The Vermont Legislative Research Service

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Environmental Impacts of Renewable Energy

All types of energy generation are known to have some negative impacts on the natural environment. Fossil fuels such as coal, oil, and natural gas account for the worst of these impacts through harmful green house emissions and toxic pollution.[1] Even renewable energy sources have adverse environmental effects that can be attributed to them. The type and severity of these environmental impacts can vary depending on the type of renewable energy technology and its energy generating capacity. This report will investigate the environmental impacts associated with wind, solar, hydroelectric, biomass, and geothermal power.

Wind Power

According to the Union of Concerned Scientists, generating power from wind is a clean and sustainable way to produce electricity. Wind is "abundant, inexhaustible, and affordable, which makes it a viable and large-scale alternative to fossil fuels."[2] Wind power does not cause any direct toxic emissions. Although wind power is a clean alternative to fossil fuels there are still environmental impacts involved in the manufacturing and deployment of system components.[3]

Land Use

Wind turbines located in hilly areas typically use less land than those placed in flat areas.[4] Based on a study conducted by the National Renewable Energy Laboratory, large wind facilities in the United States use between 30 and 141 acres per megawatt (MW) of power

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[1] Working Group III, "Climate Change 2014 Mitigation of Climate Change," Cambridge, United Kingdom: Cambridge University Press, 2014, accessed April 21, 2016, https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf.
[2] Union of Concerned Scientists, "Environmental Impacts of Wind Power," Cambridge, MA: Union of Concerned Scientists, 2016, accessed April 14, 2016, http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-wind-power.html#bf-toc-1.
[3] Working Group III, "Climate Change 2014: Mitigation of Climate Change."
[4] Union of Concerned Scientists, "Environmental Impacts of Wind Power."

output capacity (a typical new utility-scale wind turbine is about 2 MW).[5] However, less than "1 acre per MW is disturbed permanently and less than 3.5 acres per MW are disturbed temporarily during construction." [6]

Wildlife and Habitat

The National Wind Coordinating Collaborative (NWCC) conducted a study in 2010 that researched bird and bat fatalities linked to wind turbines. The report stated that fatalities of birds and bats fluctuate depending on different types of wind facilities and regions of the country where they are located. Although wind turbines are known to be responsible for migratory bird deaths, current literature suggests, "turbine-related fatalities are unlikely to affect population trends of most North American birds."[7] The NWCC also concluded that keeping wind turbines motionless during times of low wind speeds can help to lower bat deaths by 50% without altering wind power production.[8] Additionally, "potential adverse wildlife impacts also include direct and indirect habitat loss from the construction and operation of wind energy facilities."[9] One study concluded that a species of songbirds were displaced during the construction of wind turbines. However, once the construction was completed and the turbines became operational, the habitat returned to normal and the population grew back to normal size.[10]

Public Health and Community

When constructing wind turbines in densely populated areas, sound and visual effects must be taken into account. A common effect known as *shadow flicker* occurs "when rotating wind turbine blades interrupt the sunlight producing unavoidable flicker bright enough to pass through closed eyelids."[11] This phenomenon can have an impact on people who are inside as light is illuminated through windows. Although there have been complaints by people living near large wind facilities about noise and vibrations from the turbines, a study conducted by the Canadian Ministry of Health found that there is no scientific evidence available linking turbine noise to negative health effects.[12] More recent

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[5] National Renewable Energy Laboratory, "Land Use Requirements of Modern Wind Power Plants in the United States," Golden, Colorado: Denholm, Hand, Jackson, and Ong, 2009, accessed April 14, 2016, http://www.nrel.gov/docs/fy09osti/45834.pdf.

[6] Union of Concerned Scientists, "Environmental Impacts of Wind Power."

[7] Union of Concerned Scientists, "Environmental Impacts of Wind Power."

[8] National Wind Coordinating Collaborative (NWCC), "Wind Turbine Interactions with Birds, Bats, and Their Habitats," Washington, DC: NWCC, 2010, accessed April 14, 2016, https://nationalwind.org/wp-content/uploads/assets/publications/Birds_and_Bats_Fact_Sheet_.pdf.

