WORLD BANK GROUP

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Environmental, Health, and Safety Guidelines

ELECTRIC POWER TRANSMISSION AND DISTRIBUTION

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CONTENTS

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 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 environmental 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 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 Electric Power Transmission and Distribution (ETD) include information relevant to the electric grid comprising transmission lines, substations, operating systems, and distribution lines carrying power to consumers in residential, commercial, and industrial areas across terrestrial, aquatic, and marine habitats. Annex A: General Description of Industry Activities provides a summary of industry activities.

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. ETD projects can present linear impacts over long distances. Early consideration of EHS issues helps prevent costly and challenging remedial actions. The following considerations for key risks are discussed:

- Infrastructure siting and route planning – to prevent and minimize risks and impacts to land use, biodiversity (aerial, terrestrial and aquatic), soil erosion and water quality, electrical safety, fire hazards and communities
- Infrastructure and equipment design – to promote biodiversity-safe designs, climate resilience and reduce safety risks such as fire hazards or infrastructure failure from landslides or flooding
- Climate resilience – considerations of acute and chronic climate hazards that can exacerbate risks

3.1 Infrastructure Siting and Route Planning

8. Routing an electric transmission line begins by identifying the energy and power requirements, operational voltage, and endpoints reflecting project objectives such as connecting a new power generation site, expanding service areas, or linking networks. A high-level routing study should screen and identify potential macro-corridors, considering major technical, environmental, biodiversity, social and land-use constraints and opportunities.[2] This process narrows options to preferred macro-corridors, which can be further refined using site-specific data. Tools like GIS, field surveys, multicriteria analysis, financial data, and stakeholder input help evaluate and select the preferred corridor.

9. Once a corridor is chosen, a detailed alignment study defines the right of way (ROW), tower locations (angle points, at a minimum), maintenance roads, and substations. Siting criteria should:

[2] Guidance on social aspects, including land acquisition and involuntary resettlement, is available in other WBG publications (see paragraph 5).

- Avoid sensitive receptors and hazard-prone zones (flood, erosion, landslide, fire, and unconsolidated deposits).[3]
- Consider land-use constraints, such as proximity to airports and flight paths, coordinating safety and anti-collision measures (such as lighting, marking systems, power line burial) with aviation authorities.
- Co-locate with existing linear infrastructure (transmission lines, roads, railroads) to reduce impacts and fragmentation.
- Incorporate climate resilience by avoiding areas vulnerable to sea-level rise, storm surge, or extreme weather events.

10. Line alignment within the utility corridor (including underwater cables) should be informed by baseline pre-construction biodiversity assessments considering:
    - Site-specific aspects (location, topography/ bathymetry, sensitive receptors and habitats)
    - Species-specific aspects (IUCN red-listed as CR/EN/VU, range-restricted, migratory or congregatory species, collision-or noise-susceptible species)[4]
    - Season-specific aspects (breeding and calving sites, reproductive cycles, migratory patterns)

11. For aerial lines, alignments should reduce collision risks by avoiding high-density bird habitats such as wetlands and nesting sites and orienting lines parallel to dominant flight patterns. Anti-collision measures are prioritized for power lines within 1 kilometer (km) of habitats where collision-susceptible species concentrate and within 1.5 km of priority species nesting sites.[5]

12. Substation siting should minimize hazard exposure and environmental impacts, provide safe access, proper electrical equipment layout, and compliance with electrical safety requirements. For low-voltage distribution lines, siting should also minimize exposure to electromagnetic fields (EMF) and impacts to biodiversity, water, land use, and noise.

3.2 Infrastructure and Equipment Design

13. Physical infrastructure (towers, poles, conductors, substations) should be designed following recognized international, regional and national standards.[6]

14. ETD infrastructure alignment, layout, design, materials, height and spacing influence electrical safety and can reduce fire hazards. Materials selection should consider environmental durability and fire resistance. Design of foundations (circular, rectangular) and substations (air or gas insulated) should be chosen to minimize EHS risks. Fire prevention designs, such as buffers along the ROW, reduce the risk of forest fires.

[3] Sensitive receptors are determined in the impact assessment. For ETD, this may include for example critical habitats, collision-prone species, Indigenous Peoples lands, high-density residential and commercial areas, vulnerable households, schools, hospitals, among others.
[4] IBAT Alliance, *IBAT*. IUCN, *Red List*. IBAT provides data, tools and guidance that help identify biodiversity-related risks and opportunities. IUCN Red List of Threatened Species provides information on the global extinction risk status of animal, fungus and plant species. CR: Critically Endangered species; EN: Endangered species; and VU: Vulnerable species.
[5] IUCN, *Wildlife and Power Lines Manual.* Provides guidelines and best practices for addressing power line related mortality of birds from electrocution and collision.
[6] For example, the standards from International Electrotechnical Commission and American National Standards Institute.

15. Tower locations should avoid riverbanks, with safe distances maintained. If unavoidable, foundation design should prevent erosion, settlement, or landslide risks that could cause the tower foundation to fail and threaten the safety of the community and the infrastructure. Transmission lines should maintain minimum vertical clearances from the highest flood level (HFL).

16. Security, health, and safety considerations should be integrated into the ETD infrastructure design, informed by risk assessment techniques.[7] ROW width is determined by voltage, anticipated powerline height, safety clearance, EMF exposure, and local environmental conditions.[8]

17. In higher-risk wildlife areas, design adjustments, such as tower spacing, height and micro-routing /micrositing, may help minimize impacts. The design of ETD infrastructure should minimize wildlife electrocution risk, particularly for large birds. For low and medium voltage distribution lines in open habitats, design should consider relevant measures in areas that attract raptors and other large birds that may use these structures and lines as perches, as well as arboreal and tall mammals that may come into contact with conductors. Undergrounding of low- and medium-voltage distribution lines can be considered as a mitigation measure in sections crossing areas with high densities of vulnerable species and high collision and/or electrocution risk. “Wildlife friendly” design principles generally include:[9]

- Separating electrified parts or electrified and grounded parts with clearances wider than the wingspan of the largest target species
- Using non-conductive materials for poles and/or cross-arms
- Installing covered or bundled insulated cables and using high quality insulation materials
- Using suspension insulators and avoiding the use of upright pin insulators, if possible
- Suspending electrified cables below cross-arms
- Positioning jumper cables below perching structures (poles, tension-holding cables, and cross-arms)
- Insulating caps for grounded poles, and electrified hardware (transformer bushings, reclosers, and surge arrestors), and optimizing safe distancing
- Installing elevated perching structures or perch discouragers (as last resort), after applying safe distancing and insulation[10]

[7] IEEE SA, Guide for SF6 handling. Safety in design review standards need to be established based on GIIP for design risk assessment methodologies that can be deployed at the design and engineering phase, either individually or in combination, such as the National Electrical Safety Code. American Society for Quality, FMEA. Example methodology includes the commonly used Failure Mode and Effects Analysis (FMEA)
[8] US Bureau of Land Management, *Energy Corridor Guidebook*. Provides guidance on considerations for ROW widths for a variety of structure types and voltage levels, as well as structure framing configuration, see Table 5-1.
[9] APLIC, Suggested Practices for Avian Protection; EC, Guidance on Energy Transmission; Martin et al., Wildlife and Power Lines Guidelines; Prinsen et al., Guidelines on Migratory Birds; RPS, Electrocutions & Collisions of Birds; UNEP, Guidelines for Mitigating Conflict. This is a list of general principles of raptor-friendly pole design and is not meant to be comprehensive or prescriptive for any particular project. Project-specific solutions should be developed based on available technical guidance, and in consultation with a technical specialist.
[10] APLIC, Suggested Practices for Avian Protection. Elevated perches and obstructive perch deterrents (e.g., insulated “V” designs) may be effective in moving birds from unsafe to safe perches on utility structures.

