Technical Appendix C: Methodology for Quantifiable Environmental Costs and Benefits

Contents

Introduction

In the development of a new resource strategy for the power plan, the Northwest Power Act requires that the Council compare the incremental system costs of different generating and conservation resources and give priority to those resources which the Council determines to be cost-effective. In estimating the system cost of a particular resource, the Council must include any quantifiable environmental costs and benefits directly attributed to that resource over its effective life.

The Act directs the Council to develop a methodology to determine and apply these quantifiable environmental costs and benefits as part of the overall system cost of a new resource or measure. The methodology's development and implementation are a required element of the power plan.

The Act also requires that in developing the power plan's resource strategy that the Council give "due consideration" to environmental quality and fish and wildlife concerns. These are broader considerations than fit within the methodology for quantifying environmental costs and benefits, which is strictly applied to new resources and their cost-effective comparison, and is described in the later part of this section.

In the Power Act

As laid out in the Northwest Power Act, the Council's power plan is tasked with assuring the Northwest of an adequate, efficient, economical, and reliable power supply. Within that planning the Council must give priority to resources it determines to be cost-effective.[1] Cost-effectiveness is determined by comparing the estimated system costs of different resources;[2] a resources system cost is inclusive of all direct costs of a measure or resource over its effective life. This includes cost of distribution and transmission to the consumer, as well as waste disposal costs, end-of-cycle costs, and fuel costs, and such quantifiable environmental costs and benefits as determined on the basis of a methodology developed by the Council as part of the plan that are directly attributable to such measure or resource.[3]

Within that definition of system cost, the Act explicitly calls out "quantifiable environmental costs and benefits as determined on the basis of a methodology developed by the Council as part of the Plan." Later the Act identifies the development and application of a "methodology for determining [the] quantifiable environmental costs and benefits" of new electric generating and conservation resources as a distinct element of the power plan,[4] clarifying that costs and benefits identified and quantified by the methodology are part of the incremental system cost of a new resource. Notably, the Act does *not*

[1] Northwest Power Act, Section 4(e)(1).
[2] Northwest Power Act, Section 3(4)(A).
[3] Northwest Power Act, Section 3(4)(B).
[4] Northwest Power Act, Section 4(e)(3)(C).

define environment, quantifiable, or directly attributable. The methodology is tasked with defining and justifying the interpretation of these terms and concepts.

Methodology

The Council considers four categories when considering when and how to apply the environmental methodology to determine and quantify the costs and benefits of new resources:

1. Costs of compliance with existing environmental regulations
2. Cost of compliance with proposed environmental regulations
3. Environmental effects beyond regulatory control
4. Quantifiable environmental benefits

Cost of Compliance with Existing Environmental Regulations

The Council's planning assumes all generating resources will meet existing federal, state, tribal, and local environmental regulations. Therefore, the estimated costs of compliance – when quantifiable – are included as part of the total system cost of a new resource. This has been the primary method for capturing and quantifying the environmental costs and benefits in past power plan and will remain so in the Ninth Plan.

- Regulated environmental effects – and the cost of assumed compliance – are varied and are incorporated when applicable across supply and demand side resources. Specifics are discussed in Technical Appendices G through J focuses on new generating and demand side resources and Technical Appendix B is focused on the existing system and policies. Some examples include: Air emissions from generation (SO_x, NO_x, CO_2, methane, mercury) regulated by the Clean Air Act
- Wastewater discharges from generation, regulated by the Clean Water Act
- Solid waste from generation such as toxic/hazardous wastes like coal ash, chemicals in solar panels etc. and nuclear waste
- Regulated environmental effects of fuel productions
- Direct operational effects on fish and wildlife (birds at wind turbines, new hydro effects on fish etc.)
- Cost of environmental compliance in sitting and construction

Cost of Compliance with Proposed Regulation

Quantifying compliance costs for existing regulations is a primary piece of the Council's methodology; however, an additional consideration is compliance with proposed environmental regulations. The Council has typically dealt with proposed regulations on a case-by-case basis depending on the proposal, the effects the proposal addresses, and the quantitative data available. For the Ninth Power Plan, the Council did not include the cost of compliance for any new proposed regulation, as there were no relevant regulations to consider at the time of power plan analysis.

Environmental Effects Beyond Regulatory Controls

The Council recognizes there are environmental damages or social costs of environmental effects that are not comprehensively regulated and have made efforts to capture what can be quantified. However there remains insufficient data to determine and quantify all environmental effects. These additive effects can be categorized as residual or unregulated.

Residual effects refer to a generating facility's environmental effects beyond the regulated level. For example, coal plant emissions are regulated by strict limits, but they still emit particulates, sulfur dioxide, and hazardous gases up to that limit. Similarly, there are regulatory requirements set on wind turbines intended to reduce bird and bat mortality, but wind farms still kill some birds.