[9] American Wind Wildlife Institute, "Wind Turbine Interactions with Wildlife and their Habitats," Washington, DC: AWWI, 2014, accessed, April 29, 2016, https://awwi.org/wp-content/uploads/2014/05/AWWI-Wind-Wildlife-Interactions-Factsheet-05-27-14.pdf

[10] American Wind Wildlife Institute, "Wind Turbine Interactions with Wildlife and their Habitats."

[11] The Society for Wind Vigilance, "Visual Health Effects and Wind Turbines," Ontario, Canada: The Society for Wind Vigilance, 2012, accessed April 14, 2016, http://www.windvigilance.com/about-adverse-health-effects/visual-health-effects-and-wind-turbines.

[12] Chief Medical Officer of Health of Ontario, "The Potential Health Impact of Wind Turbines," Toronto, Ontario: Ministry of Health and Long-Term Care, 2010, accessed April 24, 2016, http://www.health.gov.on.ca/en/common/ministry/publications/reports/wind_turbine/wind_turbine.pdf.

technological advancements such as sound-absorbing turbine materials have been able to reduce the noise generated by wind power facilities.[13]

Greenhouse Gas Emissions

Wind energy generation itself does not produce carbon emissions. But the related manufacturing and installment of turbines can produce harmful emissions.[14] See Table 1 below for full chart of emissions statistics including the emissions associated with the manufacturing and deinstallment of wind turbines.

Impacts of Wind Power in Vermont

In order to build wind turbines in the most wind-effective areas in the Vermont Green Mountains, roads and access ways must be constructed. Wind turbines that are built on mountainous ridgelines typically produce the most efficiency, with a variety of environmental consequences as a result. Constructing these roads requires large-scale projects such as detonating rocks, removing trees, and cutting forests.[15] Building roads and clearing forests is necessary to construct wind turbines in the most effective areas, but there are environmental drawbacks such as pollution.

Solar Power

The 2016 Comprehensive Energy Plan (CEP) developed under 30 V.S.A. § 202 provides an overview of renewable energy generation in Vermont.[16] The CEP states that as of 2015 there are 120 megawatts (MW) of solar photovoltaic (PV) systems in Vermont. Residential rooftop-scale solar PV systems under 10 kilowatt (kW) account for 30 MW of this capacity.[17] According to the CEP, each MW of solar PV requires approximately 7 acres of land, meaning solar represents around 840 acres of Vermont's land currently.[18] In order to meet the CEP's goal of reaching 90% renewable energy by 2050, Vermont would need an additional 8,000 to 13,000 acres of solar PV by 2050 assuming 12% will be met by solar.[19]

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[13] Union of Concerned Scientists, "Environmental Impacts of Wind Power."
[14] Working Group III, "Climate Change 2014: Mitigation of Climate Change."
[15] Energize Vermont, "Ridgeline Wind in Vermont," Rutland, VT: Energize Vermont, 2012, accessed April 21, 2016, http://energizevermont.org/wp-content/uploads/2012/06/WindTriFold-Brochure-2012-06-6.HR_.pdf.
[16] Vermont Agency of Natural Resources, "Report on the Environmental and Land Use Impacts."
[17] Vermont Agency of Natural Resources, "Report on the Environmental and Land Use Impacts."
[18] Vermont Agency of Natural Resources, "Report on the Environmental and Land Use Impacts."
[19] Vermont Agency of Natural Resources, "Report on the Environmental and Land Use Impacts."

