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Environmental, Health, and Safety Guidelines

SOLAR POWER

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1 INTRODUCTION

1. The Environmental, Health, and Safety Guidelines (EHS Guidelines) are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP).[1] They are comprised of the General Environmental, Health, and Safety Guidelines (General EHS Guidelines) and Industry-specific Sector Guidelines (Industry Sector EHS Guidelines). The General EHS Guidelines present common environmental, health, and safety (EHS) issues that potentially apply across industry sectors. The Industry Sector EHS Guidelines present EHS issues specific to each industry sector.

2. When one or more members of the World Bank Group are involved in a project, the EHS Guidelines are applied as described in their respective policies and standards. The Industry Sector EHS Guidelines are designed to be used together with the General EHS Guidelines. For complex projects, multiple Industry Sector EHS Guidelines may be relevant. A complete list of Industry Sector EHS Guidelines can be found at www.ifc.org/ehsguidelines.

3. The EHS Guidelines specify the performance levels and measures that are generally considered to be GIIP and achievable in new facilities by using existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve establishing site-specific targets, with an appropriate timetable for achieving them.

4. The applicability of EHS Guidelines should be tailored to the hazards and risks identified for each project based on results of an impact assessment that considers site-specific variables, such as host country context, assimilative capacity of the environment, and other project-specific factors. The applicability of specific technical recommendations should follow GIIP and be based on the professional opinion of qualified and experienced professionals. When a host country's regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent measures than those in the EHS Guidelines are appropriate due to specific project circumstances, a detailed justification for any proposed alternatives is needed as part of the site-specific assessment and should demonstrate that the alternate performance levels are protective of human health and the environment.

5. The scope of the EHS Guidelines includes environmental, occupational health and safety, and community health and safety aspects. Guidance on social aspects is not included and can be found in relevant Guidance Notes to IFC/MIGA Performance Standards, relevant Guidance Notes to World Bank E&S Standards, and various other World Bank Group good practice publications.

[1] GIIP is defined as the professional skill, diligence, prudence, and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of prevention and control techniques available to a project may include, but are not limited to, varying levels of EHS capabilities and capacities, and financial and technical feasibility.

2 APPLICABILITY

6. The EHS Guidelines for solar energy include information relevant to utility-scale and distributed generation systems, including industrial, residential, ground-mounted, rooftop photovoltaic (PV), agri-PV, and floating PV (FPV) installations.[2] It applies to solar energy facilities from the design, siting, construction, installation, operation, maintenance, and decommissioning phases. The guidelines do not cover the manufacturing of solar panel components (e.g., PV modules, cells, wafers, and ingots) or raw material extraction and processing. Concentrated Solar Power (CSP), other solar-thermal, or concentrating solar technologies are not covered in these guidelines. Annex A contains a full description of industry activities for this sector.

3 DESIGN CONSIDERATIONS

7. This section summarizes key aspects related to project siting and design for this industry sector. Design considerations for buildings and ancillary facilities that are common to various industry sectors are detailed in the General EHS Guidelines.

8. The siting and design of solar PV facilities are primarily determined by the availability of adequate solar exposure (for example, in the case of rooftop installations), spatial requirements of the proposed array, and site�specific environmental, social, and safety constraints. Early integration of siting and design considerations can help avoid or minimize environmental, health, and safety (EHS) risks over the full project lifecycle.

9. Key siting and design considerations applicable to all solar PV installations include the following:

- Visual and landscape impacts: The siting and layout of PV panels, mounting structures, and ancillary infrastructure should consider visual sensitivity of surrounding receptors. Visual, landscape, or glint and glare assessments may be used at the design stage to avoid or mitigate impacts, particularly for large-scale or elevated installations (see Section 4.1.1 and Section 4.3.3).[3]
- Noise: While PV modules are silent, balance-of-system components (e.g., inverters, transformers, electrical switchgear) may generate continuous or intermittent noise. Siting and layout should maintain adequate separation from sensitive receptors and project boundaries, informed by site-specific noise assessments where relevant.[4]

[2] Agri-PV and FPV are relatively new solar technologies, and their impacts and risks are less documented compared to conventional PV systems. Site-specific assessments should be conducted to identify potential risks and impacts.
[3] US DOE, *Visual Impacts of Solar*; US DOT FAA, *FAA Review of Solar*; US DOT FAA, *Form 7460-1*; UK HCLG, *Planning Practice Guidance;* ICAO, *Glare and Glint*. The FAA's Review of Solar requires a glare analysis for PV projects near airports using SGHAT, with FAA Form 7460-1 confirming no significant glare toward control towers or flight paths. *Planning Practice Guidance* from UK DCLG provides general direction on assessing glint and glare impacts of solar developments, particularly regarding cumulative landscape and visual effects. ICAO's *Glare and Glint from Solar Panels* promotes evaluation of glint and glare intensity, duration, and reflection angles toward sensitive receptors.
[4] Sensitive receptors are determined in the impact assessment and may include schools, hospitals, elderly housing, roads, residences, water bodies, and aircraft zones.

- Biodiversity: Early biodiversity risk screening should be undertaken to identify and avoid or minimize disturbance to areas of high biodiversity value.[5] Screening should be proportionate to project scale and informed by national and internationally recognized biodiversity datasets (see Section 4.1.2).[6]
- Climate resilience and natural hazards: Site selection and layout should consider local hydrology, water scarcity, climate, and exposure to natural hazards (e.g., flood risk, extreme heat, high winds), including climate change projections, to enhance system resilience and avoid damage to electrical equipment and support structures that can in turn pose risks to communities, livestock or other infrastructure.
- Access and public safety: Siting and layout should provide safe and adequate access for installation, inspection, and maintenance activities, while enabling the management or restriction of public access to energized equipment and hazardous areas. Siting should also consider compatibility with surrounding land uses, such as nearby airports.
- Electrical safety and lightning protection: PV systems should be designed and constructed in accordance with relevant international electrical safety standards, integrating appropriate earthing, bonding, lightning protection, and arc-fault prevention and detection measures, consistent with system scale and configuration.[7]
- Traffic safety and internal roads: Traffic related risks in solar PV facilities are associated with constrained array layouts, maintenance vehicle movements, and limited visibility between panel rows and tracker systems. Site design should define clear internal traffic routes with adequate turning radii, configure panel rows and ancillary infrastructure to avoid blind spots, and provide dedicated pedestrian walkways to minimize vehicle–worker interaction. Internal roads should be designed and maintained to control dust, erosion, skidding and surface degradation.

10. Specific considerations for siting and design of rooftop solar PV include the following:

- Verify that buildings and roof structures have sufficient load-bearing capacity and resistance to wind uplift and seismic forces, based on site-specific structural assessments.
- Provide safe roof access for installation and maintenance, and integrate permanent fall-prevention features (e.g., anchor points, guardrails, walkways) where feasible to reduce reliance on temporary controls.
- Design rooftop layouts to maintain access for firefighting and emergency response, including clear access pathways, appropriate setbacks, and clearly identifiable isolation and rapid shutdown points.[8]
- Plan for suitable indoor or protected spaces for inverters and electrical cabinets that minimize safety risks, allow safe access, and promote adequate heat dissipation.

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[5] IFC, *Guidance Note 6*. Areas of high biodiversity value may include key biodiversity areas (KBAs), critical habitats, and areas of high ecosystem service value.
[6] SolarPower Europe, *Solar, Biodiversity, Land Use*; IFC, *Guidance Note 6*.
[7] IEC, *60364*; IEC, *61215*; IEC, *61730*.
[8] Fire Protection Research Foundation, *Roof-Mounted Photovoltaic Installation*.

- Clearly label rooftop PV systems to indicate the presence of a solar generator for electrical maintenance and emergency response purposes.
- Avoid proximity to trees or structures that could pose risks from falling objects or shading.