Unregulated effects are those environmental effects not currently regulated but that still cause known impacts to the environment. In past power plans, CO_2, methane, and other greenhouse gas emissions fell within the unregulated category. The regulation of greenhouse gases has evolved in recent years, and the Council has worked to adapt their treatment accordingly. Emissions regulations include a mix of some direct, but fluctuating, regulation under the Clean Air Act, and more ancillary regulations by way of laws and policies that reduce emissions by affecting resource choices, such as state renewable portfolio standards and other clean policy targets.

In the Ninth Plan, the Council has not explicitly included any costs to new resources for these unregulated effects. However, they are still considered in the resource strategy through the implementation of existing policies described above. Through the cost of compliance with these policies and the limits they place on emitting resources, the Council is able to, in part, account for the effect of greenhouse gas emissions at a portfolio level. Greenhouse gas emissions, when not quantifiable, are discussed more broadly as a piece of due consideration of environmental effects. That discussion, can be found in Technical Appendix B – Existing System Parameters and Policies.

Quantifiable Environmental Benefits

The Power Act calls for the quantification of environmental cost, as outlined above, *and* environmental benefits to be included in a new resource cost. This has been a difficult and contentious piece of the environmental methodology throughout the Council's history. Environmental benefits are difficult to capture quantitatively. What, for example, is the dollar value of improved human health outcomes? They are also easily double counted, such as when an environmental benefit comes from reducing an activity with an environmental cost that has already been accounted for. Additionally, benefits are difficult to directly attribute to a specific resource or measure and are hard to apply consistently, which risks skewing our cost comparisons because we have access to some data for some resources but not others.

Water savings can be used to demonstrate the way the Council has contended with incorporating the environmental benefit of reducing an existing activity that has an environmental cost into the costs of a new resource. For example, installation of an efficient washing machine not only saves energy, but also reduces the amount of water used to wash clothes, which is an environmental benefit. To determine a quantitative estimate of this benefit, the water saved, the Council can use the reduced water and wastewater bills paid by consumers to assign a dollar value to this benefit and incorporate it into the resource cost of the conservation measure. While this quantification captures the benefit as it applies to the consumer, the money saved by needing less water, it does not capture the broader environmental benefits of reduced water use, which would be nearly impossible to reasonably quantify.

Due to these challenges, the Council is unable to quantify any distinct and directly attributable environmental benefits through the environmental methodology in the Ninth Plan. However, this does not preclude the Council from recognizing and emphasizing in the resource strategy the value of certain resource choices in helping to mitigate harmful environmental effects. A more systematic breakdown of how different cost and benefits are or are not considered in the planning process, outside of the environmental methodology, can be found in the Quantifiable Resource Cost Framework available on the Ninth Plan webpage.[5]

Due Consideration of Environmental Effects of Generating Resources

The Act requires that in developing the power plan's resource strategy that the Council give "due consideration" to environmental quality and fish and wildlife concerns. Due consideration for environmental quality is pursued through a number of avenues throughout the planning process. It is an explicit goal of the Environmental Methodology, described above, but it also is achieved through the Council's Fish and Wildlife Program, compliance with clean energy regulations, climate model analysis etc. The intention of this section is to narratively address the environmental effects of supply-side generating resources and give due consideration to their impact on the region's environmental quality. These impacts in most cases are not explicitly included in modeling, but can inform decisions and recommendations made by the Council in the power plan.

Every generating resource has adverse effects on the environment, to varying degrees. The following section describes at a high level some of the primary environmental effects of generating resources. This section is not intended to be a comprehensive account of these effects. A more exhaustive analysis was performed for the Seventh Power Plan, and much of that evaluation remains relevant.[6]

[5] https://nwcouncil.box.com/v/ninthplancostframework.
[6] Council Northwest Power and Conservation Council's Seventh Power Plan, Appendix I: Environmental Effects of Electric Power Production.

A few related resources include:

- Council's Methodology for Determining Quantifiable Environmental Costs and Benefits and due consideration for environmental quality to understand how the Council incorporates environmental impacts into its power plan analysis.
- Council's quantifiable resource cost framework to understand how costs and benefits are applied across all resource options and see new generating resource options for the application of quantifiable environmental costs and benefits, along with environmental considerations such as decommissioning costs.[7]
- Section on Select Federal Statutes and Regulation Updates for a description of some of the major federal statutes and regulations that address environmental impacts of generating resources. A brief description of such statutes is found in Technical Appendix B: Existing System Parameters and Policies.

A high-level summary of the environmental effects of generating resources can be found in Table C - 1 below followed by more detailed summaries for each resource.