Table 1: Emissions of electricity generating systems					
Options	**Direct emissions (gCO2eq/kWh)**	**Infrastructure & supply chain emissions (gCO2eq/kWh)**	**Biogenic CO2 emissions and albedo effect (gCO2eq/kWh)**	**Methane emissions (gCO2eq/kWh)**	**Lifecycle emissions (incl. albedo effect) (gCO2eq/kWh)**
	Min/Median/Max	**Typical values**			**Min/Median/Max**
Currently Commercially Available Technologies					
Coal—PC	670/760/870	9.6	0	47	**740/820/910**
Gas—Combined Cycle	350/370/490	1.6	0	91	**410/490/650**
Biomass—co-firing	n. a.	–	–	–	**620/740/890**
Biomass—dedicated	n. a.	210	27	0	**130/230/420**
Geothermal	0	45	0	0	**6.0/38/79**
Hydropower	0	19	0	88	**1.0/24/2200**
Nuclear	0	18	0	0	**3.7/12/110**
Concentrated Solar Power	0	29	0	0	**8.8/27/63**
Solar PV—rooftop	0	42	0	0	**26/41/60**
Solar PV—utility	0	66	0	0	**18/48/180**
Wind onshore	0	15	0	0	**7.0/11/56**
Wind offshore	0	17	0	0	**8.0/12/35**
Pre-commercial Technologies					
CCS—Coal—Oxyfuel	14/76/110	17	0	67	**100/160/200**
CCS—Coal—PC	95/120/140	28	0	68	**190/220/250**
CCS—Coal—IGCC	100/120/150	9.9	0	62	**170/200/230**
CCS—Gas—Combined Cycle	30/57/98	8.9	0	110	**94/170/340**
Ocean	0	17	0	0	**5.6/17/28**
Data From: Working Group III, "Climate Change 2014 Mitigation of Climate Change," Cambridge, United Kingdom: Cambridge University Press, 2014, accessed April 21, 2016, https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf.					

Land Use

Many solar systems are built in former agricultural areas as well as on "high elevation ridgelines, floodplains and low lying meadows dominated by wetlands" in Vermont.[20] Nationally, solar projects are less commonly found on agricultural lands and more commonly found in low-quality areas such as abandoned mining land, along transportation routes, along existing transmission corridors (areas cut out for transmission power lines) and in brownfields. A brownfield is a property that may be tainted by the presence of a hazardous substances, pollutants, or contaminants.[21,22] According to the National Renewable Energy Laboratory, the land use for different types of solar systems can vary. In states such as California, Arizona, Colorado, Florida, Hawaii, Nevada and Utah, Concentrating Solar Power (CSP) systems are deployed in addition to small-scale (1 MW to 20 MW) and large-scale (greater than 20 MW) photovoltaic (PV) systems.[23] CSP systems include parabolic troughs, power towers, and dish-stirling technologies. Parabolic troughs use "concave, parabolic-shaped mirrors to focus the direct beam radiation on a linear receiver."[24] The linear Fresnel is a type of parabolic trough that has become more commercialized due to its lower cost. The original parabolic trough has synthetic oil circulating through the tube where as the linear Fresnel is a stainless steal tube with no oil circulation.[25] Power towers consist of many two-axis mirrors that follow the incoming sunlight and direct it to a receiver located on top of the tower.[26] Dish-stirling uses a "two-axis parabolic dish to concentrate solar energy into a cavity receiver where it is absorbed and transferred to a heat engine/generator."[27]

Small-scale PV systems have a more minimal land use impact than larger systems because they can be built on top of commercial and residential buildings, where as larger systems require more acreage.[28] Table 2 shows land usage of different sized solar PV systems in the U.S., including fixed, single-axis, duel-axis, duel-axis Concentrator PV (CPV) and different types of CSP. Ground mounted systems can typically be categorized as fixed tilting or tracking.[29] Fixed tilting consists of a structure set at a specific tilt and remains at that tilt

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[20] Vermont Agency of Natural Resources, "Report on the Environmental and Land Use Impacts."

[21] Union of Concerned Scientists, "Environmental Impacts of Solar Power," Cambridge, MA: Union of Concerned Scientists, 2013, accessed April 19, 2016, http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-solar-power.html#.VxZs_iMrKL0.

