks of falling into water and drowning.

Mitigation Hierarchy (ESS3)	Measures
Avoid	• Avoid overwater installation. • Subcontract the work to a specialized company that has a track record
Minimize	• Assemble panels and connect the arrays on land and minimize the operation over water. • Minimize manual works overwater and use mechanical equipment instead.
Mitigate/Control	• Provision should be made for: • As appropriate the passive safety system such as fencing, and safety nets are installed to prevent workers from falling into the water; • The rescue of workers in danger of drowning; • Safe and sufficient transport. • Availability and use of life jackets. • Gangways, pontoons, bridges, footbridges, and other walkways or workplaces over water should possess adequate strength and stability and be sufficiently wide to allow the safe movement of workers.
Compensate/offset	• Revision of rescue plan to comply with adverse weather (heavy and torrential rain etc.) and fire.

Residual risks: *Moderate*; even with all safety measures in place, the consequences of failure of the measures are high as fatality may occur, resulting in a moderate residual rating.

Table 6 Mitigation measures for the impacts on surface water due to the cleaning of accumulated bird droppings.

Mitigation Hierarchy (ESS3)	Measures
Avoid	• Collection of bird dropping during cleaning and safe disposal to designated area • Design should consider reducing the size of the spaces in between the panels
Minimize	• Schedule frequent cleaning during the bird migration period to minimize the accumulation. • Large amounts of droppings should not be disposed of into the water body. They should be removed and properly disposed of along with other organic toxic waste to avoid adding large amounts of nutrients to the waterbody
Mitigate	• Use bird deterrents such as lasers, sound machines (project predator calls to intimidate birds), bird scarers that reflect the sunlight in random directions which scare off birds, bird spikes along the side of the panels, and other design measures to prevent birds from landing on the panels
Compensate/Offset	• Improve habitat and ecosystem quality of nearby waterbodies (such as the south pond) to allow winter birds to the stage there instead.

Residual risk: *Low*.

Table 7 Mitigation measures for the changes to water quality, thermal structure, and evaporation due to shading.

Mitigation Hierarchy (ESS6)	Measures
Avoid	Avoid building the FPV plant on water and instead mount it on land
Minimize	• Keep the coverage of each waterbody to a minimum to reduce the coverage of shading and resultant changes in water quality, thermal structure, and evaporation • FPV design should allow enough space between rows of panel strings for light to pass through wherever possible. • Keep panel string row widths to a minimum by installing solar panels in a landscape orientation
Mitigate	• Addition of an aeration system to manage deoxygenation risks, if needed based on water quality monitoring results • Prevent stratification and maintain dissolved oxygen bubble plumes or mechanical aerators can be used to maintain the circulation and exchange of water between the surface and lower levels. This is not likely to be required due to low water retention time. The measure should only be implemented if monitoring indicates that stratification is an issue. • Consider the use of glass-glass PV modules, enabling light to reach the water surface to minimize ecological impacts • Schedule low retention time of water if monitoring found stratification, by releasing water in the dam or utilizing them in the turbine to prevent water from being stagnant for too long (research the optimal timing).
Compensate/Offset	• Fund research into how to improve the water quality and ecosystem to maximize ecosystem services

Residual risk: *Moderate*; even with all mitigation measures in place, there may still be an impact on the water quality, especially for Site 2 as the surface coverage from the panels is high.

Table 8 Mitigation measures for the direct impacts of shading on fish and aquatic algae and plankton.

Mitigation Hierarchy (ESS6)	Measures
Avoid	• Avoid building the FPV plant on water and instead mount it on land or other suitable locations
Minimize	• Place the panels so light and wind penetration is maximized (determine the optimal space in between the panels to maximize light and wind penetration without expanding the area the panels together take up) • Keep string row widths to a minimum by installing solar panels in a landscape orientation
Mitigate	• Use glass-glass PV modules, enabling light to reach the water surface to minimize ecological impacts
Compensate/Offset	• Fund research into how to improve the ecosystem given the pressures

Residual risk: *Moderate*; even with all mitigation measures in place, there may still be an impact on the organisms living in the water, especially for Site 2.

Table 9 Mitigation measures for the changes to bird habitats from panel installation.

Mitigation Hierarchy (ESS6)	Measures
Avoid	• Avoid panel installation in waterbodies
Minimize	• Prioritize choosing compact panels so they take up less space • Install the panel in such a way by allowing larger space as a staging ground for birds

Mitigate	• Install more efficient solar panels so fewer panels can be used to obtain the same electricity generation • Install barrier and/or non-barrier bird deterrent systems if considered necessary to prevent impacts on birds. This may also decrease the need for cleaning panels, thereby minimizing use of cleaning agents during the operation
Compensate/Offset	• Clean up ponds/water bodies in nearby areas and improve them so birds have a different location to go to if needed • Improve the habitat quality of the south pond in the Ghazi-Barotha Forebays with supplies of food for the birds, so that they can have an alternative preferred staging ground

Residual risk: *Moderate*; even with all mitigation measures in place, there may still be an impact on habitat availability, especially for Site 2 as the surface coverage from the panels is high.