11. Specific considerations for siting and design of ground-mounted solar PV include the following:

- Layout and grading should maintain natural drainage patterns to avoid downstream flooding, surface runoff, erosion, or submergence of electrical equipment.
- Minimize soil compaction and impermeable surfaces. Where piled foundations are used, provide sufficient underground clearance to avoid damaging archaeological resources, buried utilities, landfills, areas with potential environmental liabilities or other subsurface risks (e.g., unexploded ordinances).
- Consider existing and planned land uses when selecting sites and defining layouts to reduce conflicts with adjacent activities or communities.

12. Specific considerations for siting and design of floating solar PV, given their interaction with water, include the following:

- Waterbody conditions and climate exposure: Assess vulnerability to wind, wave action, currents, seasonal water level- variations, floating debris, and extreme weather events, including climate change projections, that may interfere with the FPV array.[9]
- Mooring and anchoring systems: Design mooring and anchoring systems based on quantified site conditions. Deficient design presents a high risk of catastrophic failure and is mitigated through independent design reviews (see Section 4.3.2).
- Ecological and water use- considerations: Evaluate potential impacts on aquatic ecosystems (e.g., plankton, algae, benthos, birds, reptiles, aquatic mammals) from light penetration, habitat changes and materials toxicity (see Section 4.1.4). Identify applicable regulatory requirements such as water rights and navigation and safety regulations. Identify underwater infrastructure (e.g., pipelines, cables), seabed characteristics, culturally sensitive marine zones (including archaeological sites), traditional fishing grounds, commercial and recreational uses to inform the planning and design and minimize impacts. Avoid obstruction of known navigation routes (see Section 4.3.4).[10] Establish exclusion and buffer zones for culturally sensitive marine sites.
- Materials and water quality protection: Use FPV components with high ingress protection ratings and corrosion resistance (see Section 4.3.2).[11] Consider drinking-water-certified floats and coatings to prevent release of contaminants (e.g., plasticizers, heavy metals, fire retardants, microplastics, lubricants).[12] For salt-water environments, consider modules

[9] IMO, *Safety Around Offshore Installations*.
[10] IMO, *Preventing Collisions at Sea*.
[11] IEA PVPS, *O&M of Floating PV*.
[12] SolarPower Europe, *Floating PV Best Practice*.

certified for salt-mist corrosion (see Section 4.1.2).[13] Verify that FPV components are compatible with the pontoons' specifications and that module weight, dimensions, mounting methods, and string and cable arrangements are planned to minimize mechanical stress and reduce water/moisture ingress.[14]

- Electrical safety in water environments: Electrical design should minimize leakage currents and electric risks to surrounding water. For systems with floating electrical potential, consider insulation monitoring devices (IMDs) and residual current monitoring units (RCMs).[15] Lightning protection and earthing designs should account for water-based configurations.[16]

13. Specific considerations for siting and design of agri-PV, considering land use compatibility, include the following:

- Agricultural operations and machinery: Accommodate the continued use of tractors and harvesters through adequate clearance, wider inter-row spacing, and impact-resistant mounting systems. Vehicle–structure collision risks should be addressed through spatial zoning and layout planning.[17]
- Microclimate and crop compatibility: Assess how panel layouts may alter shading, humidity, wind exposure, and soil conditions that may affect crop yields. Coordinate with and assess the agricultural operations to support compatibility with site activities. Site-specific agroecological studies can inform compatible crop types, panel spacing, and arrangements that maintain soil structure and fertility (see Section 4.3.1 and Section 4.3.2).[18]
- Animal interactions: Protect cables, junction boxes, and electrical components from animal interference (e.g., rodents, livestock, grazing animals) using shielding, elevation, fencing, or buried conduits, as appropriate.[19]
- Materials and food safety: Avoid or minimize the use of hazardous coatings, cleaning agents, or heavy-metal-containing components in proximity to soil and crops, consistent with precautionary principles and food safety or organic agriculture requirements (see Section 4.3).[20]

4 CONSTRUCTION AND OPERATIONAL CONSIDERATIONS

14. This section provides a summary of sector-specific EHS issues typically associated with the operational phase and provides guidance for mitigation and management measures. Where there are unique aspects to the construction, refurbishment, and decommissioning of this industry sector, guidance is also included. Recommendations for EHS issues and management common to the construction, refurbishment, and decommissioning phases, are provided in the General EHS Guidelines.

[13] IEC, *61701*.
[14] World Bank, *Floating Solar Handbook*.
[15] IEC, *62109-2*.
[16] Konrad Sobolewski and Emilia Sobieska, "Lightning Protection."
[17] Carlos Toledo and Alessandra Scognamiglio, "Agrivoltaic Systems Design."
[18] Loan Madej et al., "Sheep-Grazed Agrivoltaic Systems."
[19] Fraunhofer ISE, *Agrivoltaics*.
[20] ISO, *14001-2015*; EU, *2018/848 Organic Production*; SolarPower Europe, *Agrisolar Best Practice Guidelines*.

4.1 Environment

15. Key environmental issues for the solar PV sector include the following:

- Landscape – seascape and visual impacts
- Water consumption and quality
- Solid and hazardous waste management
- Biodiversity and land use

4.1.1 Landscape – Seascape Visual Impacts

16. Visual impacts may result from the contrast between the solar facility and the existing character of the surrounding seascape or landscape, particularly in rural, scenic, or undeveloped areas.

17. Avoiding or reducing negative effects on landscape, seascape, and visual views from solar PV projects mainly depends on decisions made early in the project's planning specifically during the site selection, layout, and design stages, including panel arrays, type of mounting structures / trackers, inverters, substations, and access routes (see Section 3).[21]

18. Other measures to reduce visual impacts include the following:

- Limit panel height and consider including buffer zones.
- Use and maintain natural screening (e.g., hedgerows, topography, or planting of native vegetation) to reduce visual exposure.
- Evaluate the possibility to establish multi-layered native planting buffers, vegetated earth bunds in key sightlines, or wildflower meadows between and around panels.[22]
- Use low-profile, non-reflective designs with vegetative or topographic screening to minimize visual intrusion.
- Implement erosion control measures and restore disturbed areas promptly using native plant species to blend infrastructure into the surrounding environment.[23]
- Prepare zone of visual influence maps, wire-frame representations, and photomontages from representative viewpoints to inform the impact assessment and stakeholder consultation processes.[24]
- Remove decommissioned or inoperative equipment in a timely manner to avoid long-term visual degradation.

[21] US DOI BLM, *Solar Development Environmental Considerations*.
[22] In some countries, such as South Korea, layouts have been designed to mimic flower patterns, which improved visual aesthetics and community acceptance.
[23] IEA-PVPS, *End-of-life management of photovoltaic panels (Task 12)*, 2016.
[24] Landscape Institute & Institute of Environmental Management and Assessment, *Landscape Visual Impact Assessment*.

4.1.2 Water Consumption and Quality

19. Water consumption may occur depending on the type of technology and site-specific operational practices. Water may be used for panel cleaning, dust suppression and construction activities.[25] The magnitude of water use can be particularly significant in arid or semi-arid regions, where it may place additional pressure on limited water resources or compete with agricultural, municipal, or ecological water demands.

20. Panel cleaning is the most common source of water use in PV installations, especially in areas with high dust loads or infrequent rainfall. In some regions, cleaning is required multiple times per month to maintain operational efficiency (see Section 5.1).[26]

21. Water sources (e.g., groundwater, surface water, or municipal supply) availability should be evaluated to avoid over-extraction.

22. Discharges from cleaning activities (e.g., runoff from panel washing) should be managed to prevent sediment loading, chemical contamination, or thermal pollution of nearby water bodies.