Table C - 1: Summary Table of Environmental Effects by Generating Resource

Generating Resource	Environmental Effect
Hydropower	Fish and wildlife – blocked fish passage Water quality – changes in temperature and flow rates Erosion and sedimentation Land-Use
Coal	Air emissions – carbon dioxide, particulates, sulfur oxides, nitrogen oxides, mercury, other heavy metals Water quality – discharge of cooling water Reduced visibility – smog The disposal of waste from the coal combustion process requires a significant amount of land and, depending on the waste disposal structure, can pollute surface water.
Nuclear	Radioactive waste from spent fuel Water use Land use
Natural Gas	Greenhouse gas emissions from combustion Water use Pollution from waste heat cooling processes Leakage of methane (fugitive emissions) during the extraction, processing, transportation and storage Drilling for natural gas and the construction of pipeline infrastructure

[7] The full framework can be found at https://nwcouncil.box.com/v/ninthplancostframework.

Generating Resource	Environmental Effect
Biomass	Land use Water use and quality Emissions: nitrogen oxides, sulfur dioxide, carbon monoxide, mercury, lead, volatile organic compounds, particulate matter, carbon dioxide, and dioxins
Geothermal	Land and wildlife disturbances Air and water quantity
Wind - Onshore	Land use Habitat and wildlife interference Decommissioning of plant components
Wind - Offshore	Impacts during construction and decommissioning Noise during construction and operation Disruptions to local ecosystems and behavior of wildlife (marine species)
Solar PV	Land-use Interference with wildlife End-of-life disposal - cadmium and lead in the panels
Battery Storage	Extensive mining, extracting, and processing of the minerals used in a lithium-ion battery: cobalt, nickel, and manganese
Transmission System	Land-use Wildfire risk Interference with wildlife

Environmental Effects of Hydropower Generation

Under the Northwest Power Act, the Council develops a program to protect, mitigate, and enhance fish and wildlife adversely affected by the development and operation of hydropower facilities on the Columbia and its tributaries. To address the effects from the existing system, the Council's 2026 *Columbia River Basin Fish and Wildlife Program* includes measures and objectives to protect and benefit fish and wildlife. Measures to limit the direct impact of hydropower development include fish screens and bypass systems, bypass spills, and fish ladders to help fish navigate through the hydropower dam; minimum flows, flow augmentation requirements and stable storage reservoir operations; and the installation and implementation of systems to maintain powerhouse discharge and minimize or eliminate fluctuations in water and flow levels. Offsite protection and mitigation actions include both habitat protection and improvement measures and artificial propagation facilities and strategies. Mitigation for the effects of the development of the system on wildlife has focused primarily on the offsite acquisition, improvement, and protection of habitat for the affected wildlife species. The representation of the existing hydro system in the power plan assumes implementation of all measures prescribed by the Council's fish and wildlife program, along with any additional existing requirements for system operations.

The principal environmental effects of hydropower are water quality impacts, hydrological impacts, erosion and sedimentation, land-use impacts, and fish and wildlife impacts. The environmental effects associated with any one hydropower project are site specific and therefore can be different when comparing projects; for example, a project that involves adding generators to an existing non-powered dam or other existing water control structure will typically cause less of an incremental environmental impact than a project that requires new dam construction. There are few serious air emissions or solid waste issues associated with hydropower development or operation.

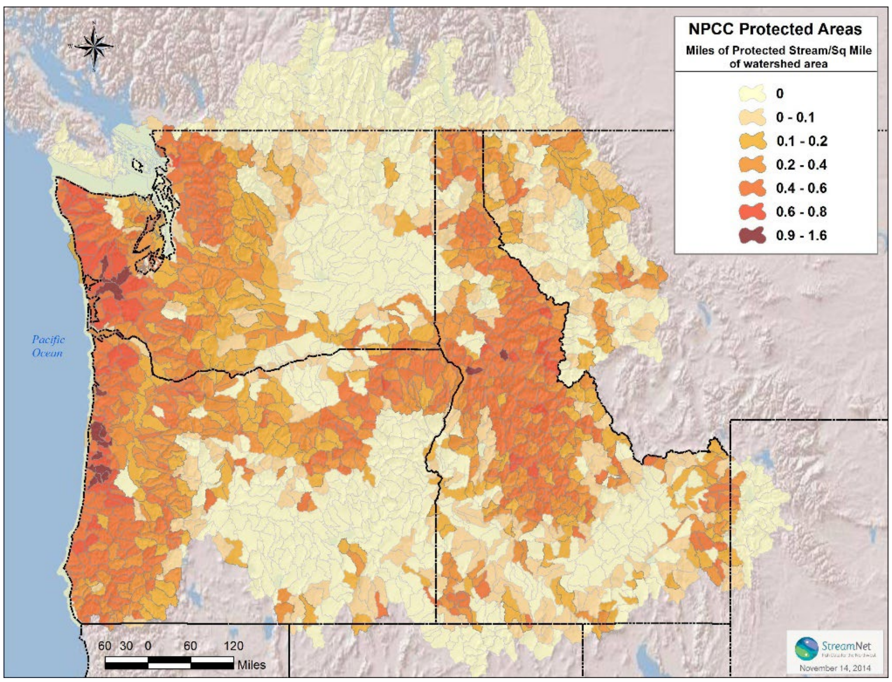
Of particular concern to the Council is the potential impact of hydropower on fish and wildlife. A hydropower dam presents a migration barrier to the passage of upstream (adult) and downstream (juvenile) anadromous and resident fish. Habitat is completely blocked by some projects in the system. At dams that allow passage, juvenile downstream migrants face the risk of mortality at each dam because of passage through turbines, exposure to water supersaturated with nitrogen, delay in start of migration, increased travel times, and increased predation. Filling an impoundment behind a hydropower dam inundates land and transforms a free-flowing river into a lake-like environment. This transition of habitat changes the composition of terrestrial and aquatic biota at the project site which may be beneficial or detrimental to wildlife. System storage operations to optimize power generation also alter flows important for the emergence, rearing, and migration of juvenile salmon and other fish, and for adult spawning.