[22] U.S. Environmental Protection Agency (EPA), "Brownfield Overview and Definition," Washington, DC: EPA, 2015, accessed April 19, 2016, https://www.epa.gov/brownfields/brownfield-overview-and-definition.

[23] National Renewable Energy Laboratory, "Concentrating Solar Power Projects," Golden, CO: 2014, accessed April 19, 2016, http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=US%20(%22_self%22.

[24] National Academy Press, "Electricity from Renewable Resources: Status, Prospects, and Impediments," Washington, DC: National Academies of Science, 2010, accessed April 18, 2016, http://www.nap.edu/read/12619/chapter/2.

[25] National Academy Press, "Electricity from Renewable Resources."

[26] National Academy Press, "Electricity from Renewable Resources."

[27] National Academy Press, "Electricity from Renewable Resources."

[28] Union of Concerned Scientists, "Environmental Impacts of Solar Power."

[29] Joe Simon and Gail Mosey, "Feasible Study of Economics and Performance of Solar Photovoltaics at the Kerr McGee Site in Columbus, Mississippi," Washington, DC: National Renewable Energy Laboratory, 2013, accessed April 19, 2016, http://www.nrel.gov/docs/fy13osti/57251.pdf.

(usually based on latitude and wind conditions).[30] Tracking systems rotate according to location of the sun. Single-axis can be rotated on a single axis (vertically) and duel-axis tracking is able to follow the sun all day because it can rotate both vertically and horizontally.[31] CPV solar systems use lenses and mirrors to concentrate focused sunlight onto cells.[32]

Table 2: Summary of Land-Use Requirements for PV and CSP Projects in the United States

Technology	Direct Area		Total Area	
	Capacity-weighted average land use (acres/MWac)	Generation-weighted average land use (acres/GWh/yr)	Capacity-weighted average land use (acres/MWac)	Generation-weighted average land use (acres/GWh/yr)
Small PV (>1 MW, <20 MW)	5.9	3.1	8.3	4.1
Fixed	5.5	3.2	7.6	4.4
1-axis	6.3	2.9	8.7	3.8
2-axis flat panel	9.4	4.1	13	5.5
2-axis CPV	6.9	2.3	9.1	3.1
Large PV (>20 MW)	7.2	3.1	7.9	3.4
Fixed	5.8	2.8	7.5	3.7
1-axis	9.0	3.5	8.3	3.3
2-axis CPV	6.1	2.0	8.1	2.8
CSP	7.7	2.7	10	3.5
Parabolic trough	6.2	2.5	9.5	3.9
Tower	8.9	2.8	10	3.2
Dish Stirling	2.8	1.5	10	5.3
Linear Fresnel	2.0	1.7	4.7	4.0

Data from: Sean Ong, Clinton Campbell, Paul Denholm, Robert Margolis and Garvin Heath, "Land-Use Requirements for Solar Power Plants in the United States," Washington, DC: National Renewable Energy Laboratory, 2013, accessed April 2016, http://www.nrel.gov/docs/fy13osti/56290.pdf.

Water Quality and Water Use

Renewable generation can have an impact on wetlands in many ways. Wetlands, are "commonly known as bogs, fens, marshes, wet meadows, shrub swamps, vernal pools and wooded swamps," and can help filter and store water during natural events such as storms.[33] Wetlands also provide habitat for wildlife and rare plant species in some cases. In

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30 Joe Simon and Gail Mosey, "Feasible Study of Economics and Performance of Solar Photovoltaics."
31 Simon and Mosey, "Feasible Study of Economics and Performance of Solar Photovoltaics."
32 Solar Energy Development Programmatic EIS, "Solar Photovalic Technologies," Washington, DC: Solar Energy Development Programmatic EIS, accessed April 19, 2016, http://solareis.anl.gov/guide/solar/pv/index.cfm.
33 Vermont Agency of Natural Resources, "Report on the Environmental and Land Use Impacts."