23. To mitigate impacts on water availability and quality, the following measures can be applied:[27]

- Conduct a water resource assessment during site selection as described in the General EHS Guidelines. The assessment should identify any water users that may be affected or water related impacts, in consultation with communities.
- Implement water-efficient cleaning methods, such as dry-cleaning technologies (e.g., robotic brushes or air blowers) or low-pressure, targeted washing systems, to minimize water use during photovoltaic panel maintenance. Consider use of panel soiling sensors to avoid unnecessary washing cycles. Integrate these methods into system design in line with GIIP.
- Store fuels and hazardous chemicals in contained areas with adequate drainage systems to treat any contaminated water that may have come into contact with spills.
- Install drainage systems to manage stormwater runoff.
- Where cleaning agents are used, select biodegradable and non-toxic substances, and implement containment measures such as sediment traps, buffer strips, or retention ponds.
- Utilize non-potable water sources, including harvested rainwater, treated wastewater, or other approved alternatives, for cleaning and dust suppression, thereby reducing demand for local freshwater resources.
- Consider installing water metering systems and regularly monitoring consumption to track usage, identify potential inefficiencies, and support alignment of water management practices with applicable regulatory requirements and sustainability targets.

[25] IRENA, *Water in Electricity Generation*.
[26] IEA-PVPS, *Water Use Solar Operations*.
[27] IEA-PVPS, *Water Use PV Operations*. IEA-PVPS, *Fact Sheet: Soiling Losses*. US DOE, *Solar Photovoltaic Energy Facilities*.

4.1.3 Hazardous Materials and Waste Management

24. Solar energy facilities generate both hazardous and non-hazardous waste streams that are distinct from those of other energy infrastructures due to the material composition of PV technologies and the relatively low-maintenance design. Waste is generated throughout the project lifecycle: during construction (e.g., panel and inverter packaging, cable offcuts, mounting hardware, and concrete residues), operation (e.g., damaged PV modules, soiled filters, spent cleaning agents), and decommissioning (e.g., dismantled support structures, electrical and electronic components, and end-of-life PV modules). General waste management practices are addressed in the General EHS Guidelines.

25. A significant waste stream from solar facilities consists of damaged or end-of-life PV modules, which are typically classified as non-hazardous industrial waste, depending on module composition and applicable regulations. These modules are typically composed of recyclable glass, aluminum, polymer laminates, and silicon wafers. Proper handling and on-site storage are essential to prevent breakage and cross-contamination, and to support efficient downstream material recovery. Where feasible, module take-back and processing by manufacturers or certified recyclers should be prioritized.

26. Decommissioning and recovery plans should be developed early in the project lifecycle to minimize the volume of recyclable material sent to landfill.[28] If landfill is the only option, assess the host country's regulatory and technical capacity to manage and dispose of damaged or decommissioned PV modules and associated hazardous waste. Where adequate domestic systems are absent, projects should implement appropriate interim storage and management measures and select sound treatment or disposal, including compliance with applicable transboundary movement requirements.[29]

27. Certain PV technologies (e.g., cadmium telluride [CdTe], copper indium gallium selenide [CIGS], or legacy modules with lead-based solder) may contain hazardous materials embedded within the module layers. While these materials are inert during normal operations, cracked or broken modules, depending on the technologies, may release hazardous dust or leachate. Regardless of the technology, a robust end-of-life process should be implemented. Modules should be classified, labelled and returned to the manufacturer/recycler or managed as hazardous waste where applicable and handled using appropriate PPE and containment.

28. Other hazardous materials present at solar facilities, such as small volumes of solvents, insulating oils, paints, and chemical cleaning agents, and coatings should be handled in accordance with national hazardous waste regulations, disposed of through licensed facilities, and follow the principles outlined in the General EHS Guidelines.[30]

[28] SolarPower Europe, *End-of-Life Management.*
[29] UN, *Basel Convention Hazardous Wastes*.
[30] US EPA, *End-of-Life Solar Panels: Regulations and Management.*

29. The use of herbicides and pesticides when managing vegetation under/around the solar panels should be avoided. If their use is unavoidable, integrated vegetation management (IVM) and integrated pest management (IPM) guidelines should be followed in line with the General EHS Guidelines.[31]

30. The following measures address the management of hazardous and non-hazardous solar-specific waste streams:

- Establish on-site waste separation protocols for damaged modules, packaging, and electrical components.
- Store damaged or potentially hazardous PV modules in secure, weather-protected containment pending appropriate disposal or recycling.
- Where available, suppliers should participate in nationally recognized Extended Producer Responsibility (EPR) programs for PV modules, inverters, and associated components.[32] They should demonstrate compliance through registration with relevant authorities, implementation of take-back and recycling mechanisms, and regular reporting on end-of-life collection and treatment. Documentation of EPR participation is advised as part of contractual obligations and due diligence process.
- In countries lacking adequate capacity to manage and dispose of hazardous waste, projects are encouraged to plan for and allocate resources for appropriate handling and safe disposal.
- Incorporate waste minimization and recovery strategies into construction, operation, and decommissioning plans.
- Maintain up-to-date waste inventories with all hazardous waste streams documented and managed in accordance with local and international regulations.[33]

4.1.4 Biodiversity and Land Use

31. Development of solar PV facilities, particularly utility-scale ground-mounted arrays and FPV systems, may result in direct, indirect, and cumulative biodiversity impacts, including habitat loss, fragmentation, barrier effects, displacement due to attraction to reflective surface of solar panels and disturbance or injury to species from collision impact with solar panels and electrocution with on-site transmission lines.[34] Mitigation measures should be clearly defined, implemented through environmental management plans, and monitored for effectiveness. Changes in land use, such as clearing of natural vegetation, alteration of drainage patterns, and installation of impermeable surfaces, can reduce habitat quality and connectivity, particularly in previously undisturbed or ecologically sensitive areas.[35] When located near wetlands, lakes, or other aquatic ecosystems, solar facilities may affect hydrological regimes, shoreline vegetation, and the availability of habitat for aquatic and semi-aquatic species.

[31] WHO, *Recommended Classification of Pesticides*.
[32] Typically, in OECD countries.
[33] PV CYCLE, *EPR Compliance Solar Europe*.
[34] IUCN, *Biodiversity Impacts Solar Projects*.
[35] R.R. Hernandez et al., "Environmental Impacts."

32. In agri-PV systems, PV arrays may affect agricultural land use by modifying sunlight availability through module shading and by causing uneven water distribution from panel runoff. System design should minimize impacts on crop productivity and routine agricultural activities through appropriate module spacing, height, and orientation; optimized array density; and effective drainage and water-management measures. Layout and maintenance planning should account for crop seasonality and standard farming practices.[36]

33. FPV systems are increasingly deployed on artificial reservoirs, lakes, and other surface water bodies as a land-efficient form of renewable energy generation. Site-specific environmental risks may still arise due to the interaction between the floating infrastructure and aquatic ecosystems. Given the limited scientific literature on long-term ecological impacts, a precautionary approach should be adopted, particularly where FPV installations are located on water bodies with ecological, water provision, food production, or community significance.[37]

34. The main environmental impact of FPV systems is shading and reduced sunlight reaching the water, which can alter growth of algae and other primary producers. These changes can affect ecological processes such as the balance of small organisms in the water that influence the availability of food for fish, birds, and other species that rely on aquatic food chains. As a result, shading effects from FPV can lead to shifts in the overall ecosystem structure and function.[38]

35. Of particular concern is the potential for floating or ground-mounted solar installations to contribute to the phenomenon known as the lake effects hypothesis, in which reflective solar panel surfaces are mistaken by obligate waterbirds (e.g., loons, grebes, and pelicans) as water bodies.[39] This misperception can result in birds landing on panel surfaces, leading to physical injury, dehydration, or death, a phenomenon referred to as "avian stranding." Such risks are most acute for nocturnally migrating or water-dependent species and may be exacerbated in arid or semi-arid landscapes where natural water bodies are scarce.[40]

36. To mitigate impacts on biodiversity and prevent habitat conversion, consider the following measures:

- Conduct biodiversity baseline assessments specific to solar projects that consider seasonal variation and species use. Include targeted avian surveys and, where relevant to floating or pile-supported installations, aquatic and benthic surveys to inform site selection and array layout.[41]
- Implement targeted construction controls and monitoring to protect sensitive biodiversity and cultural heritage features, especially where siting of facilities near sensitive areas is unavoidable.