- Providing ground clearance to prevent electrocution from tall fauna (giraffes, elephants) using extensions for towers

18. Bird collision risks should be considered in powerline design, especially near wetlands and water bodies where collision-prone birds are common. Narrow, high voltage aboveground transmission lines, as well as lower hanging cables (in certain cases), are not readily visible to collision-prone, large waterbirds. Design features such as co-routing multiple circuits, co-locating transmission lines within the ROW, horizontal cable arrays, and Bird Flight Diverters (BFDs) enhance cable visibility for birds (also refer to 4.1.4).[11]

3.3 Climate Resilience

19. Climate change introduces acute and chronic hazards that can exacerbate environmental, occupational health and safety (OHS), and community health and safety (CHS) risks for ETD projects. Acute hazards, such as storms, floods, wildfires, and heatwaves, can damage ETD infrastructure, causing failure and collapse, heightening the risks of pollution (uncontrolled release of pollutants from leaking transformers affected by floods), and threatening local ecosystems.[12] Chronic hazards, like rising temperatures and altered precipitation patterns, may increase heat stress for workers, contribute to long-term ecosystem degradation and intensify fire risks.[13]

20. Climate resilience in ETD infrastructure is most effective when climate change vulnerabilities are understood and considered during siting, routing and design. Considerations for climate resilience include:[14]

    - Avoid disaster-prone areas such as those affected severely by flooding, erosion or forest fires.
    - Design and adapt equipment, substations and tower foundations to withstand flooding, sea level rise, erosion and landslides through optimized siting, elevated structures, insulated conductors, effective water management and erosion protection and control.
    - Design robust flood protection for equipment and hazardous materials storage and reinforce coastal defenses (seawalls, bulkheads, etc.).
    - Incorporate grid modernization into design to obtain data analytics that can prevent risks (see Annex A).

21. The compounded risks of climate change should also be considered during project construction, operation and closure.

[11] APLIC, Reducing Avian Collisions; BirdLife International, Birds and Power Lines; Martin et al., Wildlife and Power Lines Guidelines; Prinsen et al., Guidelines on Migratory Birds.
[12] Climate risks to infrastructure is outlined further in Annex A.
[13] WBG, Energy Sector Adaptation. Good practice note to assist in incorporating climate adaptation and resilience into power sector projects.
[14] Braun & Fournier, Adaptation in the Energy Sector; CA PUC, Climate Adaptation in the Electric Sector; EUEI PDF, Energy and Climate Change Adaptation; IEA, Energy Sector more Resilient to Climate Change; US DOE, Climate Change and the Electricity Sector.

4 CONSTRUCTION AND OPERATIONAL CONSIDERATIONS

22. This section provides a summary of sector-specific EHS issues typically associated with the operation and maintenance phases 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.

4.1 Environment

23. The following key environmental issues specific to ETD systems are described in this section:

- Terrestrial and aquatic habitats
- Wildlife electrocution and collision
- Pollution prevention

4.1.1 Terrestrial Habitats

24. Construction of ETD lines typically requires clearing the ROW vegetation, which may transform terrestrial habitats and impact biodiversity depending on existing vegetation and topography. Habitats may be disturbed, converted, fragmented, or lost, and adversely affect wildlife. ROW clearing may also enable the spread of invasive alien species.[15]

25. In addition to site-selection and routing (see Section 3.1), specific measures for ETD infrastructure (primarily HVL) include:

- Demarcate sensitive sites identified in preconstruction assessments (nesting and denning habitat, critical habitat, sensitive vegetation communities) with buffers/setbacks of undisturbed vegetation.[16] For example, establish setbacks around wetlands or around sensitive plant species.
- Limit ground disturbances to well-marked areas such as tower work pads, access roads, and pulling and tensioning areas. For underground lines, limit disturbances to a predefined corridor. Demarcate work areas with flags or fences and instruct workers to stay within the marked work areas.
- Narrow the cleared ROW to avoid or minimize impacts on sensitive areas (riparian zones at watercourse crossing points).
- Apply seasonal restrictions for construction during breeding or other sensitive periods.
- Train workers to minimize wildlife disturbance and prohibit hunting, poaching or killing wildlife.

[15] Biasotto and Kindel, Powerlines and Impacts on Biodiversity. This document provides more information on potential adverse impacts to habitat and biodiversity from transmission and distribution development.
[16] Manitoba Hydro, Fur, Feathers, Fins, and Transmission Lines; SaskPower, Environmental Beneficial Management Practices, 15-43.

- Dispose of cleared vegetation and timber to avoid disrupting wildlife movement and minimize wildfire risk.[17]
- Use selective initial ROW clearing to remove tall-growing species while leaving low-growth species for safety.[18]
- Prioritize existing access roads to prevent habitat fragmentation and access to previously inaccessible areas, minimize new access roads, limit or avoid paving and restrict use of access roads.
- Close and reinstate construction access roads unnecessary for maintenance to promote habitat restoration.
- Consider use of helicopter for difficult terrain in highly sensitive areas (steep slopes, narrow valleys, dense forests with high canopy, some protected areas).
- Reuse cleared vegetation and soil to re-establish wildlife habitat features post-construction. Store topsoil for future rehabilitation.
- Minimize slope instability and soil loss by limiting infrastructure on slopes, especially where significant excavation is required, and take precautions during periods of saturated soil conditions. Use equipment and techniques that minimize soil loss and compaction, such as low ground pressure tires or wide pad tracks, and use of mats in sensitive areas.[19]
- Restore and recontour disturbed areas to prior drainage patterns.

26. During operations, maintain the ROW by trimming, pruning and mowing vegetation and applying herbicides. These activities should remain within the ROW and avoid extending into natural habitats. Use selective herbicides with an integrated vegetation management (IVM) approach (see Herbicides).

4.1.2 Aquatic Habitats

27. Transmission and distribution powerlines, access roads, and facilities may cross aquatic and/or marine habitats, potentially disrupting watercourses, wetlands, and riparian vegetation. Construction activities can increase sediment and turbidity in surface waters. In marine environments, submarine cables are typically installed using cable-laying vessel and buried in the intertidal zone, which may impact intertidal and benthic vegetation, sensitive ecosystems (coral reefs, sea grass areas), and feeding and spawning areas for fish and marine mammals.[20] Sedimentation and resuspension can result in increased turbidity and affect water quality. Cable-laying vessels and underwater cables may also generate underwater noise, heat, electromagnetic fields and release of hazardous substances (older cables may contain insulating oils or PCBs) affecting aquatic habitats and fauna.[21]

[17] SaskPower, Environmental Beneficial Management Practices,22-25. An example of a mitigation measure to facilitate wildlife movement and to minimize potential barrier effects is to limit collections of cleared debris to no more than 200 meters in length and 1 meter in height and to include separation gaps of 5 meters to facilitate wildlife movement.
[18] NERC, Transmission Vegetation Management; BC Hydro, Integrated Vegetation Management Plan; LIFE Elia-RTE, *Vegetation Management Practices*; LIFE Elia-RTE, Vegetation in Forest Corridor, Brochures 01-03-04-05-06-7.
[19] Mats can be placed on the ground in sensitive areas (including erosion-prone area, waterlogged soils, etc.) to reduce compaction, erosion and damage to soil due to the circulation of heavy equipment and machinery.
[20] BC Hydro, Submarine Cable Maintenance, 8–20; UK BERR, Cabling Techniques and Environmental Effects,110–112. These documents provide more information on submarine cable installation and sensitive habitats, including intertidal zones.
[21] OSPAR Commission. Cable laying and Operation; SaskPower, Environmental Beneficial Management Practices; BC Hydro, Submarine Cable Maintenance.

28. Mitigation measures to protect aquatic and marine biodiversity include:[22]

- Avoid or minimize new access roads or infrastructure across aquatic habitats; maximize use of existing crossings and opt for low-impact vehicular crossing methods such as clear span bridges or open-bottom culverts when new crossings are needed.
- Position crossings (including fording, culverts, and bridges) to maximize bank stability and minimize erosion.
- Consider helicopter construction for difficult terrain or sites in highly sensitive areas, such as wetlands.
- Avoid spawning and overwintering habitat and seasons for sensitive aquatic species.
- Avoid coral reefs and seagrass prairies, if possible.
- Conduct in-stream construction for tower installation without disrupting flow; maintain downstream flow to preserve ecosystem functions.
- Set site-specific restrictions for submarine cable laying to minimize disturbance to fish and marine mammals during sensitive periods (breeding, calving, spawning, and other sensitive seasons or times of day). Monitor marine mammal presence and modify activities to avoid collision or excessive noise; implement a “slow start” approach to allow passive dispersal of marine mammals and fish.
- Use markings while crossing sea bottom areas, where feasible, to protect benthic vegetation, coral reefs, sea grasses and other supporting ecosystem functions.
- Favor laying techniques that minimize sediment displacement such as ploughing or horizontal directional drilling.[23] If horizontal drilling is not possible and vegetation is present, remove and replant the vegetation.
- Schedule cable laying to reduce sediment displacement and habitat disturbance such as during low tides in tidal flats or outside periods when these areas are more intensely used (feeding and resting areas, coastal breeding habitats, spawning grounds, etc.).
- Selecting sufficient burial depth (1 to 3 m) to minimize temperature increase of surface sediment and effect of magnetic and electric fields which could affect benthic communities.
- Consider removal of unused cables containing fluids to minimize future risk of contamination. However, the impacts of removal should be considered and evaluated against those of leaving the cable in place.