Vermont, wetlands are protected by Title 10 of the V.S.A, but areas on agricultural properties that are wet and unusable for farming are considered class two wetlands or wetland buffers and although they are protected from being used for agricultural purposes, energy generation in these locations are allowed.[34] Specific impacts of solar systems in wetlands include: disrupting animal habitat, loss of carbon sequestration function (long-term carbon storage), reduced ability to absorb filter pollutants due to a lack of vegetation biomass and invasion of invasive weeds due to soil disruption.[35]

Solar photovoltaic (PV) requires water for cleaning panels and thermal generation; its consumption rate is 0 to 33 gallons/megawatt hour (MWh) with a median value of 26 gallons/MWh.[36] Concentrating Solar Power (CSP) systems also require water for cooling towers ranging from 600 and 650 gallons of water per MWh.[37] CSP systems in Southwestern deserts can utilize dry-cooling systems. These systems use "ambient air, instead of water, to cool the exhaust steam from the turbines."[38]

Wildlife and Habitat

In the Southwestern part of the U.S., solar renewable energy system construction has and will continue to have significant impacts on desert species, many of which are endangered.[39] In the Southwest, areas rich in flora and fauna that have adapted to the heat and sun can be easily disturbed by the development of solar systems. CSP often requires thousands of acres for development.[40] This land is first cleared of any vegetation and in some cases, must be leveled to have minimal slope.[41] The clearing and sometimes leveling of the ground can have both direct (mortality) and indirect (habitat loss and degradation) impacts on species in these areas as well as their habitat.[42]

Hazardous Materials

Solar photovoltaic (PV) system manufacturers are constrained by many regulations including the Resource Conservation and Recovery Act (RCRA), and financial incentives to

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[34] Vermont Agency of Natural Resources, "Report on the Environmental and Land Use Impacts."
[35] Association of New Jersey Environmental Commissions, "Solar Siting and Sustainable Land Use," Mendham, NJ: Association of New Jersey Environmental Commissions, 2012, accessed April 19, 2016, http://www.anjec.org/pdfs/SolarWhitePaper2012.pdf.
[36] Geoffrey Klise, Vincent Tidwell, Marissa Reno, Barbara Moreland, Katie Zemlick and Jordan Macknick, "Water Use and Supply Concerns for Utility-Scale Solar Projects in the Southwestern U.S.," Albuquerque, NM: Sandia National Laboratories, 2013, accessed April 20, 2016, http://energy.sandia.gov/wp-content/gallery/uploads/SAND2013_5238.pdf.
[37] Klise, Tidwell, Reno, Moreland, Zemlick and Macknick, "Water Use and Supply Concerns."
[38] Jeffrey Lovich and Joshua Ennen, "Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States," Reston, VA: American Institute of Biological Sciences, 2011, accessed April 20, 2016, doi: 10.1525/bio.2011.61.12.8.
[39] Lovich and Ennen, "Wildlife Conservation and Solar Energy Development in the Desert Southwest."
[40] U.S. Fish and Wildlife Service, "Solar Energy," Falls Church, VA: U.S. Fish and Wildlife Service, 2015, accessed April 20, 2016, http://www.fws.gov/ecological-services/energy-development/solar.html.
[41] Lovich and Ennen, "Wildlife Conservation and Solar Energy Development in the Desert Southwest."
[42] Lovich and Ennen, "Wildlife Conservation and Solar Energy Development in the Desert Southwest."

recycling PV solar panels properly.[43,44] The recycling of PV systems is still an issue and will continue to be in the future.[45] The PV manufacturing process requires chemicals such as: "hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, trichloroethane, and acetone," mostly to clean and purify the semiconductor surface of the PV panels.[46] Solar panels have a lifespan of approximately 20-30 years while the inverter (changes direct current (DC) to alternating current (AC)) has a lifespan of 10 years.[47] The solar industry started major installments in the late 1980s and early 1990s meaning that decommissioned solar PV panels are just beginning to become an environmental concern.[48] If panels are not decommissioned properly, it is possible for chemicals to leach out degrading the surrounding environment.[49]