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[36] Carlo Renno and Olga Di Marino, "Agrivoltaic Systems."
[37] R. Cazzaniga et al., "Floating Photovoltaic Plants."
[38] Z. Liu et al., "Aquatic Impacts."
[39] Anderson, C. et al., "Waterbirds."
[40] Horváth, G., et al. *Polarized light pollution.* Hernandez, R.R. et al., *Aligning floating photovoltaic with waterbird conservation.*
[41] IUCN, *Mitigating biodiversity impacts associated with solar and wind energy development.*

- Preserve and incorporate wildlife corridors to allow free movement of species and introduce habitat-friendly measures such as insect and small animal habitat, especially if avoidance of high ecological value areas is not completely possible.
- Consider green roofs and permeable surface coverings, if feasible.
- Allow livestock-grazing or other low-impact land uses as alternatives to mechanical or chemical vegetation control (e.g., integrated pest management) where feasible, considering livestock safety with moving machinery and energized parts.
- Maintain natural vegetation buffers between infrastructure and nearby terrestrial or aquatic systems.
- Maintain open buffer zones around the perimeter of the array to facilitate air–water exchange and access.
- Assess the impacts of shadows, particularly in sensitive aquatic and terrestrial systems and where negative, design installations to minimize shadow effects and where possible promote positive effects.[42] Some alternatives include elevated panel structures, strategic row spacing, or partial array coverage.
- When risks are significant, utilize anti-reflective coatings, glass texturization and panel alignment strategies that reduce the likelihood of misidentification by birds.[43]
- Implement adaptive biodiversity monitoring programs specific to solar energy applications (e.g., floating and agri-PV systems) and proportionate to identified risks, including monitoring of habitat conditions and species where relevant including aquatic species and water quality for FPV and pollinators, birds, and small mammals for agri-PV, to track ecological impacts over time and guide mitigation or corrective measures. Monitoring results should inform adaptive management measures to address unforeseen impacts during construction and operation.[44]

4.2 Occupational Health and Safety

37. This section presents specific considerations for worker occupational health and safety (OHS) during construction, commissioning, operations and decommissioning phases in the solar PV sector, while OHS hazards and management common across sectors are discussed in the General EHS Guidelines.

38. OHS hazards specific to the solar PV industry include the following:

    - Working at height
    - Mechanical hazards
    - Ergonomics and manual handling

[42] In some contexts, FPV installations may also provide positive effects for fisheries by creating shaded refuges, moderating water temperatures, or offering structural habitat that can attract certain fish species. These benefits are site-specific and should be evaluated alongside potential ecological risks.
[43] NGA, *Bird-Friendly Glazing Design*.
[44] IUCN, *Mitigation of Solar Projects*.

- Electrical safety
- Fire safety
- Exposure to weather and environmental conditions
- Working near water and floating PV safety

4.2.1 Working at Height

39. Working at height is a common requirement in Solar PV projects, particularly during the installation and maintenance of rooftop and captive systems, agri-PV installations, or other elevated structures. Solar-specific risks often occur on rooftops with limited or sloped access, fragile or uneven roof elements not designed to bear weight; where workers handle large, fragile modules in confined or unsecured areas; and/or absence of integrated fall protection or anchor points in system design. Elevated ground-mounted systems also pose hazards during construction and tracker installation when workers access structures without fixed walkways or platforms and collapse of racking frames.

40. Environmental or weather factors add to these risks, including glare and heat from modules that can impair visibility and concentration, while wind, rain, snow, and extreme temperatures create slippery surfaces, reduce visibility, and compromise balance, increasing the likelihood of falls.

41. Mitigation and control measures include the following:

- Prohibit workers from stepping on solar modules.
- Install non-slip walk-paths between rooftop panels and at rooftop access zones to prevent slips and facilitate maintenance without stepping on modules.[45]
- Conduct rigging inspections, including bracing and joints, corrosion protection, and snow or ice control to prevent collapse of racking frames.
- Establish exclusion zones beneath elevated work areas to prevent injury from falling tools or materials, particularly during the assembly of ground-mounted structures such as racking or trackers.[46]
- Schedule tasks to avoid periods of high wind, glare, or extreme heat or stop work if conditions worsen.
- Train personnel conducting elevated work in solar-specific height safety procedures, with provision and regular inspection of appropriate PPE, including safety harnesses, tool lanyards, non-slip footwear, and other relevant equipment.

[45] SolarPower Europe, *O&M Guidelines*.
[46] US DOL OSHA, *Green Jobs Hazards: Solar.*

4.2.2 Mechanical Hazards

42. Solar PV installations using mechanical tracking systems may introduce occupational risks associated with unexpected or automatic movement of tracker structures and associated components during installation, commissioning, operation, or maintenance activities. Movement of torque tubes, rotating structures, or automated repositioning systems may create struckby, entrapment, or pinchpoint hazards for workers positioned within or beneath array rows. These risks may be elevated during system testing, energization, softwarecontrolled repositioning, or fault recovery, when mechanical movement can occur without direct worker initiation.

43. Mitigation and control measures include the following:

- Use tracker safe-maintenance or lock-out modes to physically prevent unintended movement of tracker rows, torque tubes, or drive mechanisms during installation, commissioning, or maintenance.
- Apply permit-to-work requirements specifically for tracker-related tasks, particularly where work is conducted within, beneath, or between tracker rows during commissioning, testing, or fault recovery.
- Maintain clear coordination between field personnel and tracker control systems, including confirmation of system status (e.g., manual, automated, or testing mode) before work begins.
- Train workers on tracker-specific mechanical hazards, including recognition of pinch points, zones of potential movement, and risks associated with automated or software-controlled repositioning.

4.2.3 Ergonomics and Manual Handling

44. Solar PV projects involve repetitive and load-intensive tasks that present sector-specific ergonomic risks. PV modules are large, flat, and fragile components that often require two-person handling. Their dimensions and limited grip points increase shoulder loading and spinal torsion during lifting, positioning, and fastening. Installation on fixed-tilt or tracker systems frequently requires sustained forward flexion, overhead reaching, or static holding while securing clamps. String wiring beneath modules, installation of torque tubes and mounting rails, and handling of inverters or battery cabinets can further expose workers to awkward postures, asymmetric loads, and repetitive strain.

45. Mitigation and control measures, in addition to those described in the General EHS Guidelines, include the following:

- Use mechanical aids (e.g., trolleys, hoists, or pulley systems) to move panels, mounting structures, and other heavy equipment.
- Implement team lifting protocols for heavy or awkward loads (e.g., solar modules and inverters).
- Train personnel in safe lifting techniques, posture management, and solar specific ergonomics.

- Design work layouts to minimize bending, twisting, or overreaching, including adjustable supports and access platforms.
- Schedule high-intensity handling tasks with rest breaks and task rotation to reduce fatigue.
- Keep pathways clear and surfaces stable to prevent slips, trips, or falls.
- Provide PPE as needed, including gloves to improve grip, safety footwear with anti-slip soles, and back support belts if required.