[22] Most of these mitigations are applicable to high voltage lines.
[23] OSPAR Commission. Cable laying and Operation. For other general mitigation measures for laying and operating underwater cables, consult OSPAR.

- To minimize disturbance to riparian habitat adjacent to waterbodies and at watercourse crossings, avoid or selectively clear the ROW (cutting only species reaching high elevation) within the buffer/setback from the bank.[24] Use of manual clearing techniques is recommended.

4.1.3 Wildlife Electrocution

29. As introduced in Section 3.2, large birds, especially raptors, and some wildlife are known to be electrocuted on powerlines when they make simultaneous “flesh-to-flesh” contact with either two different electrified parts or an electrified part and a grounded part. Wildlife electrocution impacts are most prevalent in certain groups of birds with a behavioral tendency to perch and/or nest on powerlines and support structures (poles, pylons), especially eagles, falcons, other raptors, owls, vultures, and storks. Wildlife electrocution impacts also regularly occur with non-flying animals with a tendency to climb on powerline structures, such as snakes, monkeys, sloths and squirrels. Large mammals such as giraffes and elephants may be electrocuted when clearance is insufficient.

30. Wildlife electrocution impacts typically occur on poles/pylons, not spans. Wildlife electrocution impacts are generally of greatest concern for low and medium voltage distribution lines, though high voltage transmission lines may also pose a risk, especially in areas where vultures or other large birds’ roost. Raptors are at most risk in open areas such as grasslands, agricultural areas, and other open habitats with abundant prey. Arboreal animals such as monkeys and snakes are generally more vulnerable in forested areas.

31. During operations, if significant wildlife electrocution impacts are discovered (see Section 5.1.2 for details on post-construction fatality monitoring), problematic portions of powerlines may need to be retrofitted to reduce electrocution impacts. This will generally entail installation of many of the same “wildlife friendly” design features discussed in Section 3.2; however, retrofitting a powerline during operations is generally more costly than incorporating the same wildlife friendly features during the design phase, because of increased installation costs and the lost service time while improvements are being installed.

4.1.4 Wildlife Collisions

32. As mentioned in Section 3.2, large-bodied birds, as well as birds with poor vision and aerial maneuverability, are most vulnerable to powerline collisions, which occur when the bird fails to see the cables in time to avoid them. Bird species most sensitive to powerline collision impacts include bustards, flamingos, cranes, waterfowl, pelicans, and large-bodied waterbirds. Wildlife collisions are most concerning for high voltage transmission lines, particularly the thin “aboveground,” “static,” or “ground” wire. Collisions can occur with low and mid-voltage (i.e., distribution) lines, especially within and close to areas where collision-susceptible species concentrate. Wildlife collisions with powerlines generally occur along spans rather than near poles/pylons.

[24] Setbacks or buffer areas in the ROW may be necessary to provide protection around sensitive habitats identified in preconstruction surveys. Setbacks should be based on site-specific assessment of habitats, species, seasons, and/or the type of activity to be undertaken during phases of the project. For example, buffers or setbacks may be established along the high-water mark of waterbodies and around riparian zones.

33. During operations, if significant wildlife collision impacts are discovered (see Section 5.1.2 for details on post-construction fatality monitoring), problematic portions of powerlines may need to be retrofitted to reduce collision impacts. This will generally entail installation of Bird Flight Diverters (BFD), as discussed in Section 3.2; however, retrofitting a powerline during operations is generally more costly than installing BFD during construction, due to increased installation costs and lost service time while BFD are being installed.

4.1.5 Pollution Prevention

34. Hazardous materials specific to ETD projects include insulating oils (in some cases containing polychlorinated biphenyl (PCBs), which is no longer acceptable in new equipment, but may still be found in older grid infrastructure; gases such as sulfur hexafluoride (SF_6) used in substation equipment; and preservatives for wood poles and other materials.

Insulating Oils or Gases

35. Highly refined mineral insulating oils and gases are commonly found in substation electrical equipment (power transformers, circuit breakers, etc.) and some transmission cables (e.g., pipe-type cable systems used for buried transmission lines). When refurbishing an existing installation, the risk of leaks may increase due to handling both old and new equipment. Measures to manage oil leaks as well as fuels from machinery and electrical generators are presented in the General EHS Guidelines.

36. Sulfur hexafluoride (SF_6), the most potent and persistent greenhouse gas with a significantly higher global warming potential than carbon dioxide (CO_2), may be found in older equipment and used as a gas insulator in electrical switching equipment and cables, tubular transmission lines, and transformers.[25] SF_6 may also be used as an alternative to insulating oils. Equipment containing SF_6 should be avoided or minimized.[26] If SF_6 is used in high-voltage applications (>52 KV), equipment with leakage rates of less than 1 percent should be used.[27]

37. An SF_6 management plan should be developed to handle equipment containing SF_6 and to control gas leakage. Key elements of the plan should include:[28] (i) maintaining a SF_6 inventory (e.g., purchases; on-site volumes and stocks; and gas taken offsite for recycling or disposal); (ii) developing SF_6 handling procedures (e.g., transport, storage, labeling, transfers of gas from cylinders, gas evacuation of circuit breakers, and by-product handling[29]—see Section 4.2); (iii) conducting regular leak detection (e.g., using hand-held halogen detectors, tracking pressure drops and additions of SF_6 gas in equipment, and using laser leak detection cameras); (iv) developing emergency SF_6 gas leak procedures; (v) planning for gradual replacement of equipment containing SF_6;

[25] IPCC, Climate Change 2013. According to the Intergovernmental Panel on Climate Change's *Fifth Assessment Report*, the global warming potential (GWP-100 year) of SF_6 is 23,500 times greater than CO_2.
[26] Ecofys and GFM, SF6-free Transmission and Distribution of Electrical Energy; US EPA, Workshop for SF6 Reduction Strategies. Equipment using SF_6 alternatives are commercially available depending on the required voltage application.
[27] EIC, Specification,standard 60376.; IEEE, Guide for SF6 handling standard C37.122.3. These standards offer additional guidelines for the use of SF_6 gases.
[28] US EPA, Electric Power Systems Partnership. GIIP associated with the handling and disposal of SF_6, SF_6 by-products, and SF_6 equipment.
[29] When exposed to sustained or intense electrical arcs, SF_6 gas decomposes to form fluoride gases and metal-fluorides, which are toxic. If moisture is present, the decomposition by-products may also include sulfur-oxyfluorides and hydrofluoric and sulfuric acids.

and (vi) coordinating equipment recycling and final disposal at facilities capable of safely transporting and disposing of SF_6 gas, by-products, and equipment.

38. Polychlorinated Biphenyls (PCBs), once used as a dielectric fluid for electrical insulation, are no longer used due to their harmful effects on human health and the environment.[30] Transformers and capacitors are the main sources of PCBs in the ETD industry, typically found in old equipment still in use or needing replacement.[31]

39. Facilities with PCB-containing equipment should work with local authorities to remove and eliminate it. Recommended actions to eliminate PCBs from existing ETD sites include:

- Create a PCB phaseout plan to identify and replace PCB-containing transformers and equipment and to eliminate PCB-containing oils. Include approaches for interim storage prior to equipment decontamination, reuse, or recycling via authorized methods (e.g., thermal destruction). During interim storage, protect PCB-containing oil from potential spills or exposure to flood events.
- Remove PCB-containing equipment with certified personnel or company that will drain and clean it before disposal. Store PCB-oil and residues in containers labelled to reflect their hazardous waste characteristics. Promptly move the equipment and containers with PCB residues to authorized sites or store temporarily in a secure facility.
- Dispose of PCB-containing residue through certified companies that adhere to its safe transport and disposal. If the PCB-containing residue is transported across country borders, measures should adhere to the Basel Convention and supply evidence of safe disposal.
- Cleaned equipment can be reused with PCB-free insulating oil or recycled by an authorized company.
- Sample and analyze water and soil exposed to PCB leaks in a certified laboratory. If contamination is detected, follow proper removal and/or remediation measures.

40. Guidance on spill prevention, emergency response, cleanup, and contaminated soil remediation is discussed in the General EHS Guidelines. Acute and chronic climate hazards can increase the risk of release of hazardous materials (see Section 3.3).