The construction and operation of a hydroelectric project may affect water quality through thermal changes causing wide fluctuation of stream temperatures, nitrogen supersaturation (total dissolved gas), turbidity, and oxygen depletion. A hydroelectric dam slows the movement of water in a river system, which can lead to temperature stratification and oxygen depletion in the reservoir behind the dam. Spill flows from a dam may increase the levels of total dissolved gas in the river downstream. While these water quality changes are not always adverse, they can influence the aquatic environment and can prove lethal for fish and wildlife. Water quality can also affect the aesthetics of the project site.

The process of developing a hydroelectric dam alters the physical hydrology (the movement and distribution of water) of the site and the watercourse. These changes can have significant primary and secondary effects on water quality, habitat, fish and wildlife. The operation of a hydroelectric facility during times of maintenance, outages, or to meet peak energy demands causes fluctuations of water level in both the impoundment and the stream below. These fluctuating water levels may prohibit development of shoreline vegetation, reduce shoreline use by riparian (riverbank or streamside) species of wildlife, and lower reproductive success of fish species that spawn near the impoundment margin. Fluctuations in rivers below dams can strand immature fish on shorelines or in shallow waters and may lead to the exposure of eggs of shoreline spawners and nests of salmonids. Storage dams tend to reduce some of the seasonal fluctuations in river flow, creating a more stable riparian zone and changes in habitat characteristics associated with variable flows. Impound water can flood islands that are important breeding grounds for certain avian species. Issues with erosion and sedimentation may occur during construction and continue long after a project is retired or removed. Changes in the sediment load and flow can affect the natural sediment equilibrium found in free-flowing waters and increase water turbidity due to accretion and settling in the backwaters behind a dam. This can result in increased sediment deposits near the physical dam and decreased sediment downstream, both affecting the growth of organisms that depend on nutrients carried by the sediment. As the water levels fluctuate, erosion can occur, changing the physical environment. A lack of vegetation along the riverbank can also lead to perpetual carving away of the earth surrounding the water source. The amount of land required for the development of a hydroelectric dam varies significantly depending on the site and project. A storage project can take up thousands of acres, while a small run-of-river project may take up less than an acre. Nonetheless, between the physical infrastructure and the equipment used for construction, land is disturbed, and the surrounding environment is altered.

From the inception of the Program, the Council has supported the concept of protecting some streams and wildlife habitats from hydroelectric development where the Council believes such development would have major negative impacts that could not be reversed. This distinctly limits prospects for large-scale new development that is consistent with the Council's Protected Areas[8] identified on the map in Figure C - 1.

Figure C - 1: NWPCC Protected Areas



[8] https://www.nwcouncil.org/fish-and-wildlife/fw-topics/protected-areas.

Environmental Effects of Coal Generation

Environmental effects of coal generation range from the combustion of fuel to the disposal of waste, and result in significant environmental and human health impacts, notably, air emissions, impacts on water quality, and reduced visibility.

Coal Plant Operation

A coal-fired steam-electric power plant consists of coal receipt, storage, handling and preparation facilities, a furnace and steam generator, a steam turbine and condenser, an electric power generator, a switchyard, flue gas handling and emission control equipment and a closed-cycle condenser cooling system. Coal-fired generation produces significant carbon dioxide emissions, with coal emitting markedly more than natural gas-fired generation. In the region, coal-fired generation has historically accounted for most carbon dioxide emissions from power plant combustion, although that percentage is decreasing with coal unit retirements. In addition to carbon dioxide, coal combustion also causes atmospheric releases of an assortment of pollutants, including particulates, sulfur oxides, nitrogen oxides, and mercury and other heavy metals.

The intake and discharge of the cooling water (which may be contaminated by waste and metals during the cooling process) can affect nearby ecosystems and aquatic life. The disposal of waste from the coal combustion process requires a significant amount of land and, depending on the waste disposal structure, can pollute surface water.

Coal Extraction/Mining

Coal is extracted either from underground mines or surface mines. Underground mines have limited surface impacts, relying on discreet above-ground points of entry to enable miners and equipment to access the coal seam. The development of an underground mine typically involves the transportation of heavy equipment and workers to the site, which may require the construction of new roads. In addition, preparation of the site may entail drilling, blasting, excavation and pile driving. These operations often result in air impacts from fugitive dust and vehicle exhaust, as well as water impacts from altered drainage patterns and increased pollutant and sediment loads in runoff from the site. Wildlife may be affected by associated noise and human activity, as well as habitat disruption.