4.2.4 Electrical Safety

46. Electrical hazards are a significant occupational risk throughout the lifecycle of solar PV projects. Unlike conventional electrical systems, solar installations pose unique dangers due to the presence of direct current (DC), continuously live panels during daylight hours, and the potential for water-related electrocution risks, particularly in floating or rooftop systems. This limits the effectiveness of traditional lockout/tagout (LOTO) procedures and necessitates tailored mitigation strategies. Therefore, the LOTO program should include a permit-to-work process and clearly defined roles and responsibilities for the isolation, verification, and re-energization of PV equipment.

47. Additional risks include arc flashes or faults caused by degraded wiring or loose connections; shock hazards in wet or floating PV environments; and residual voltage in PV inverters due to capacitors that retain charge post-shutdown. Commissioning of solar sites can introduce elevated electrical and fire risks during energisation, unexpected movement of mechanical or tracking systems, and hazards linked to final inspections or transformer/BESS testing. During decommissioning, damaged or weathered modules may still hold electrical charge, posing risks of contact with live parts.

48. Mitigation and control measures include the following:

- For live DC exposure: Schedule work during low-irradiation conditions to minimize electrical risks. Use clearly labeled DC disconnect switches and PV-specific LOTO protocols, including a proper permit-to-work process. Install warning signs such as “Live When Exposed to Sunlight” and support appropriate workers training on the characteristics of solar DC systems and the risks of energized components throughout all project phases.
- Electrical isolating switches: Position isolators as close as possible to the equipment being maintained. Adequate earthing of metallic components (e.g., support structures) is essential to protect against touch potential given the high DC voltage levels in large PV arrays.[47]
- For arc flash or arc faults: Develop and implement an arc flash program with written standard operating procedures (SOPs), appropriate tools, PPE, warning signage, and regular personnel training. Regular thermal imaging and infrared (IR) inspections can help detect early signs of electrical degradation.

[47] IEC, *62738*; IEC, *62548*.

- For wet or floating PV environments: House electrical components in enclosures with suitable ingress protection (IP) ratings and use water-resistant cabling and marine-grade fittings. Install residual current devices (RCDs) and ground-fault protection systems designed for wet conditions, and train workers in rescue techniques specific to water-based electrical incidents.
- For inverter-related hazards: Observe minimum wait times after shutdown to allow for capacitor discharge according to manufacturer specifications. Keep inverter cabinets locked and clearly labeled with electrical hazard warnings. Restrict intervention to qualified personnel trained in DC-AC conversion systems.
- For decommissioning risks: Follow safe disconnection sequences (e.g., string → combiner → inverter). Use insulated tools and arc-rated PPE and provide workers with training in solar decommissioning procedures. Observe the Waste Electrical and Electronic Equipment (WEEE) Directive or applicable local regulations for PV waste disposal.[48]

4.2.5 Fire Safety

49. Fire risks in solar PV arise from electrical faults, overheating components, poor installation, and the proximity of flammable materials to energized equipment.

50. Specific mitigation and control measures include the following:[49]

- Conduct periodic thermal imaging and infrared scanning of connectors, junction boxes, inverters, and battery enclosures.
- Develop site-specific fire response plans covering PPE, evacuation routes, and coordination with local fire services experienced in energized PV systems; include battery-specific fire measures where batteries are co-located.
- Avoid flammable material storage near inverters or battery systems, maintain site housekeeping, exercise vegetation control across the site, including ground-mounted arrays and the power plant perimeter, to reduce wildfire risk and prevent fire spread to electrical equipment.
- Meet applicable fire safety standards to PV systems; install clearly labeled rapid shutdown and isolation mechanisms appropriate to the system type and location, especially during emergency and maintenance work.
- For installations with large oil-filled transformers, incorporate appropriate fire risk mitigation measures, including adequate fire separation distances, oil containment systems, and drainage control, ensuring alignment with applicable international standards (e.g., NFPA, IEEE).

[48] Solar Best Practices, *End-of-Life Management*.
[49] SolarPower Europe, *O&M Guidelines*. NFPA, *70 NEC Article 690*.

4.2.6 Exposure to Weather and Wildlife

51. Workers involved in installation, inspection, or maintenance of solar PV modules may face heat stress, dehydration, UV exposure, glare and reflected sunlight causing visual fatigue, lighting, sudden weather hazards such as high wind and heavy rainfall, and, depending on the project area, exposure to wildlife (e.g., snakes, insects) or endemic infectious diseases. Remote locations have an increased risk of delayed medical response.

52. Mitigation and control measures include the following:[50]

- Adapt work schedules and task planning to avoid peak solar radiation hours and prioritize labor-intensive tasks early or late in the day.
- Implement heat stress protocols including hydration stations, shaded rest zones, scheduled breaks, and heat acclimatization plans.
- Provide UV-protective PPE, such as long-sleeved breathable clothing, wide-brimmed hard hats, neck coverings, and UV-safety eye protection, supply sunscreen on-site.
- Install on-site meteorological monitoring for temperature, wind, and UV; allow suspension of work during unsafe conditions.
- Train personnel to recognize and respond to heat-related illnesses, weather emergencies, and wildlife hazards.
- For remote sites, maintain first-aid kits and establish site-specific emergency and medical response plans, including identified referral facilities and emergency transport arrangements.
- Manage vegetation around work areas, access routes and equipment locations to reduce wildlife risks.
- Implement disease prevention measures, including worker health screening, vaccination programs, vector control, safe water/sanitation, hygiene promotion, and outbreak response procedures.

4.2.7 Working Near Water and Floating PV Safety

53. Working near or over water introduces unique health and safety risks during the construction, operation, and maintenance of FPV systems. Accidental falls can lead to drowning, slips in wet surfaces, difficulty in rescue and potential for delayed response times, platform instability, exposure to waterborne diseases and wildlife, contaminated water, and currents. Some of these risks can be mitigated by minimizing time on water through remote monitoring and modular designs that allow pre-assembly.

[50] US DOL OSHA; *Green Jobs Hazards: Solar;* ILO, *Heat at Work;* SolarPower Europe, *O&M Guidelines*.

54. Mitigation and control measures include the following:[51]

- Use personal flotation devices (PFDs) for all work on floating structures or within fall range of water bodies.
- Adapt fall prevention to suit FPV platforms, which often cannot support traditional fixed anchors.
- Install non-slip, stable walkways and working surfaces and inspect them regularly for algae buildup, damage, or misalignment.
- Develop site-specific emergency rescue plans that incorporate water recovery procedures, lifebuoys, trained rescue staff, and clear emergency evacuation routes.
- Implement waterproofing, earthing, and electrical isolation appropriate to splash or submersion zones (e.g., ingress protection [IP] ratings, ground fault circuit interrupter protection).
- Include water surface conditions (e.g., wave height, current speed) and weather monitoring protocols to support safe access during inspections or repairs.
- Provide FPV-specific safety training, including use of flotation equipment, water rescue basics, and emergency response.
- Maintain proper sanitation and vaccination precautions when working in contaminated water (e.g., irrigation channels, ponds, flood-prone sites) and monitor water quality.
- Manage wildlife risks by raising awareness with workers on local aquatic and semi-aquatic species present around waterbodies and training on safe response procedures.

4.3 Community Health and Safety

55. This section presents sector-specific considerations for community health and safety (CHS) risks during construction, commissioning, operations and decommissioning in the solar PV sector. CHS risks and hazards common across industries are described in the General EHS Guidelines.

56. Specific CHS risks in the solar PV sector include the following:

- Electrocution risk
- Fire and emergency preparedness
- Glint and glare/visual distractions[52]

[51] World Bank, ESMAP, and SERIS, *Where Sun Meets Water*.
[52] Glint (brief flashes of reflected sunlight and glare a sustained reflection of bright sunlight).