Wood Preservatives and Treated Poles

41. Most wooden utility poles are treated with oil-based pesticide preservatives like creosote, pentachlorophenol (PCP), and chromated copper arsenate (CCA) to protect against insects, bacteria, fungi, and rot. These chemicals are restricted or banned in

[30] PCBs are most commonly found in powerlines and substations constructed before 1980. The management of PCBs is often a key environmental issue during decommissioning, replacement, or upgrading of equipment related to existing powerlines.
[31] The global PCB inventory estimates that approximately 4 million tons of equipment and material containing or contaminated with PCB have been eliminated to date, while approximately 14 million tons remain to be disposed of (80 percent of the total). Transformers and capacitors represent the two largest source categories, respectively, of PCB. The Stockholm Convention on Persistent Organic Pollutants obliges parties to phase out the use of PCB by 2025 and ensure environmentally sound management / disposal by 2028.

some countries due to their environmental toxicity.[32] Poles free of PCP, CAA or any other potentially toxic chemicals should be prioritized.

42. The most significant potential environmental impacts occur at wood treatment facilities and storage yards, where wood preservatives may be present as spare treated poles or in containers, and which in some cases are managed by the ETD company. Utility poles should be pretreated at an appropriate facility to optimize chemical fixation, prevent leaching, and reduce surface residues at the ROW.[33]

43. Recently treated poles stored at work sites may leach preservatives into soil and groundwater, especially in areas where water table levels are close to the surface. Storage can leach preservatives and contaminate surface run-off of rainwater and drainage. This can be avoided by storing poles on impervious surfaces located outside flood prone areas and covering them with tarps or other impermeable materials.

44. While in use, poles can leach preservatives into soil and groundwater, with concentrations highest near the poles and decreasing to normal levels at approximately 30 centimeters from the pole.[34] Recommended measures to prevent and control the impacts of wood preservatives at the point of use include:[35]

- Evaluate the costs and benefits of alternative pole materials, including steel, concrete, or fiberglass.[36]
- Avoid the use of treated wood poles in sensitive areas (e.g., wetlands and marshes, flood prone areas, agricultural land, areas with elevated groundwater levels).
- Use environmentally friendly wood preservatives such as copper azole for pest and rot protection.[37]

45. Consider stubbing techniques to extend the life of treated wood poles by reinforcing below ground pole decay.[38] Used poles should be disposed of properly. Wood waste with preservatives should be treated as hazardous waste and sent to a waste treatment and disposal facility equipped to handle waste that may have chemical leaching properties or in an incinerator with air pollution controls.

[32] US EPA, Overview of Wood Preservative Chemicals. The European Union has banned PCP and CCA, while they are still used with restrictions in North America. This document presents alternatives to PCP, CCA, and Creosote. UNEP, Report of the Persistent Organic Pollutants. This study carried out by UNEP found costs quoted for non-chemical alternatives were comparable to treated poles.
[33] Environment Canada, Recommendations for Wood Preservation Facilities. This document includes technical environmental management guidance for a variety of preservative-specific treatment facilities. Lebow and Tippie, Minimizing the Effect of Preservative. This guide offers guidance for surface residues.
[34] Zagury, Chromated Copper Arsenate-treated Utility Poles
[35] BC Hydro, Submarine Cable Maintenance. This document offers an example of a technical pest management approach to wood preservatives.
[36] Stockholm Convention. Alternatives to POPs.
[37] UNEP, Persistent Organic Pollutants; US EPA, Alternatives to Pentachlorophenol.; US EPA, Overview of Wood Preservative Chemicals. These documents provided a detailed discussion of preservative alternatives.
[38] BC Hydro, Pest Management Plan, 20. Stubbing is a technique applied to reinforce the ground line area of a wood pole by attaching a reinforcing stub (e.g., of steel or wood) next to the pole as a support. Stubbing may add 15–25 years to the existing pole's working life and generally involves less soil and environmental disturbance than pole replacement.

Herbicides

46. An integrated vegetation management (IVM) approach is preferred for vegetation control, with herbicides as a preferred or complementary option to control fast-growing vegetation within transmission and distribution ROW(s) and other ETD infrastructure.[39] The IVM plan should prioritize low-growing plant species to minimize herbicide use. If herbicides are necessary, they should be handled and stored to prevent contamination of soil, wildlife, and water resources. The plan should specify herbicide types, use purposes, and good practice for procurement and storage.

47. Herbicides should be managed in compliance with the General EHS Guidelines, Food and Agricultural Organization (FAO) and World Health Organization (WHO) guidelines.[40] Herbicide use should be consistent with country commitments under the Stockholm, Rotterdam, and Basel Conventions.[41]

48. The use of pesticides, such as insecticides, fungicides or rodenticides, are minimally or infrequently used in ETD ROW. Guidance on pesticide management can be found in the General EHS Guidelines.

4.2 Occupational Health and Safety

49. Most of the occupational health and safety issues during the construction, operation, and decommissioning phases of ETD projects are similar to those of large industrial facilities, for example, exposure to dust and noise, accidents involving heavy equipment (e.g. wire drums); working in confined spaces, exposure to harsh climatic conditions, which are covered in the General EHS Guidelines. Project developers should implement a comprehensive health and safety management system throughout the ETD project life cycle.

50. Major health and safety hazards in ETD infrastructure include:[42]

- Physical hazards
    - Live conductors and energized components
    - Falling or dropped objects (i.e., crane lifting, helicopters, wire stringing)
    - Working at heights (i.e., tower erection, inspection of aboveground lines)
    - Electromagnetic fields
- Chemical hazards
- Herbicides, insulating gas, insulating oils, fire suppression gas, chemical preservatives, and other hazardous materials

[39] US EPA, Integrated Vegetation Management Factsheet.
[40] CropLife, Obsolete and Unwanted Pesticide Stocks; FAO & WHO. Managing Pesticides; FAO, Code of Conduct on Pesticide Management; Ohio State University, Effective and Efficient Pesticides Application; US NIEHS, Electric and Magnetic Fields.
[41] Stockholm Convention, Stockholm Convention; UNEP, Rotterdam Convention; UNEP, Basel Convention.
[42] Other relevant GIIP include: US OSHA 1910 (Occupational Safety and Health Standards) Subpart R – Electric power generation, transmission, and distribution; OSHA 1926 (Safety and Health Regulations for Construction) Subpart V – Electric Power Transmission and Distribution; ILO, Power Generation and Distribution; US OSHA, Electric Generation, Transmission, and Distribution E-Tool. The E-Tool provides typical OHS hazards related to electric transmission and distribution lines and equipment.

4.2.1 Physical Hazards

Live Conductors and Energized Components

51. Workers can face electrical hazards resulting in electrocution, burns, and ventricular fibrillation from contact with live powerlines or energized electrical components during construction, operation, and maintenance. Other exposure to electrical hazards may result from:

- Power line grid connection and commissioning
- Arc flashes
- Line clearance and tree trimming
- De-energizing, proof-dead testing, grounding, and re-energizing activities

52. Only trained and certified workers should install, maintain, or repair electrical equipment. Qualified workers should:

- Work in teams for reaction capacity in case of an emergency.
- De-energize and properly ground live transmission and distribution lines before work is performed.[43]
- Adhere to documented and approved live line work standards.[44]
- Distinguish live parts from other electrical system parts.
- Determine the voltage of live parts.
- Understand the minimum approach distances outlined for specific live line voltages.
- Properly use electrical personal protective equipment (PPE) and follow safety procedures when working near or on exposed energized parts.

53. Workers should not approach exposed energized parts even if properly trained unless:

- The worker is insulated from the energized part with certified high voltage gloves or other approved insulation;
- The energized part is insulated from the worker and any other conductive objects; or
- The worker is isolated and insulated from other conductive objects (live-line work).

54. Workers not directly involved in power transmission and distribution should follow local regulations and standards on minimum approach distances for activities near power lines or substations. Minimum working distance for insulated poles and tools can be reduced only if the distance remaining is greater than that between the energized part and a grounded surface. For activities

[43] US OSHA, Electric power generation, transmission, and distribution, Standard 1910.269.
[44] U.S. OSHA, Electric Power Generation, Transmission, and Distribution Industry. Further information is available on this website.

necessary within minimum approach distances of transport, transmission and distribution lines, additional safety measures should be included in a health and safety plan.[45] These measures may include a job hazard analysis, training, personal safety equipment, safety protocols such as establishing exclusion zones, and effective communication between workers. Such activities should be supervised by a qualified person.

55. Work on electrical or mechanical equipment with potential energy can only be done when safe work conditions are achieved:

- Implementing a documented energy isolation procedure under a permit-to-work system, which provides written approval and authorization for an isolated and/or de-energized condition, except for authorized live-work tests
- Isolating and de-energizing electrical equipment according to GIIP
- Removing the equipment from any energy source, confirming no ready means of connection, and discharging all stored energy

56. Avoid work during inclement weather, such as high winds, severe heat, icing, and thunderstorms.

Falling or Dropped Objects

57. Assembling and operating ETD infrastructure involves hazardous activities, such as tower erection, hoisting workers and materials and installing insulators and hardware using mobile equipment or helicopters, and conductor stringing and sagging.