A surface coal mine causes significantly more visible above-ground impacts than underground mines. The two predominant methods of surface coal mining are mountaintop removal, which commonly occurs in the Appalachian coalfields, and area strip mining, which is typically employed in the Western states. Mountaintop removal mining involves the use of explosives and machinery to access coal seams beneath mountaintops. The displaced rock and dirt are disposed of in adjacent valleys. In addition to causing harmful effluents, mountaintop removal operations often permanently bury headwater streams with overburden and alter flow patterns in associated drainages. Area strip mining uses heavy machinery to remove soil and rock to access underlying coal seams. Large scrapers remove the soil covering the area to be mined, and either stockpile the soil for later reclamation use or use them to reclaim a previously mined area. The overburden beneath the soil is then leveled, blasted and removed to a spoils pile to expose the underlying coal seam. These methods of surface mining have obvious implications for vegetation and wildlife habitat. Surface mines may also have a detrimental impact on water quality. Surface mining often results in acidic runoff containing harmful levels of sediment, salinity and trace metals.

After coal is mined from either an underground or surface mine, it is typically processed to remove impurities before being transported to a coal plant. The coal cleaning process raises a variety of environmental and human health concerns, primarily resulting from the water effluents associated with the cleaning process. Run-of-mine coal stockpiles may be stored outside, uncovered, which exposes them to wind and rain. Rainwater leaches contaminants from the coal, and the runoff is generally captured in a coal pile runoff pond. These contaminants include metals such as copper, aluminum, nickel, and iron, as well as suspended solids. Coal pile runoff ponds are designed to settle out solids but typically do not treat the water for metal content before discharging. Effluents are also produced in the coal washing process, where much of the non-coal material removed during preparation of the coal is suspended in water and stored in tailings ponds.

In addition to water effluents, coal processing may result in particulate matter air emissions in the form of coal dust during conveyor belt pour off, stockpile construction or consumption, crushing and sorting operations, thermal drying or wind erosion.

Environmental Effects of Nuclear Generation

Nuclear is a carbon-free generating resource, and thus the environmental effects of nuclear generation are focused primarily on water use and radioactive waste from spent fuel disposal. Nuclear power is generated through the fission (splitting of atoms) of uranium, and the spent fuel is therefore radioactive waste. This waste must be disposed of in long-term storage in an environmentally safe way, often in steel-lined concrete canisters above or below ground. Nuclear power plants use a large amount of water for steam production and cooling, which potentially affect nearby ecosystems and aquatic life. In the case of the Columbia Generating Station, its water withdrawal from the Columbia River represents a small fraction of the overall river flow and would have to increase by six times to trigger the Environmental Protection Agency's minimum threshold for industrial water intake regulations.[9] The water that CGS returns to the Columbia River from the wet cooling system is free of radioactive materials; it is separate from the water that is used in the reactor to create steam.

Cooling water withdrawals have the potential to impact water flows and entrain aquatic organisms, while water discharges may occur at temperatures higher than that of the receiving waterbody. The cooling process may also cause toxic materials to dissolve into the water and accumulate as it circulates through the cooling system.

In addition to direct environmental effects from the generation of nuclear energy, there are specific and intricate safety features deployed on site to protect and prevent against any accidental

[9] This threshold is 2 million gallons per day of cooling water, see: https://www.epa.gov/cooling-water-intakes.

widespread contamination event (unmitigated radioactive waste released into the air and/or water) – such as an uncontrolled nuclear reaction, extreme weather event, or earthquake. The Nuclear Regulatory Commission (NRC) regulates and oversees all safety protocols regarding nuclear power plants, and they utilize a strategy of redundant security to minimize all risks.

While the environmental impacts associated with the normal operation of a nuclear power plant are limited, the mining, processing and disposal of nuclear fuel create a variety of adverse environmental effects. Uranium, the typical fuel source for nuclear power generation, is generally mined in open pit mines or extracted through in situ leaching. Preparation of mine sites requires drilling, blasting and road construction, which may disrupt wildlife and existing land uses, in addition to potentially contaminating nearby waterbodies and groundwater. Water runoff from open pit mines may be contaminated with heavy metals and small levels of radioactive material, while in situ leaching operations may also introduce drilling fluids and leaching solutions. In situ leaching involves injecting a fluid (called a "lixiviant") that dissolves uranium and then pumping that uranium containing solution to the surface. That fluid must then be processed to purify and dry the uranium from the solution. Most operating uranium mines in the United States (approximately three percent of total world production) are in situ leaching mines.