- Water and marine safety
- Noise nuisance from balance-of-system equipment (e.g., inverters, transformers, switchgear) near sensitive receptors (see Section 3 and the General EHS Guidelines)

4.3.1 Electrocution Risk

57. Electrocution hazards to communities can arise from unauthorized access to energized solar PV equipment (e.g., inverters, transformers, BESS, or overhead/underground cables) or panel damage exposing live parts. PV-system specific risks include the following:

- FPV: Installations on conductive, moving, or corrosive water surfaces can degrade insulation and increase leakage currents, causing short-circuit and electrocution risks for nearby water users; moisture-related degradation, even before power loss is detected, can trigger arc hazards.[53]
- Ground-mounted: Distributed DC cabling and electrical equipment across large footprints can increase electrocution and arc-flash risks if people access boundary areas or if damage exposes live parts.[54]
- Agri-PV: Placing electrical components within active farming areas increases contact risks from machinery, livestock, or farmers.[55]

58. Mitigation and control measures include the following:[56]

- Install buoys, barriers, or warning tape around FPV platforms and raise community awareness on electrical hazards.
- Restrict rooftop PV access on public or community buildings (e.g., schools, hospitals, government buildings); meet relevant building and interconnection codes under the Life and Fire Safety provisions.[57]
- Protect public boundaries and crossings for ground-mounted PV with access control; enclose cabling and secure electrical equipment; provide external emergency disconnects or shutdown arrangements for trained responders and keep access clear; apply lighting and surge protection to exposed arrays and long cable runs.[58]
- Maintain separation of agri-PV electrical equipment from agricultural activities; route cabling away from travel lanes and work areas; protect cables/junctions via buried or mechanically protected conduit with appropriate IP rated connectors for wet or flood-prone areas; install livestock-safe barriers around inverters, transformers, and storage enclosures accessible

[53] Ricardo Rebelo et al., "Photovoltaic Cable Submersion Testing;" SolarPower Europe, *Floating PV Best Practice*; World Bank, ESMAP, and SERIS, *Where Sun Meets Water*.
[54] IEC, *62548*.
[55] SolarPower Europe, *Agrisolar Best Practice Guidelines*.
[56] IEC, *61557*; IEC, *60364*; IEC, *62446*; NFPA, *70 NEC*; ISO, *7010*; IEC, *60417*.
[57] NFPA, *70 NEC Article 690;* IEEE, *Standard for Interconnection.* The NFPA resource provides safety requirements for solar PV electrical energy systems, including specifications for design, installation, and operation of modules, inverters, and controllers, as well as wiring methods, grounding, conductor sizing, disconnecting means, rapid shutdown, module listing, guarding of live parts, and access pathways.
[58] IEC, *62548*; IEA-PVPS, *Photovoltaics and Firefighters' Operations*; NFPA, *70 NEC Article 690*; IEC, *62548*.

from farming areas; post safety signs and provide farmers and nearby residents with awareness training; on electrical hazards and reporting damaged equipment or exposed cabling and inspect after storms or floods before normal access resumes.[59]

4.3.2 Fire and Emergency Preparedness

59. PV sites present a fire risk which, if not carefully planned, can spread beyond project boundaries, particularly in dry and arid climates.[60] Community exposure to such incidents can lead to smoke inhalation, respiratory distress, burns, and secondary health impacts. Sensitive receptors, especially occupants of buildings with rooftop PV and those with preexisting respiratory conditions, may be disproportionately affected by smoke exposure and evacuation stress.[61]

60. FPV sites present specific community health and safety risks during severe weather events or electrical system failures. Extreme wind and wave loads can overturn float arrays, sever mooring lines, and create debris fields that may threaten water users and shoreline communities.[62] Electrical faults or short circuits may ignite modules, releasing smoke and particulates.[63] Poor cable routing and mechanical wear can increase electrical fault and fire risk, while limited water access may delay inspection and repairs, heightening risks to nearby water users and communities.

61. Key mitigation and control measures, specific to solar PV that complement general fire and emergency measures, include:[64]

<u>Solar PV</u>

- Install lightning protection systems (e.g., air-termination/lightning rods, down-conductors, grounding with potential bonding and surge arresters) to prevent flashovers.
- Maintain adequate clearance from hazards.
- PV plants with large transformers can experience violent fires, including explosions from rapid pressure buildup caused by internal electrical faults. Vaporized mineral oil can rupture the tank, releasing burning oil and smoke; without compliant containment (NFPA/IEEE), oil may spread beyond the plant boundary. High-capacity Class B foam or dry-chemical extinguishers are required. Water is generally unsuitable due to high voltage, but water mist may be used for cooling and to protect adjacent transformers, electrical controls and nearby structures.

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[59] Fraunhofer ISE, *Agrivoltaics*; IEC, *60529*; SolarPower Europe, *Agrisolar Best Practice Guidelines*.
[60] US DOE FEMP, *Solar Photovoltaic Hardening*.
[61] Hong-Yun Yang et al., *Fire Hazards Photovoltaic Modules*. According to this resource, in real fire scenarios with flame temperatures of 800–1,000 °C and PV modules up to ten times thicker than test specimens, PV modules mounted on buildings can be much more dangerous when exposed to actual fires than these experimental ones, underscoring the need for tailored fire-safety provisions and full-scale burn testing.
[62] For example, typhoons in Japan (2016 and 2019) and a tornado in the Netherlands (2019) caused damage to floating PV installations, including overturned arrays and broken mooring systems.
[63] World Bank, ESMAP, and SERIS, *Where Sun Meets Water*.
[64] IEA-PVPS, *Floating Photovoltaic Power Plants;* IEC, *60364*; IEC, *62446*.

- Procedures for securing panels during high winds and for post-storm inspection, including coordination with PV recycling partners for damaged panels, should be in place and include the following:
    - O&M and Pre-storm Actions:
        - Clean debris and vegetation around solar structures
        - Tighten bolts and check panel integrity
        - Train personnel on pre- and post-event procedures
        - Implement site lock-down when required
        - Secure all equipment and materials
    - Post-storm Actions:
        - Conduct a full post-storm assessment
        - Use backup power to maintain plant standby mode
        - Clean and dry electrical systems
        - Test for system faults
        - Arrange for safe removal of damaged panels to prevent leakage or contamination and recycling
        - Do not re-energize systems until inspections confirm they are safe, as damaged panels or wiring may pose shock hazards.

FPV

- Install submarine-grade underwater cables that are consistent with international standards to prevent insulation failure and unintended energization of surrounding water bodies.[65]
- Provide safe access to the FPV arrays and anchoring and mooring lines, including diver access where needed, for maintenance and emergency response.
- Conduct risk assessments of electrical system design, addressing potential immersion of components such as cables and connectors, water ingress, cable management, and earthing solutions.

Agri-PV

- Minimize ground cabling; route cables beneath module roofs or along mounting structures where possible.
- Where underground installation is needed, bury cables at depths consistent with applicable standards and local conditions; protect trenches to avoid interference with agricultural activities.[66]
- Install above-ground cables at heights that prevent human and livestock contact; shield cables in livestock areas to prevent damage or safety risks, and mark cables for clear visibility.[67]

[65] World Bank, ESMAP, and SERIS, *Where the Sun Meets Water*; IEC, *60794;* IEEE, *400-2023*.
[66] IEC, *60364*.
[67] SolarPower Europe, *Agrisolar Best Practice Guidelines;* IEC, *60332*; IEC, *TS 62852*.

Rooftop PV

- Design arrays and support structures to avoid overloading, obstructing escape routes, or impairing roof drainage or waterproofing.
- Preserve designated refuge areas with proper fire separation.
- Provide appropriate and accessible fire extinguishing equipment suitable for electrical fires, in accordance with applicable national fire codes or relevant guidance and the project's fire risk assessment[68]
- Provide easy access to the roof at two separate locations, if possible, and maintain updated documentation (drawings, narratives) of the location of main PV equipment in the building, for the utilization by the fire department and other first responders.