58. Tower erection involving gin poles, cranes and derricks, winches, rigging, and anchors/guys requires safe rigging and lifting standards near ETD infrastructure. Rigging and lifting equipment includes mobile cranes, overhead cranes, monorail lifting systems, lifting booms, electrical hoists, and other hoisting equipment.

59. Documented safe lifting and rigging standards should include:

- Conducting a rigging and lifting risk assessment prior to any lifting operations to determine safe boundaries based on minimum approach distances and identify restricted zones
- Holding and documenting meetings with the lifting equipment operator and workers to discuss power line locations, potential hazards, and safety steps
- Erecting an elevated warning line or barricade with high-visibility markings 20 feet from the power line[46]
- Retaining training records and certifications for all workers authorized to operate rigging and lifting equipment. This includes riggers, rigging supervisors, crane operators, flag people (or flaggers), and operations assistants.

[45] US OSHA, Electric power generation, transmission, and distribution, Standard 1910.269. Recommended minimum approach distances are detailed in Minimum Approach Distance Calculator - Text Version | Occupational Safety and Health Administration, particularly Table V-2 AC Live-Line Work Minimum Approach Distance, Table V-6 Alternative Minimum Approach Distances for Voltages of More Than 72.5 kV and Table V-8 DC Live-Line Minimum Approach Distance with Overvoltage Factor.
[46] US OSHA. Safety and Health Regulations for Construction. The Standard 1926 Subpart CC Cranes and Derricks in Construction, particularly section 1926.1408 on power line safety (up to 350 kV) equipment operations provides additional information.

- Retaining inspection and maintenance records for all rigging and lifting equipment per original equipment manufacturer (OEM) specifications and national regulations
- Train workers on emergency response procedures for lifting and rigging operations, including managing equipment malfunction.

60. Use of helicopters for personnel transport, line maintenance and inspection, and to hoist requires additional safety protocols[47], including safety training and briefings, weather and environmental considerations, and clear responsibilities for the helicopter operator, contractors, and employees.

61. For hoisting materials and equipment with helicopters, conduct an aerial lifting operations plan and risk assessment. Follow construction regulations, including regarding the use of helicopters, including delineation of responsibilities of work parties, contractor ground crew procedures, defining staging and placement areas, pre-flight briefing and inspection, and special consideration for hazardous loads.[48]

Working at Height

62. Working-at-height hazards pose significant safety risk with respect to ETD infrastructure and are present during tower erection, maintenance and inspection of aboveground lines. Prevention and control measures include:

- Test tower and utility structures for integrity using approved structural testing methodologies.
- Remove obstructions from poles or structures prior to undertaking work.
- Install fixtures on towers to facilitate the use of fall protection systems.
- Provide workers with an adequate work-positioning device (connectors on positioning systems should be compatible with the tower components to which they are attached).
- Establish and document a fall protection system to protect workers working at heights. The fall protection system should be appropriate for the tower structure and necessary movements, including ascent, descent, and moving from point to point. If working above or in proximity to energized equipment or conductors, the maximum fall distance—including shock absorbing lanyard—should be calculated such that the worker is prevented from breaching the minimum setback distances to the energized conductor in the event of a fall.
- Use load-rated and maintained hoisting equipment with trained operators and appropriate tool bags for raising/ lowering materials.
- Use safety belts of appropriate material and strength, with a backup belt when operating power tools at height.

[47] HAI, Safety Guide for Helicopter Operators.
[48] IHSA, Helicopter Lifting (M033).

- Maintain inspection records for all fall prevention / arrest equipment per OEM requirements.

Electromagnetic Fields

63. Where transmission lines and substations are proposed near residential or occupied areas, EMF levels should be assessed using industry recognized EMF measurement and modeling techniques. The assessment should be based on the proposed structure and conductor design including nearby transmission lines and substation electrical equipment. The EMF levels at the edge of the ROW or occupied areas should meet occupational and public exposure limits consistent with applicable host country regulations or the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, whichever is more stringent.[49] Electric utility workers have a higher exposure due to their proximity to powerlines, substations, and transformers while performing their duties. The ICNIRP guidelines for public exposure and occupational exposure are in Section 5.1.3 and Section 5.2, respectively.

64. Occupational EMF exposure should be prevented or minimized by implementing an EMF safety program that includes:

- Assessing potential EMF sources and exposure levels, including surveys of EMF exposure levels for existing or planned infrastructure[50]
- Training workers to identify EMF levels and hazards, especially those at higher risk to EMF exposure, such as those working with medical devices, or near explosive or flammable materials, and pregnant workers[51]
- Implementing action plans for exposure levels that exceed ICNIRP occupational limits (see Table 2 in Section 5.2).[52] Such action plans may include work rotation to limit exposure; personal exposure monitoring; increasing the distance between the source and the worker; or using shielding materials and PPE such as conductive suits.

4.2.2 Chemical Hazards

65. Occupational exposure to chemicals and hazardous materials includes handling herbicides for ROW maintenance, exposure to sulfur hexafluoride (SF_6) gas and PCB in transformers, CO_2 and argonite gas from fire extinguishers, and contact with wood preservatives on treated poles. Prevention and control measures for occupational exposure to chemical hazards are detailed in the General EHS Guidelines.

[49] WHO Radiation and Health – Protection and Norms https://www.who.int/teams/environment-climate-change-and-health/radiation-and-health/protection-norms
[50] Exposure assessments for EMF are typically based on a review of industry-specific published studies and guidelines, equipment manufacturer safety data, and workplace data such as occupational health and safety records. This information can be used to determine whether occupational exposure to EMF sources exceeds occupational exposure limits. Where it can be demonstrated that occupational activities in proximity to EMF sources do not exceed the reference levels, it can be assumed that the activities are in compliance with basic restrictions. Where this cannot be demonstrated, further investigation is generally required. This may include a risk assessment of certain electrical equipment and work practices, including measurement and/or calculation of EMF by trained personnel to determine exposure levels. See examples of practical guidance for undertaking initial exposure assessment and risk assessment of EMF sources can be found in EC, non-binding guide, vol.1.; EC, non-binding guide vol.2.; ENA, EMF Management Handbook.; ENA, National Grid, and UK Energy, Occupational Exposure Limits.
[51] UK HSE, Electromagnetic Fields at Work
[52] ICNIRP, Guidelines for Limiting Exposure. ICNIRP, a nongovernmental organization formally recognized by WHO, provides *basic restrictions* for occupational exposure to EMF for the central nervous system (CNS, the head area), and the peripheral nervous system (PNS, the rest of the body), which are related to the threshold showing adverse effects, with an additional reduction factor to account for any scientific uncertainties pertaining to the determination of the threshold. However, the basic restriction levels are technically complex to measure. As a result, ICNIRP provides exposure levels outside the body, called *reference levels*, which are derived from the basic restrictions using worst-case assumptions, in such a way that remaining below the reference levels (in the air) implies that the basic restrictions will also be met (in the body). The reference levels are set below the field required to produce the basic restriction.

4.3 Community Health and Safety

66. Community health and safety issues during the construction, operation and decommissioning phases of ETD projects are described in the General EHS Guidelines. Projects should implement a comprehensive community health and safety management system throughout the ETD project life cycle to manage accident hazards. Specific ETD aspects described in this section include:

- Electrocution and fire risks
- Electromagnetic fields
- Visual and noise impacts
- Aircraft navigation hazards

4.3.1 Electrocution and Fire Risk

67. Live conductors and energized components that may be accessed by communities present electrocution and fire risks, including from arc flashes. Fires may release toxic emissions containing PCBs, resins, pesticide residues and SF_6. Acute climate hazards, such as storms, floods, and wildfires, can damage infrastructure, resulting in downed power lines and exposed live conductors. These conditions increase the risk of public exposure to electrocution, especially where awareness of such dangers is limited.

68. Preventive and protective measures include:

- Restricting access by installing fences with adequate height, signs and barriers, locks and steel posts around transmission towers. especially in urban areas, and grounding all conducting objects near powerlines to prevent shock
- Raising awareness and educating the public about electrical safety and risk prevention through public safety programs, engagement and communication[53]
- Maintaining the ROW and equipment through regular monitoring and maintenance of infrastructure, phasing out equipment containing hazardous chemicals (PCBs), and managing vegetation within and adjacent to the ROW to reduce fire hazards
- Monitoring technical and non-technical losses and anomaly detection using advanced metering and monitoring technologies. Identifying potential intrusions including illegal activities within the ROW through manual or automatic detection methods.[54] Conducting periodic infrastructure monitoring, including in-situ condition-based inspections and systems to manage vegetation that can create fire hazards from ETD infrastructure.