Although nuclear electricity generation does not directly produce any significant air pollution, the mining, processing, and transportation of nuclear fuel all require energy inputs, which are typically drawn from other energy sources. Depending on the source of energy, then, these steps may result indirectly in carbon dioxide and other emissions

Decommissioning represents the final phase of a nuclear power plant's lifecycle and may result in a variety of environmental and human health impacts. Decommissioning typically involves the removal and disposal of highly radioactive spent fuel, the demolition of structures and removal of debris, and the clean-up of contaminated soil and groundwater. Most waste produced in decommissioning a nuclear facility is not radiologically contaminated or is minimally radioactive and may be landfilled. Intermediate level waste, such as fuel rod casings and reactor vessel parts, requires shielding and may be disposed of at shallow depths. High level nuclear waste, such as the spent fuel stored on-site in casks or pools, requires cooling and shielding and may be reprocessed or disposed of in deep geological formations. The risk of a large-scale release of radioactive material from decommissioning activities is low, however workers involved in decommissioning a nuclear facility may have heightened risks of exposure due to their interaction with the radioactive debris. The pathways for public exposure to radioactive material may arise from the demolition of structures and debris, which has the potential to release radioactive dust and gas, and the penetration of water into the disposal site, which may dissolve radioactive isotopes and transport them into the water system. These risks can be mitigated through the introduction of proper safety measures, such as protective barriers and monitoring programs. The carbon emissions impact of the decommissioning stage is typically limited to exhaust from worker and construction vehicles and transportation of waste materials.

Environmental Effects of Natural Gas-Fired Generation

Environmental effects of natural gas generation and cogeneration are primarily greenhouse gas emissions from combustion, and water use and pollution from waste heat cooling processes. Natural gas is the cleanest burning of fossil fuels, with about half of the carbon dioxide emissions of coal and about two-thirds that of distillate fuel oil. In addition to carbon dioxide, nitrogen oxide and volatile organic compounds are also released.

The air emissions of principal concern from gas turbines are carbon dioxide, nitrogen oxides (NOx), carbon monoxide and to a lesser extent volatile organic compounds. Sulfur oxide emissions are of potential concern if fuel oil is used. Like all fossil fuel technologies, gas turbines produce carbon dioxide as a product of complete combustion of carbon. Carbon dioxide emission factors are a function of plant efficiency, so newer units in general, and aeroderivative and intercooled units in particular, have lower CO_2 emissions per MW than older units. Though technology for separating CO_2 from the plant exhaust is available, as a practical matter it is unlikely that CO_2 removal technology would be employed for simple-cycle gas turbines because of the relatively low carbon content of natural gas and the relatively small size and limited hours of operation of these units.

When considering the full life cycle of natural gas beyond the combustion of fuel into energy, there are environmental effects from the release or leakage of methane (also known as fugitive emissions) during the extraction, processing, transportation and storage of natural gas. In addition, drilling for natural gas and the construction of pipeline infrastructure have an adverse effect on the land, water, and wildlife.

Unconventional wells are designed to access gas resources in formations with small permeability, which require “stimulation” to start producing. Stimulation increases the permeability of the gas bearing formation. The most common forms of well stimulation are hydraulic fracturing using proppants, hydraulic fracturing using acid, and matrix acidizing. All these forms of stimulation have the potential to adversely impact the environment and human health. Fracking requires the withdrawal of a considerable amount of water, anywhere from 1.5 to over 15 million gallons. This water is mixed with other chemical ingredients to produce fracking fluid. Water withdrawals associated with fracking may cause water quantity impacts in water-constrained areas. Additionally, water quality concerns arise when fracking fluid contaminates freshwater resources, either through migration into freshwater aquifers through inadequately completed wells, or through improper wastewater management. Fracking fluid may contain diesel fuel, polycyclic aromatic hydrocarbons, methanol, formaldehyde, ethylene glycol, glycol ethers, hydrochloric acid, sodium hydroxide, and other toxic compounds.

Environmental Effects of Biomass Generation

The term biomass includes solid fuel, such as wood, wood waste and agricultural residues, as well as methane produced by the decay of organic material in landfills, sewage treatment facilities, and farming operations. Since biomass energy refers to a diverse array of fuels and technologies, the potential environmental and human impacts that result from biomass-fueled electricity generation are varied. The primary concerns are water and land use impacts associated with feedstock production and air quality concerns relating to biomass combustion.

Biomass generation uses similar technology to coal and natural gas and therefore is subject to emissions arising from the production process; however, in general biomass emits fewer pollutants than its fossil fuel counterparts. The primary air emissions caused by biomass combustion include nitrogen oxides, sulfur dioxide, carbon monoxide, mercury, lead, volatile organic compounds, particulate matter, carbon dioxide, and dioxins. Biomass generation can be considered a carbon dioxide-reducing resource only if re-plantation of the spent fuel occurs (e.g. woody residues). Most existing biomass projects in the region are fueled by already spent resources rather than resources grown for the purpose of energy production, for example animal waste, woody residues, and municipal garbage, and therefore the impact to land and water use to supply the fuel is minimal as it already exists. Depending on the type of technology and fuel used in power production, there are greenhouse gas emissions and water quality issues associated with biomass. Cooling water can affect nearby land and water sources, depending on where/how it is used. If a closed-loop system is utilized by the power plant, there are fewer impacts to nearby water sources than a once-through or open loop cooling system.