4.3.3 Glint, Glare, and Visual Distraction

62. Glint and glare from PV module surfaces and metal frames can pose risks to nearby communities, motorists, or waterway users. Reflections can impair visibility, causing temporary visibility loss, distraction, or discomfort, which may increase collision and navigational risks.

63. Large-scale ground-mounted and FPV installations can alter the visual character of rural and peri-urban areas and increase reflective hazards. PV arrays sited near airports or airfields may affect pilot visibility.

64. Although modern solar modules have reduced reflective radiation, glint and glare assessments should be considered for projects near sensitive receptors, such as airports. Assessment should evaluate the potential reflection intensity, duration, and angle.

65. Mitigation and control measures include the following:

- Maintain buffer distances between PV arrays and nearby receptors; consider vegetative screening (e.g., using plants, hedges, or landscaping to create visual barriers).
- Apply anti-reflective coatings on modules.
- Optimize panel orientation such as adjusting the tilt and azimuth to direct reflections away from the roads, rivers, or flight paths while maintaining energy efficiency.
- Engage with national and local authorities when project siting or design may affect public safety, infrastructure, or regulated airspace.

[68] See, for example, Government of the Hong Kong Special Administrative Region, *Guidance Notes for Solar Photovoltaic (PV) System Installation*, 2024.

4.3.4 Water and Marine Safety

66. Floating and nearshore PV installations may create navigational hazards and interfere with marine activities such as fishing or recreation, particularly near ports, harbors, boat corridors, or community access points.[69] Risks include collision, drowning, and exposure to electrical or fire hazards, as outlined in Section 4.2 and the General EHS Guidelines.

67. Construction-phase vessel movements for transport and installation activities of nearshore facilities can increase risks for community water navigation users, cause asset damage, or interfere with small- and medium-sized vessel routes. Low-profile installations may not be easily visible to all waterway users (e.g., recreational jet-ski riders or small craft operators).[70] Poorly planned anchoring, cable layouts, or floating platform positioning may obstruct navigation routes and increase collision risk.

68. Mitigation and control measures include the following:[71]

- Plan navigation corridors through or around project infrastructure.
- Define temporary and permanent safety zones and safe passage corridors.
- Engage fishing communities during layout planning to incorporate local knowledge and reduce potential safety issues.
- Mark installations with buoys, reflective signage, and lighting consistent with applicable national and international navigation practices.
- Provide navigation safety information to water users through maritime channels (e.g., navigational warnings/maritime safety information) and local communication before and during construction and maintenance.
- Schedule construction, installation, maintenance, and vessel movements outside peak fishing or boat-traffic hours.
- Equip installations with Automatic Identification System (AIS) beacons or other navigation alerts systems to help identify structures and delineate routes/areas to avoid, consistent with IALA guidance and national requirements.
- Monitor and manage temporary construction and maintenance hazards, including increased vessel traffic, debris, and equipment near community access points.

5 PERFORMANCE INDICATORS AND MONITORING

69. This section describes relevant EHS performance indicators and industry benchmarks of GIIP for this industry sector. Indicators that are applicable across industries are available in the General EHS Guidelines.

[69] World Bank, *Floating Solar Handbook*.
[70] World Bank Group, ESMAP, and SERIS, *Floating Solar Market Report*.
[71] IMO, *Preventing Collisions at Sea*. WMO, *Maritime Safety Information Publications*. IALA, *IALA Recommendation R0126*.

5.1 Environmental Performance

70. Environmental monitoring programs should address significant impacts during normal operations and upset conditions, based on direct and indirect indicators applicable to the project. Monitoring should be conducted by trained specialists, use calibrated and maintained equipment and follow GIIP methods to collect, verify, and analyze data. Results should be compared to applicable standards, and corrective actions should be implemented for any exceedances. Refer to the General EHS Guidelines for more information.

5.1.1 Environmental Monitoring

71. Environmental monitoring programs should cover significant environmental impacts across the solar facility lifecycle, including normal operations and potential upset conditions. Solar-specific monitoring elements may include water consumption, PV module waste, and biodiversity impacts. See the General EHS Guidelines for other environmental monitoring guidance.

72. Table 1 provides examples of recommended environmental key performance indicators (KPI) for solar PV projects. Final selection and applicability should be based on project-specific risks, impact assessment results, regulatory and permit requirements.

Table 1. Examples of key environmental performance indicators

Water consumption	• Total water consumption per panel per month (L/panel/month) • Water consumption per MW installed (L/MW/month) • Average liters per panel per cleaning cycle benchmark: 3–5 L/panel/cleaning cycle[72]
PV module waste and recycling	• Ratio of damaged modules to safely stored/recycled modules • % of damaged modules stored in compliant, weather-protected areas • Number of modules recycled per reporting period
Biodiversity monitoring	Number of recorded wildlife accidents with solar PV infrastructure (e.g., collision, stranding incidents, electrocutions, other)

5.2 Occupational Health and Safety Performance

73. Solar facilities should reduce the risk of occupational incidents and injuries, particularly those leading to lost work time, disability, illness, or fatalities during construction, operation, maintenance, and decommissioning activities. Benchmark facility-level OHS performance against relevant sector standards. Suggested metrics include incident counts, workplace inspections, number of resolved and unresolved findings, and training sessions frequency. Refer to the General EHS Guidelines for more guidance.[73]

[72] SEIA, *Water Use & Management.*
[73] Accredited professionals may include certified industrial hygienists, registered occupational hygienists, or certified safety professionals or their equivalent.

5.2.1 Occupational Health and Safety Monitoring

74. Monitor the working environment for project-specific occupational health hazards. Monitoring, including auditing and reviews, should be designed and implemented by qualified or accredited professionals as part of an OHS monitoring program.[74] Facilities should maintain records of occupational accidents, injuries, diseases, and dangerous occurrences. Refer to the General EHS Guidelines for further guidance.

[74] Accredited professionals may include Certified/Chartered or Registered Industrial or Occupational Hygienists, or Certified Safety Professionals or specialists or equivalent.

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ANNEX A: GENERAL DESCRIPTION OF INDUSTRY ACTIVITIES

1. Solar energy systems capture sunlight and convert it into electrical energy through solar cells, which release electrons when exposed to light photons. These systems are broadly categorized as follows:
   - Solar thermal: Uses sunlight to heat fluids for domestic hot water, space heating, or electricity generation via steam turbines
   - Solar electrical (Photovoltaic or PV): Converts sunlight directly into electricity using semiconductor materials

2. This document focuses on Photovoltaic (PV) technologies, the most common solar energy applications. The PV industry covers diverse project types, technologies, and deployment contexts, from small-scale rooftop installations to utility-scale plants exceeding hundreds of megawatts.

3. PV systems are deployed in four primary configurations, each differing in layout, development approach, and operational context:
   - Ground-mounted PV
   - Rooftop PV
   - Floating PV (FPV)
   - Agri-PV (Agri-PV)

Rooftop Solar PV Systems

4. Rooftop applications can range from small residential or off-grid systems to large-scale or utility-scale applications:
   - Residential rooftop: Small systems (0.1–30 kW), often grid-tied or hybrid
   - Commercial rooftop: Medium systems (10–500 kW), often on warehouses or offices
   - Large-scale rooftop: Industrial systems (>500 kW), often on logistics centers or factories
   - Off-grid systems: Used in remote areas with batteries and backup generators

5. Typical elements of a rooftop PV system include the following:
   - Solar modules, which convert sunlight into Direct Current/DC electricity
   - Inverters, which convert DC into Alternating Current/AC electricity
   - Mounting structures, which support the solar modules and are fixed-tilt
   - Grid-connection point with the electrical meter

- Cabling and electrical protective devices
- Monitoring systems for performance tracking and fault detection

6. Modules should be installed to maximize energy yield while minimizing surface area use, with tilt angles optimized for year-round sunlight exposure. Modules are weather-proof; inverters may require housing or can be installed outdoors depending on type.