[53] EBRD, FMO. Electric Power and Distribution Toolkit. This toolkit provides resources and templates that projects can use to develop communication materials for public safety in electric transmission and distribution lines, including specific communications for youth and children.
[54] Li et al. Safety monitoring method, 805-815. They can be mainly classified into LiDAR-based approaches, binocular vision-based approaches and monocular vision-based approaches.

- Implementing emergency response measures that outline standard procedures for handling emergencies involving communities and the public, as described in the General EHS Guidelines, including collaboration with law enforcement to identify and address illegal connections and respond to emergencies

4.3.2 Electromagnetic Fields

69. Proposed new transmission lines often raise community concerns about perceived risks from EMF. International guidelines for public EMF exposure, such as those established by ICNIRP (see Section 5.1.3), provide a reference framework for EMF management.[55]

70. Awareness initiatives and outreach programs are important for educating communities about ETD risks. Training approaches tailored to local languages and literacy levels, as well as accessible information and feedback channels are most effective. Technical guidance for EMF management includes:

    - Calculating EMF levels at the edge of the ROW using modeling based on the structure, conductor design and nearby transmission lines (see also Section 3)
    - Verifying that the ROW and the edge are sufficiently wide to meet the ICNIRP guidelines
    - Establishing safety clearances compatible with adjacent land uses to keep EMF levels at sensitive receptors below the recommended ICNIRP guidelines
    - Defining safety zones to separate areas with acceptable EMF levels for public exposure from those with elevated levels, limiting access and exposure time for trained workers
    - Evaluating public exposure against ICNIRP reference levels and verifying that average and peak exposure levels remain within recommended thresholds (see Section 5.1.3)

71. If EMF levels exceed the recommended public exposure limits, engineering techniques may be considered, ideally in the design phase, when measures are more effective:[56]

    - Shielding (e.g., walls, fences, trees) can be effective barriers for electric fields, although less effective in reducing exposure to magnetic fields. Shielding of areas and individual equipment using structures or enclosures made from special metals can be done in special applications.[57]
    - Modifying the physical arrangement of the EMF source (e.g., reducing the conductor spacing, rearranging equipment layout and orientation, and, for low voltage, bundling the neutral conductor with other phases) and modifying the load (e.g.,

[55] ICNIRP, Guidelines for Limiting Exposure. ICNIRP, Fact Sheet on Guidelines. WHO, Extremely Low Frequency Fields. ICNIRP published the “Guidelines for Limiting Exposure to Time-varying Electric and Magnetic Fields (1 Hz–100 kHz)” following reviews of all the peer-reviewed scientific literature, including thermal and nonthermal effects. The standards are based on evaluations of biological effects that have been established to have health consequences. The main conclusion from WHO reviews is that exposures below the limits recommended by the ICNIRP international guidelines do not appear to have any known consequence on health.
[56] ENA, EMF Management Handbook. These document provides more information on engineering techniques.
[57] ENA, EMF Management Handbook.

optimally phasing and balancing circuits, optimally configuring downstream loads, applying demand management, and, for low voltage, balancing phases and minimizing residual currents)[58]

- Increasing pylon height
- Burying lines, which is effective for reducing electric field exposure but less so for magnetic field exposure

4.3.3 Visual Impact

72. Visual impacts can be avoided or minimized during the siting and design stage (see Section 3). The following measures can mitigate the visual impacts of ETD infrastructure such as aboveground lines and pylons:

- Conducting a visual impact analysis using photo simulations
- Engaging in public consultation during the planning phase to present information and understand community concerns
- Burying transmission or distribution lines in dense residential or commercial areas
- Collocating new transmission lines with existing linear facilities and utility corridors to minimize visual impacts
- Designing towers and choosing colors to minimize visual impacts
- Using non-specular conductors[59]
- Avoiding sensitive viewscapes, especially near protected lands such as parks with vistas

4.3.4 Noise

73. ETD infrastructure noise primarily comes from the corona effect and equipment.[60] High-voltage powerlines (400-800 kV) and ultra-high-voltage lines (1000 kV and higher) produce more noise.[61] Minimizing corona is critical for high-voltage transmission powerline conductors (e.g., 345 to 765 kV lines) but less so for lower voltages.[62] Corona discharge noise varies with air conditions including humidity; density; wind; and precipitation. Rain typically masks noise from transmission lines; however, other conditions may increase noise.

74. Extreme weather events can also amplify noise pollution from ETD systems, such as the corona effect, as high humidity or wet conditions enhance electrical discharge sounds, potentially impacting affected communities.

[58] ENA, EMF Management Handbook. Sections 9.1 and 9.2 of this handbook provide more information.
[59] Aboveground aluminum electrical conductors, when installed, tend to have a "reflective" or "specular" surface that can make a transmission line more noticeable in appearance against the background landscape.
[60] Corona is a discharge of electricity from an energized surface. The discharge occurs when a highly concentrated electric field causes the air surrounding the surface to become ionized. When the electric field is concentrated enough and exceeds a certain critical value, the single discharged electron collides with the air molecules and causes the release of their electrons. If a chain reaction of discharging of electrons from the surrounding air molecules – known as an electron avalanche – results, corona has occurred. The audible noise emitted by the corona effect can be heard in close proximity to a transmission line. It is caused by the discharge of energy that occurs when the electrical field strength on the conductor surface is greater than the 'breakdown strength' (the field intensity necessary to start a flow of electric current) of the air surrounding the conductor.
[61] Gerasimov, Environmental, Technical and Safety Codes.
[62] US DOE, Electricity Transmission Technologies.

75. Substations are often built near urban centers to meet power demand, emitting a constant audible background noise that may disturb nearby communities. The main sources of substation internal noise are transformers and building ventilation.[63]

76. Noise prevention and control measures include:

- Designing and maintaining lines to operate below corona-inception voltage during dry conditions
- Regularly maintaining lines to reduce humming noise from conductor hardware and otherwise.
- Using dynamic vibration absorbers on transformers
- Designing low-noise ventilation with proper mufflers
- Installing noise barriers or noise-canceling devices around substations

5 PERFORMANCE INDICATORS AND MONITORING

77. 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.

5.1 Environmental Monitoring

78. Environmental monitoring programs should be implemented to address potentially significant impacts on the environment during normal construction and operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the project. Monitoring frequency should be sufficient to provide representative data for the parameter being monitored.

79. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring results should be regularly analyzed and compared to selected standards, and corrective actions should be implemented for exceedance. Additional guidance is provided in the General EHS Guidelines.

5.1.1 Emissions and Effluent Guidelines

80. The power transmission and distribution sector does not typically produce significant air emissions or effluents. Guidelines for dust or water runoff is available in the General EHS Guidelines. National and local regulations for air and water quality may also be available.

5.1.2 Biodiversity

81. Post-construction fatality monitoring (PCFM) is used to assess and manage powerline collision and electrocution impacts on wildlife. Not all ETD projects require PCFM. The need for PCFM, as well as its specific design and scope, is typically determined

[63] Wand et al. Indoor Substation Noise Analysis.

during the impact assessment and should be based on the level and sensitivity of wildlife-related risks. The primary objectives of PCFM are:

- Systematically record and provide robust mortality rate assessments for species impacted.
- Provide information that allows wildlife impacts to be adaptively managed and minimized.
- Inform landscape-scale cumulative impact assessments of powerline infrastructure on affected species.

82. The PCFM program, when warranted for a powerline, or a portion thereof, should be designed by qualified and experienced professionals, and aligned with GIIP.[64] Specific methodological features of PCFM programs will vary across projects based on the specific site-, species-, and season-specific risks identified, for example with search areas focused around poles/pylons for electrocution-risk projects, and search areas focused underneath spans for collision-risk projects. To obtain robust estimates of fatalities, raw carcass searching results must be corrected for searcher efficiency, carcass persistence, and unsearched area biases, as all three of these factors can result in significant numbers of carcasses not being discovered during carcass searches. If mortality rates are significant for the target species, mitigation measures should be implemented (see Section 4.1.3 and 4.1.4).

5.1.3 Electromagnetic Fields

83. EMF exposure limits to protect the public are provided in Table 1. These exposure limits are set to protect the public (for workers, see Table 3) from adverse health impacts, by restricting exposure to time-varying electric, magnetic and electromagnetic fields. The table presents 'reference levels', which refer to fields in the environment, and are derived from the 'basic restrictions' for limiting exposure to the body.