Environmental Effects of Geothermal Generation

Environmental effects of geothermal generation are land and wildlife disturbances, air and water quantity and quality. Much like wind and solar, prospective geothermal power plants must undergo extensive environmental impact reviews that mitigate many land and wildlife impacts. While geothermal plants can take up to several hundreds of acres of land during development, much of that land can be reclaimed and repurposed once construction is complete. Air and water effects depend largely on the type of technology and open/closed loop cycle utilized by the power plant. There are few emissions from binary, closed-loop geothermal power plants as the water and air vapors are re-injected into the production cycle. Open-loop cycle plants emit primarily carbon dioxide and some methane, although it is at an amount that is equivalent to 30 percent of a conventional coal plant.

Environmental Effects of Wind Generation

Onshore Wind

Environmental effects of wind power generation are primarily land use, habitat, and wildlife interference. There are no greenhouse gas emissions related to the generation of power itself. While wind farms use a significant amount of land in total area (the acreage is site specific, depending on the configuration and geography of a project), much of that land is either undisturbed by development or multi-purposed. Wildlife interference occurs in two ways: direct mortality due to collisions with the wind turbines and indirect impacts to wildlife due to the loss of habitat in which the wind project resides, including blockage of migration pathways.

Bird deaths are primarily the result of direct contact with spinning wind turbines, the tips of which can travel at speeds ranging from 150 to 200 miles per hour. Most of the bird types affected by wind turbines are songbirds. Eagles and other raptors may be affected by the operation of wind facilities in and around their soaring locations and through direct contact with spinning turbine blades. Environmental Impact Statements prepared in support of wind projects in the Northwest identify several special-status raptor species that may be affected by wind development including the Northern Goshawk, Ferruginous Hawk, and the Peregrine Falcon. The Greater Sage Grouse is a species of particular concern, because its range coincides with prime wind resources in the region. The sage grouse is primarily affected by habitat disruption resulting from wind development, because the animals tend to avoid human infrastructure. Other bird species that may be vulnerable to wind project development as well, including: the Sage Sparrow, Loggerhead Shrike, Lewis' Woodpecker and Mountain Quail. Many bat species are also affected by wind energy development, through both contact with the spinning blades and contact with areas of rapidly changing pressure caused by the turbines. Abrupt changes in pressure may cause barotrauma in bats, resulting in internal hemorrhaging that can be fatal.[10]

As wind turbines reach the end of their useful life, decommissioning of plant components and the magnitude of waste created becomes an issue. Most of the wind turbine components can be recycled, salvaged, repurposed, or sold on a secondary market. However, there is not currently an adequate solution for decommissioned wind turbine blades – composed of composite fiberglass and resin. Oftentimes, blades are simply disposed of in landfills because it is the most economic option. The size of the blades can create a substantial issue for local landfills with limited capacity to grapple with, and transportation of blades to designated waste areas can get very expensive.

Much of the land and wildlife effects are mitigated during the siting and licensing of wind projects, although the effects of a significant deployment of onshore wind in a short amount of time are not yet fully understood.

Offshore Wind

The environmental effects of offshore wind include impacts during construction and decommissioning, noise during construction and operation, and disruptions to local ecosystems and behavior of wildlife. The development of an offshore wind project includes significant machinery, complex logistics, and major installation of equipment beyond the wind turbine itself (e.g. underwater transmission cables to transport the electricity to onshore substations). All of this leads to the disturbance of the existing habitat.

With the introduction of equipment above, and below the surface of the water, many marine species are affected. Under the water, species such as mussels and algae are attracted to and can colonize the structure and cables. This can cause the creation of artificial reefs and an increase in marine life and species diversity. One drawback is that an artificial reef can also attract predators and introduce new, invasive species to the ecosystem, leading to predation and threatening the existing species through competition of habitat and food sources. Underwater structures may also be spread out over a wide area, which can lead to disruption and entanglement of marine populations that typically

[10] https://rewi.org/wp-content/uploads/2025/09/REWI_Wind-Interactions-Summary_2025.pdf.

forage and migrate through the offshore wind project area. At the surface and above the water, structures pose similar risks of collision and entanglement to seabirds (which may be more attractive to the area due to the increased marine life) although the risk is less as the structures are large enough to be visible. If equipment is close to the shoreline, breeding grounds may also be disrupted or affected. Noise, during construction and operation, may disturb the wildlife in the area, although severity is likely dependent on the species.

Environmental Effects of Solar PV Generation

Environmental effects of solar PV generation are mainly land-use, interference with wildlife, and end-of-life disposal. Energy production from solar PV plants does not contribute to the release of greenhouse gases.