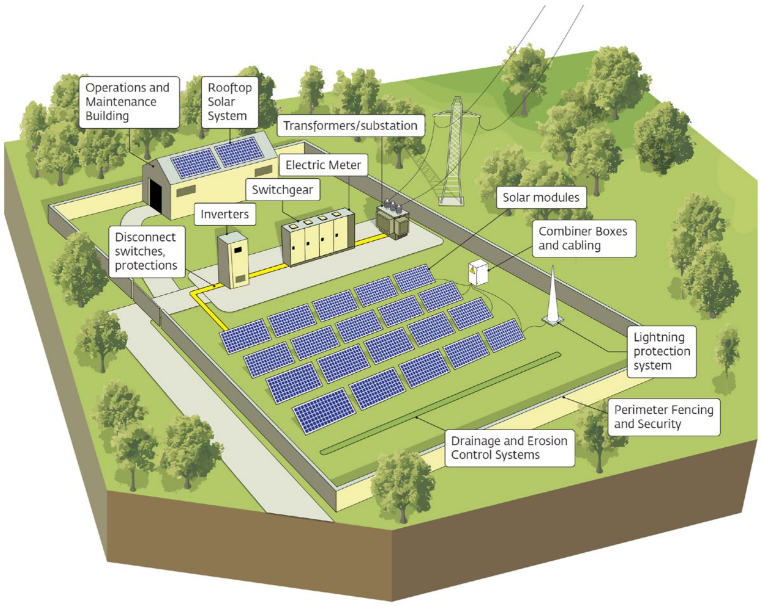
7. Inverters incorporate Maximum Power Point Trackers (MPPT) to optimize energy output in varying sunlight and temperature conditions. Protective equipment is typically located near inverters or in the main electrical cabinet connecting the solar system to the energy-consuming loads and to the grid. Off-grid systems may include batteries and backup generators.

Ground-mounted Solar PV Power Plants

8. Ground-mounted solar PV plants are typically utility-scale projects with capacities ranging from hundreds of kW to hundreds of megawatts (MW), mounted on the ground or large rooftops. They connect low-, medium-, or high-voltage electrical grids based on the system size and require large surface areas, typically 0.5 to 1.5 hectares per MW. Ground-mounted systems may use fixed-tilt structures or tracking systems to maximize sun exposure and energy yield; these also lead to higher capital and operational costs.

9. Additional components for large-scale plants include the following:
   - Combiner boxes link multiple solar module strings
   - Transformers to step inverter AC voltage to grid connection voltage
   - Electrical switchgear, which includes switching and protection equipment at higher voltages
   - Supervisory Control and Data Acquisition (SCADA) systems

Figure A1. Illustration of a utility-scale ground-mount solar plant



10. Permitting and grid connection approvals often take months and require engineering studies and site surveys. Arrays are spaced to allow for maintenance access and to reduce shading.

11. Typical construction activities include the following:

- Vegetation clearing and land grading
- Access road and perimeter fence construction
- Drainage work and trenching for conduits and grounding
- Installation of support structures, including pilings, racks, and floats
- Building or substation foundation work
- Delivery and placement of PV modules, inverters, transformers and other balance-of-system components
- Installation of overhead or underground electrical connections

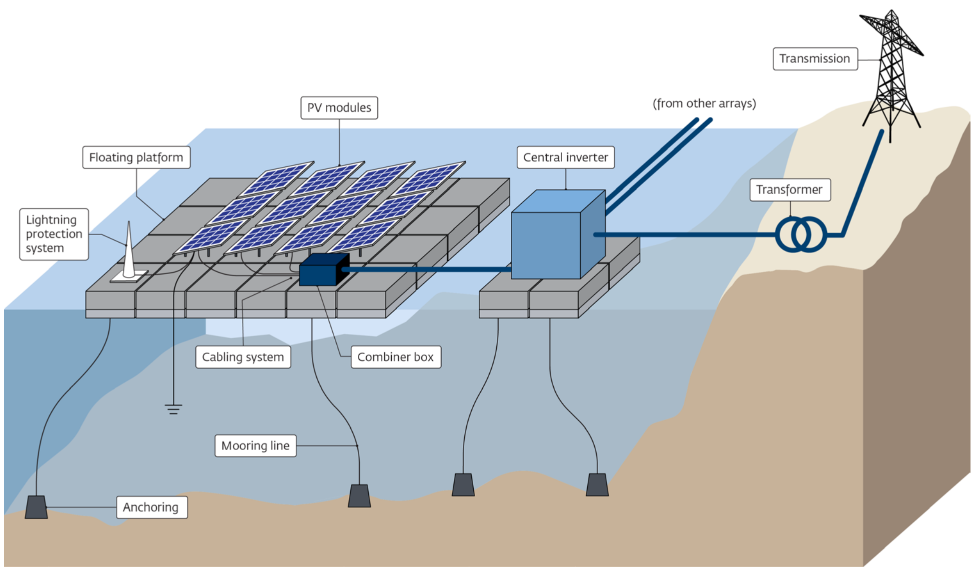
12. Commissioning involves testing against grid code and performance requirements. Preventive and corrective maintenance should be planned, with spare parts and rapid response by operations and maintenance personnel to minimize plant down-time. Module cleaning needs depend on the climate and nearby soiling sources. Decommissioning typically includes removing infrastructure and restoring the site to pre-project conditions.

FPV Power Plants

13. FPV systems are installed on water bodies such as reservoirs, lakes, or ponds, providing solutions in land constrained areas or dual use with hydropower reservoirs. FPV can reduce water evaporation and lower the module temperatures.

14. Components that are unique to FPVs include floats, anchoring and mooring systems, and floating or submerged cabling that links the floating array to on-shore electrical infrastructure.

Figure A2. Schematic of FPV installation



15. FPV may be installed on a range of water bodies, including the following:[75]

- Small freshwater: Ponds, irrigation reservoirs, mine lakes (often deep and calm with limited access)
- Large freshwater: Natural or artificial lakes; hydropower dams, drinking water reservoirs, flood-control reservoirs (often with variable wave and wind conditions)
- Nearshore seawater: Brackish lagoons, protected coastal areas

16. Development phase should consider underwater and near-shore flora and fauna, public and stakeholder use for activities such as fishing, boating, or recreation, and relevant authorities (water administration, tourism, fisheries). Bathymetric and water chemistry studies may be required, especially for drinking-water reservoirs to prevent contamination.

[75] Offshore applications are outside of the scope of this guideline.

17. Construction includes assembling floating platforms, anchoring systems, and cabling. Near-shore staging is typically needed for launching segments and towing into position. Installations should be secured against wind and currents.

18. Divers may be needed for underwater anchoring and mooring during construction and repairs. Maintenance includes boat or floating walkway access spare part delivery to the array, and regular inspection of anchors and mooring lines.

19. Decommissioning generally involves disassembly and removal of above-ground infrastructure, recycling of PV modules and batteries, and site rehabilitation. Dismantling FPV systems requires similar attention regarding water-activities and temporary mooring as during the installation phase. Complete removal of underwater anchors may not be possible.

Agri-PV Power Plants

20. Agri-PV systems are typically commercial and industrial (C&I) or utility-scale and tend to differ from standard ground-mount PV plants. Agri-PV systems include the following:

    - Elevated systems (row-based or canopy): Provide shade and water protection for crops or livestock, while allowing machinery and livestock access
    - Near-ground systems (vertical or tilted): Enable agricultural use between module rows, which may provide wind-protection

21. Agri-PV designs are typically more robust to withstand machinery and livestock interactions. Modules may have fixed or variable tilt and sometimes higher transparency to allow sunlight for crop growth.