84. For transmission lines, magnetic field strength decreases significantly with distance, often reaching typical background levels beyond 300 feet (or about 90 meters).

[64] IFC, EBRD, KfW. PCFM for onshore wind energy in emerging market countries; IFC, IDB Invest. Good Practice Guide: Managing Bird and Bat Impacts in Wind.

Table 1. ICNIRP Exposure Limits for General Public Exposure to Electric and Magnetic Fields			
Electric and Magnetic Fields	50 Hz	60 Hz	Units
Basic restriction: head	20	24	mV/m (millivolts per meter)
Basic restriction: whole body	400	400	mV/m (millivolts per meter)
Magnetic field reference levels	200	200	µT (microtesla)
Electric field reference level	5	4.167	kV/m (kilovolts per meter)
Source: ICNIRP, Guidelines for Limiting Exposure. 2010.			
Notes: On application of exposure limits: Per ICNIRP (Guidelines for Limiting Exposure, 826.), limitations of exposure that are based on the physical quantity or quantities directly related to the established health effects are termed *basic restrictions*. The physical quantity used to specify the basic restrictions on exposure to EMF is the internal electric field strength, as it is the electric field that affects nerve cells and other electrically sensitive cells. The internal electric field strength is difficult to assess. Therefore, for practical exposure assessment purposes, reference levels of exposure are provided. Reference levels are derived from relevant basic restrictions using measurement and/or computational techniques, but some address perception (electric field) and adverse indirect effects of exposure to EMF. The reference levels are obtained from the basic restrictions by mathematical modeling using published data. They are calculated for the condition of maximum coupling of the field to the exposed individual, thereby providing maximum protection. Frequency dependence and dosimetric uncertainties were taken into account. In any particular exposure situation, measured or calculated values of any of these quantities can be compared with the appropriate reference level. Compliance with the reference level will ensure compliance with the relevant basic restriction. If the measured or calculated value exceeds the reference level, it does not necessarily follow that the basic restriction will be exceeded. However, whenever a reference level is exceeded, it is necessary to test compliance with the relevant basic restriction and to determine whether additional protective measures are necessary. ICNIRP revised its guidelines in 2010 following the publication of WHO Environmental Health Criteria No. 238 (Extremely Low Frequency Electromagnetic Fields).			

5.2 Occupational Health and Safety Monitoring

85. The working environment should be assessed to identify occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals as part of an occupational health and safety monitoring program, as provided in the General EHS Guidelines.[65]. Facilities should record occupational accidents and incidents, and report significant accidents and injuries, including the frequency rates and associated lost time when reporting significant injuries. This data should be benchmarked against internationally published guidelines and standards such as the US Bureau of Labor Statistics, European Agency for Safety and Health at Work (EU OSHA) and UK Health and Safety Executive.[66]

86. Key ETD indicators include the minimum approach distances for trained employees (Table 2) and the ICNIRP limits for occupational exposure to electric and magnetic fields (Table 3).

[65] Accredited professionals may include certified industrial hygienists, registered occupational hygienists, or certified safety professionals or their equivalent.
[66] US Bureau of Labor Statistics, Injuries, Illness and Fatalities. UK HSE. Health and Safety Statistics, US OSHA Electric Power Generation, Transmission and Distribution e-Tool.

Table 2. Minimum Approach Distances for Voltages of 72.5 kV and Less [1]				
Nominal voltage (kV) range phase-to-phase	Distance		Distance	
	Phase-to-ground exposure		Phase-to-phase exposure	
	Meters	Feet	Meters	Feet
0.050 to 0.300 [2]	Avoid contact		Avoid contact	
0.301 to 0.750 [2]	0.33	1.09	0.33	1.09
0.751 to 5.0	0.63	2.07	0.63	2.07
5.1 to 15.0	0.65	2.14	0.68	2.24
15.1 to 36.0	0.77	2.53	0.89	2.92
36.1 to 46.0	0.84	2.76	0.98	3.22
46.1 to 72.5	1.00	3.29	1.20	3.94
Minimum Approach Distances for Voltages of More Than 72.5 kV [1, 3, 4]				
Nominal voltage (kV) range phase-to-phase	Distance		Distance	
	Phase-to-ground exposure		Phase-to-phase exposure	
	Meters	Feet	Meters	Feet
72.6 to 121.0	1.13	3.71	1.42	4.66
121.1 to 145.0	1.30	4.27	1.64	5.38
145.1 to 169.0	1.46	4.79	1.94	6.36
169.1 to 242.0	2.01	6.59	3.08	10.10
242.1 to 362.0	3.41	11.19	5.52	18.11
362.1 to 420.0	4.25	13.94	6.81	22.34
420.1 to 550.0	5.07	16.63	8.24	27.03
550.1 to 800.0	6.88	22.57	11.38	37.34

Source: US OSHA. Electric power generation, transmission, and distribution. Refer to Standard 1910.269

Notes:

1. Minimum approach distances apply to elevations up to 900 meters (3,000 feet) above mean sea level. For elevations greater than 900 meters above mean sea level, the minimum approach distances should be multiplied by the correction factor in Table R-5 of the source document.
2. For single-phase systems, use voltage-to-ground.
3. Minimum approach distances are valid provided that no insulated tool spans the gap, and no large conductive object is in the gap.
4. The clear live-line tool distance shall equal or exceed the values for the indicated voltage ranges.

Table 3. ICNIRP (2010a) Exposure Limits for Occupational Exposure to Electric and Magnetic Fields			
Occupational exposure	50 Hz	60 Hz	Units
Basic restriction: head	100	120	mV/m (millivolts per meter)
Basic restriction: whole body	800	800	mV/m (millivolts per meter)
Magnetic field reference levels	1000	1000	μT (microtesla)
Electric field reference level	10	8.333	kV/m (kilovolts per meter)

Source: ICNIRP, 2010. Guidelines for Limiting Exposure.

Notes: See notes in Table 1.

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ANNEX A: GENERAL DESCRIPTION OF INDUSTRY ACTIVITIES

1. Electric power transmission is the bulk transfer of electricity from a power generation facility and a substation located near consumers. Power distribution delivers electricity from a substation to residential, commercial, and industrial consumers. Transmission-level voltages are generally above 110 kilo volts (kV), also called high-voltage (HV) transmission lines. Voltages between 110 kV and 35 kV are considered sub-transmission voltages but can be used for long, light-load transmission, also referred to as medium voltage (MV).[67] Voltages below 35 kV are typical of distribution projects, also referred to as low voltage (LV).

2. ETD systems are often located along highways, roads, and other ROWs to minimize ecological, socio-economic, and cultural disturbances. Land value, view sheds, archaeological resources, geotechnical hazards, accessibility, parks, and other factors also influence the location and alignments of transmission and distribution line ROW.

3. Project development and construction activities typically include access road construction or upgrade, site preparation and development, removal of select vegetation and land clearing for transmission line ROWs, trench excavation for underground electrical lines, establishment of equipment staging areas. substation construction and/or upgrade, and installation of electrical line components such as electrical line poles or towers and maintenance roads. These activities depend on several factors, including topography, hydrology, land uses, and desired site layout.

4. Operational activities may include maintenance of access to the transmission or distribution lines, towers, and substations (e.g., low-impact trails or new or improved access roads) and vegetation management.

5. Climate change exposes ETD systems to acute hazards (heatwaves, hurricanes, floods, and wildfires) and chronic stresses (rising temperatures, sea-level rise, and shifting precipitation patterns). These impacts can reduce efficiency, damage infrastructure, and cause outages. Key risks include:[68]

   - Reduced transmission efficiency and increased cooling demand resulting from higher temperatures
   - Equipment failure, excessive sagging of powerlines, and overheating from higher temperatures or heat waves
   - Flooded substations, destabilized tower foundations, and blocked access from storms and flooding
   - Damage to towers, powerlines, and poles due to extreme winds, rainfall or flooding
   - Reduced network efficiency and structural failures from extreme temperature variation and ice storms
   - Damage to equipment containing hazardous materials, which can be released to the environment due to flooding

6. Modern or retrofitted ETD systems incorporate grid modernization into design and use data analytics to better identify vulnerabilities and asset risks. For example, the use of equipment for weather forecasting and visualization; predictive modeling; real-time data from

[67] In some countries with large power systems, voltages of 110–132 kV are also considered distribution voltages.
[68] WBG, Stronger Power-Improving Power Sector Resilience to Natural Hazards; WBCSD, Building a Resilient Power Sector.