An environmental concern is the proper disposal of solar panels at the end of their useful life. Solar panels contain hazardous materials that if disposed of improperly, could potentially pose a risk to the environment. The primary concern for toxicity is the cadmium and lead in the panels. However, panels are mostly comprised of glass, aluminum, and plastics with very little lead or cadmium (depending on the technology), and these components encapsulate the limited amount of lead and protect it from the environmental and harsh weather conditions. Thus, even when disposed of in a landfill, there is very minimal risk of toxicity.

Much of the land and wildlife effects are mitigated during the siting and licensing of solar PV projects, although the effects of a significant deployment of solar PV in a short amount of time is not yet fully understood. In the 2021 Power Plan the Council recommended that siting authorities should work to ensure that new renewable resource development is carried out in a manner that protects wildlife, fish, and cultural resources of the Pacific Northwest. Emphasizing the importance of “least impact, less conflict” siting principles to push development away from high value lands and encouraging deliberate, strategic outreach and engagement in siting processes with fish and wildlife agencies, tribes, and communities directly affected by development. The recommendation was explicit about prioritizing tribal consultation to better understand and preserve cultural resources and traditional uses in the vicinity of developments.

The production of solar PV panels requires the acquisition of raw materials, the use of toxic chemicals, the consumption of electricity, and the disposal of waste products, all of which have attendant environmental risks. In addition to silicon, which is relatively abundant and the largest component of a solar panel, the production of a PV system typically requires rare or precious metals, such as silver, tellurium and indium. These rare metals may be mined by exploited workers and supplied from areas of conflict. Although abundant, silica can cause lung disease silicosis in workers responsible for mining the material. Silica is generally mined in the form of quartz, which must be initially refined into silicon and then into polysilicon before it may be used in a solar panel. The initial refining process requires the use of energy-intensive furnaces, the operation of which may result in greenhouse gas and other air emissions depending on the energy source used. Thin-film manufacturing methods, which represent a less material- and energy intensive manner of manufacturing PV panels, may obviate the need for many of the steps described above. But thin-film technologies typically require components that contain cadmium which is a carcinogen and genotoxin. As a result, thin-film manufacturers are working on reducing or eliminating the need for cadmium in their products. The overall environmental impacts of solar panel production largely depend on the materials and processes used by the panel manufacturer.

Habitat disruption is the primary risk to plants and wildlife posed by utility-scale solar PV. The best solar resources in the Northwest are typically situated in high desert areas, so desert species are the most vulnerable to solar development. Utility-scale solar facilities typically consist of multiple rows of solar panels mounted on a concrete foundation. Once constructed, plants and wildlife are excluded from these facilities, so utility-scale PV development reduces available habitat. Solar PV development also brings with it human noise, activity and infrastructure, which may affect adjacent wildlife. Contact with increased vehicular traffic to and from the site, both during construction and operation could result in additional harm to wildlife. Mitigation measures, including limiting development to disturbed areas or existing facilities, establishing protective buffers between the facility and sensitive areas, and avoiding significant activity around the facility during mating periods can limit the risk of wildlife disruption.

Environmental Effects of Battery Storage

While environmental effects of battery storage differ based on technology and chemical properties, for lithium ion batteries and others, the primary effects of battery storage generation focus on emissions resulting from the primary source of energy charging the battery (for example, a wind plant or gas plant providing energy to be stored in the battery for discharge at a later time) and proper disposal of the battery components at the end of useful life. In addition, there are significant environmental, societal, ethical, and human rights impacts that can result from the improper or extensive mining, extracting, and processing of the minerals used in a lithium-ion battery. Responsible sourcing of these minerals is key if battery storage is set to play a large role in storing electricity and electrifying transportation.

Lithium-ion batteries contain cobalt, nickel, and manganese, which are all considered toxic heavy metals that if accumulated in large enough concentrations (through direct contact when working in both extraction and disposal methods) can cause human health hazards. These raw materials are also considered critical minerals, in that they are economically and strategically important and do not have readily available substitutes if/when sources are depleted. Finally, lithium-ion batteries are considered hazardous waste due to both their chemistries and combustibility. This all makes the proper disposal of the batteries at the end of their lifecycle very important. If batteries are disposed of in landfills, we not only risk toxic leeching or fire hazards if disposed of improperly (risks vary depending on technology and manufacturer), but we also risk losing the critical minerals. Since the cost of batteries has declined significantly, there are minimal incentives to salvage and resell components of the batteries. To minimize and avoid the waste accumulated through direct disposal in landfills, lithium-ion recycling initiatives have been launched.

Environmental Effects of Transmission System

Environmental impacts of transmission systems include habitat destruction, soil erosion, and water pollution during construction. In addition, long-term issues like habitat fragmentation, noise, and the risk of wildfires during operation. Construction can cause temporary and permanent damage to ecosystems, and ongoing maintenance can continue to disrupt wildlife and habitat.