Table 10 Mitigation measures for the anchoring and cabling (C and O) impacts on fish.

Mitigation hierarchy (ESS6)	Measures
Avoid	• Design should consider avoiding underwater anchoring and cabling systems
Minimize	• Select the areas for placing the anchors and cable by first studying fish behavior and avoiding places frequently used by the fishes • Install fish deterrents (e.g., underwater strobe lights, acoustic air bubble curtains) in the anchor cables and colored concrete blocks to alert fish of their presence underwater • Underwater strobe lights are a widely used type of lighting for fish control. Strobe lights produce flashes of light at rapid rates, depending on the target species and scale of the water body and light installation. Small-scale systems can consist of an individual cylindrical strobe light (0.16 m length by 0.04 m diameter) with a flash rate of only 86 flashes/mins. Both systems have been shown to alter fish movements in both experimental and field settings for a variety of fish species • Minimize the number of cables and anchors used underwater
Mitigate	• Research into improving designs for anchors and cables to make them more environmentally friendly • Research and survey into fish behavior around cables and anchors • Regular inspection of the cables and monitoring the fish mortality • Yearly survey of the fish population • Design the mooring and electrical system to prevent dragging on the bottom substrates by using horizontal directional drilling, anchors, and floats
Compensate/Offset	• Coordinate with the fisheries department to determine alternate ways of managing the fish populations • Create a feeding schedule for the fish so they are not limited by nutrients (the schedule must be created by a qualified professional to ensure overfeeding does not occur)

Residual risk: *Low*.

Table 11 Mitigation measures for the degradation of aquatic habitat by bird droppings.

Mitigation hierarchy (ESS3)	Measures
Avoid	• Avoid building the FPV plant on water and instead mount it on land • Design should consider reducing the size of the cracks in between the panels
Minimize	• Perform frequent cleaning of bird dropping to minimize bulk accumulation, the droppings are not left there to bake for too long [14], create a cleaning schedule (e.g., frequent cleaning during bird staging season) • Large amounts of droppings should not be disposed of into the water body. They should be removed and properly disposed of along with other organic toxic waste to avoid adding large amounts of nutrients to the water body • Design panels in such a way that there are gaps between panels that allow for sun and wind to still reach the water
Mitigate	• Use bird deterrents such as lasers, sound machines (project predator calls to intimidate birds), bird scarers that reflect the sunlight in random directions which scare off birds, bird spikes along the side of the panels, and other design measures to prevent birds from landing on the panels • Add netting around the panels to restrict birds from making nests under the panels. Other deterrents that can be used are lasers, flashing Hawkeye Bird Deterrents, and bird Spikes.
Compensate/Offset	• Improve habitat and ecosystem quality of nearby waterbodies (such as the south pond) to allow winter birds to the stage there instead

Residual risk: *Low*.

3.2.6 Mitigating the Impacts on Fish Due to Anchors and Cables

Anchors and cables to stabilize the panel strings will impede the free movement of fish, especially the Golden Mahseer (an endangered species), mitigation measures are presented in Table 10 to address this impediment.

3.2.7 Mitigating the Impacts of Aquatic Habitat Degradation Due to the Altered Quantity of Bird Droppings

Installation of FPV creates a barrier to bird droppings, which allow the accumulation of huge quantity of droppings and eventual discharge in water may degrade the aquatic habitat. Bird droppings are rich in phosphorus and nitrogen and are often acidic which can lead to algae blooms [13].

Table 11 presents the mitigation measures to protect habitat quality from bird droppings.

The mitigation measures identified are to be incorporated while designing the project. Incorporating them would make the FPV project as environmentally benign as possible and mitigate the main potentially negative impacts that could occur.

4. Conclusion

FPV plants have the potential to have both positive and negative impacts on the ecosystem. The energy-producing and greenhouse gas-reducing potentials of FPV are indisputable. FPV is proven to be more efficient than land-based solar plants and is the future of renewable energy in many countries. However, due to the complex nature of FPV and its impact on water bodies, we strongly recommend using a precautionary approach when designing and implementing future FPV plants. The anticipated impacts and solutions we presented in this study are some of the most crucial areas that should be taken into consideration. By incorporating these in the earlier stages of a project, the potential impacts can be reduced. As more information becomes available about the impacts of FPV on the ecosystem, practices can be modified to reduce the risks.

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