Supervisory Control and Data Acquisition (SCADA), Outage Management System (OMS), and distribution management systems (DMS); static data from geographic information systems (GIS), maintenance records, asset management databases, and vegetation management systems.

7. ETD facilities are decommissioned when they are obsolete, damaged (e.g., by corrosion), or replaced due to increased power demand. Many power facilities are replaced with new or updated equipment at the same site or ROW. Decommissioning depends on the site's future use, environmental sensitivities (e.g., natural grasslands), and project specifics (e.g., aboveground or underground powerlines). Activities may include demolishing and removing infrastructure (e.g., transmission towers, substations, aboveground and underground utilities, and roads) and site reclamation, including ground stabilization and revegetation.

8. The following sections describe facilities and activities associated with the construction and operation of ETD projects. Typical components of a power transmission and distribution project are illustrated in Figure A.1.

Power Transmission Systems

9. The electric power transmission system, or grid, routes power from generation facilities to customer areas via a variety of routes (powerlines), based on the economics of the transmission or distribution path and the cost of power. Its multiple routes enable power rerouting during maintenance or outages.

10. Power transmission can occur above ground, underground or on the sea floor. Aboveground transmission consists of a system of aboveground powerlines and towers located between a power plant and a substation. Underground, transmission and distribution systems can be buried within conduits. Though installation and maintenance are costly, underground transmission can reduce impacts on land, visual aesthetics, birds / bats, and vegetation. Submarine cables placed on the sea floor by special cable-laying ships are also occasionally used to transmit high-voltage power across long stretches of water to islands and other locations that are difficult to access by conventional techniques. Submarine cables are typically self-contained and solid or fluid-filled to provide insulation over long distances. They are typically operated remotely with underwater vehicles.

11. Regional transmission grids consist of several large transmission systems connected by substations that are designed to transport electricity as efficiently as possible. Transmission networks can cover thousands of kilometers and encompass tens of thousands of towers. Energy is typically transmitted using a three-phase alternating current (AC) that is more efficient than a single phase. Energy is generally produced at low voltage (up to 35 kV) at a generating facility and then stepped up by a power station transformer to a higher voltage to enable transmission over a long distance. For long distance power transfer, electricity is usually transmitted at voltages above 110 kV. Complex technical problems with current technologies preclude the use of extremely high transmission voltages (exceeding 2000 kV). Over long distances, energy can also be transmitted via high voltage direct current (HVDC) with AC/DC converters to couple to the conventional AC system at both ends of the line. Recent developments in power electronics have resulted in making heavy power transmission by DC systems competitive with conventional AC systems.

12. Transmission towers or pylons suspend high-voltage aboveground powerlines, typically transmitting three-phase electric power (the common method for transmission of high-voltage lines of over 50 kV) and, therefore, are designed to carry three (or multiples of

three) conductors, with one or two ground conductors for lightning protection. Transmission towers are made from steel, concrete, aluminum, wood, or reinforced plastic, while conductors are usually aluminum or aluminum alloys, sometimes reinforced with steel. Towers should support the load of the conductors, sometimes requiring large and costly foundations, particularly in areas where ground conditions are poor, such as in wetlands. Guy wires stabilize transmission towers and resist some of the force of the conductors. Other specialty towers such as river crossings are designed on a case-by-case basis. There are three main types of transmission towers or pylons used in a transmission system. Suspension towers support straight stretches of a transmission line. Deviation towers are located at points where a transmission line changes direction. Terminal towers are located at the end of aboveground transmission lines where they connect with substations or underground cables.

13. The most common type of transmission tower or pylon used for high-voltage powerlines is a steel lattice structure. Tubular steel monopoles are also used to support high- or medium-voltage transmission lines, usually in urban areas. Transmission towers constructed of a steel framework can be used to support lines of all voltages, but they are most often used for voltages over 50 kV. Lattice towers can be assembled on the ground and erected by cable (which uses a large laydown area), in-situ, piece-by-piece, by crane, or, in inaccessible areas, by helicopter. Transmission tower height varies with design, line voltage, and terrain, and typically ranges from approximately 15 to 55 meters in height.

14. Wooden transmission towers consisting of single poles, *H*-frames, or shapes resembling *A*'s or *V*'s are also commonly used to support high-voltage transmission lines. Wooden transmission towers are limited by the height of available trees (approximately 30 meters), and generally carry voltages of up to 132 kV, lower than those carried by steel lattice transmission towers. Aluminum towers are often used in remote areas where they can be transported and installed by helicopter. Towers of reinforced plastic are now available, but high costs currently restrict their use.

15. For underground transmission lines, the three circuits used to transmit the three-phase power should be directly buried in cables, or pulled in individual pipes, conduits, culvers, or tunnels. Underground buried cable installations typically require burial at least 1.5 meters deep. Due to difficulties in dissipating heat and other technical issues, underground conduits are typically not used for high-voltage transmission lines over 350 kV.

Power Distribution Systems

16. High-voltage transmission is stepped down to a lower voltage for use in sub-transmission or distribution systems. Distribution lines typically vary from 2.5 to 35 kV, while the International Electrotechnical Commission and industry associations standardize at a level of 20–22 (25 kV design). Finally, the energy is transformed to low voltage at the point of residential or commercial use. This voltage ranges between 100 and 600 volts depending on country and customer requirements. Power distribution poles (or utility or telephone poles) were traditionally constructed of wood, but steel, concrete, aluminum, and fiberglass are also used, with concrete becoming a dominant product, especially in countries with limited forestry. Distribution poles are typically spaced no further than 60 meters apart and are at least 10 meters in height depending on voltage and construction. Wooden distribution poles are limited by the height of available trees. Distribution lines can also be placed underground in residential areas or to avoid specific sensitive receptors.

Electrical Substations

17. Electrical substations are stations along the ETD system that transform voltage from one level to another using transformers. Substations typically consist of one or more power transformers, as well as heavy duty circuit breakers and control and protection equipment. Substations can be located in fenced areas, prefabricated enclosures, underground, or inside buildings and underground areas.

18. There are two main types of electrical substations. Transmission-switching substations contain high-voltage switches used to connect high-voltage transmission lines or to allow specific systems to be isolated for maintenance. Distribution substations, or bulk supply points, are used to transfer power from the transmission system to the distribution system. One or more transmission or sub-transmission lines enter a distribution substation, where their voltage is reduced to a value suitable for distribution. Distribution substations can also be used to protect the system from faults and isolate faulty sections in either the transmission or distribution systems. Complicated distribution substations containing high-voltage switching, distribution switching, and backup systems are often located within large urban centers.

Rights-of-Way Management

19. Above-ground transmission and distribution networks require ROWs to provide public protection in case of utility pole or tower collapse and to protect the lines from contact with trees, branches and other hazards that may result in damage to the system, power failures, or fires. ROWs are also utilized to access, service, and inspect transmission and distribution systems. Underground distribution lines require ROWs where excavation is prohibited or strictly monitored or where construction activity is limited. Higher voltages require wider sections of land and, consequently, more extensive management.

20. ROWs for transmission lines range from 15 to 100 meters wide depending on voltage, physical safety, proximity to other ROWs (typical range is between 15 and 30 meters) and adjacent land use and vegetation.[69] For aboveground distribution powerlines up to 35 kV, a typical range is 12 to 24 meters corridors (6 to 12 meters on each side). Access roads are often constructed in conjunction, or within, the transmission line ROW to provide access for maintenance and upkeep of the system.

21. Regular maintenance of ROW vegetation is required, as unchecked growth can result in impacts including power outages resulting from branch or tree contact with transmission lines and towers; forest and bush fires; corrosion of steel equipment; blocking of equipment access; and interference with critical grounding equipment.

22. Regular maintenance and clearing of ROW prevent natural forest succession and the establishment and growth of tall trees. Typically, tall trees of approximately 4.5 meters or more are not permitted within aboveground ROW. Underground ROWs have far fewer vegetation restrictions, although trees with deep tap roots that may interfere with duct banks are usually prohibited from being grown within the ROW.

23. Heavy-duty mowing equipment controls ground cover and prevents tree and shrub growth in the ROW. Herbicides, combined with mowing, control fast-growing weeds. Trimming and pruning are utilized at the boundaries of ROWs to maintain corridor breadth and

[69] US Bureau of Land Management, *Energy Corridor Guidebook*.

prevent the encroachment of tree branches. Hand removal of vegetation, though costly and time consuming, is often used near structures, streams, fences, and other obstructions where machinery is impractical or dangerous.

Figure A.1. Electric Power Transmission and Distribution