Greenhouse Gas Emissions

There are no direct carbon or methane emissions associated with the generation of solar electricity.[50] There are, however, emissions associated with the other processes in the life cycle of solar systems including the "manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement."[51] Table 1, shown above, displays solar PV systems infrastructure and supply chain emissions (emissions released during production, distribution and deconstruction) according to the International Panel on Climate Change (IPCC).[52]

Hydroelectric Power

Hydroelectricity or hydropower accounts for 7% of the U.S.'s energy, making it the largest source of renewable energy generation in the country.[53] Smaller capacity plants (30 MW or less) account for the vast majority of hydroelectricity (85%) in the U.S.[54] The remaining 15% of plants are classified as large hydro plants and have capacities greater than 30 MW.[55] Hydropower is generally considered to be one of the most environmentally benign forms of energy; however, new developments are being challenged over concerns about the loss of ecosystem benefits that occur in dammed rivers.[56] A concern over the impacts of

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[43] Solar Energy Industries Association, "PV Recycling," Washington DC: Solar Energy Industries Association, accessed April 21, 2016, http://www.seia.org/policy/environment/pv-recycling.
[44] Union of Concerned Scientists, "Environmental Impacts of Solar Power."
[45] Solar Energy Industries Association, "PV Recycling."
[46] Union of Concerned Scientists, "Environmental Impacts of Solar Power."
[47] Solar Energy Industries Association, "PV Recycling."
[48] Ishan Nath, "Cleaning Up After Clean Energy: Hazardous Waste in the Solar Industry," Standford, CA: Stanford Journal of International Relations, 2010, accessed April 21, 2016, https://web.stanford.edu/group/sjir/pdf/Solar_11.2.pdf.
[49] Ishan Nath, "Cleaning Up After Clean Energy."
[50] Working Group III, "Climate Change 2014 Mitigation of Climate Change."
[51] Union of Concerned Scientists, "Environmental Impacts of Solar Power."
[52] Working Group III, "Climate Change 2014 Mitigation of Climate Change."
[53] National Renewable Energy Laboratory, "Renewable Electricity Futures Study," Golden, CO: U.S. Department of Energy, 2012, accessed April 19, 2016, http://www.nrel.gov/docs/fy12osti/52409-2.pdf.
[54] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[55] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[56] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."

damming rivers on migratory fish species has also been a growing issue in recent years.[57] Some of the benefits and drawbacks of hydroelectric generation can be seen in Table 3 below. Additionally, because hydropower has been a part of electric generation is the U.S. for some time, many of the best locations for new systems have already been taken.[58] This has led the development of hydropower to focus more closely on improving existing sites by raising efficiency and installing new components to reduce the impacts that plants have on their host rivers.[59]

Table 3 Outlines the potential environmental benefits and drawbacks associated with hydroelectric generation.

Potential Environmental Benefits and Adverse Effects of Hydropower Production

Benefits	Adverse Effects
• No emission of sulfur and nitrogen oxides • Few solid wastes • Minimal effects from resource extraction, preparation, and transportation • Flood control • Water supply for drinking, irrigation, and industry • Reservoir-based recreation • Reservoir-based fisheries • Enhanced tailwater fisheries • Improved navigation on inland waterways below the dam	• Inundation of wetlands and terrestrial vegetation • Emissions of greenhouse gases (CH_4, CO_2) from flooded vegetation at some sites • Conversion of a free-flowing river to a reservoir • Replacement of riverine aquatic communities with reservoir communities • Displacement of people and terrestrial wildlife • Alteration of river flow patterns below dams • Loss of river-based recreation and fisheries • Desiccation of streamside vegetation below dams • Retention of sediments and nutrients in reservoirs • Development of aquatic weeds and eutrophication • Alteration of water quality and temperature • Interference with upstream and downstream passage of aquatic organisms

Data from: National Renewable Energy Laboratory, "Renewable Electricity Futures Study," Golden, CO: U.S. Department of Energy, 2012, accessed April 19, 2016, http://www.nrel.gov/docs/fy12osti/52409-2.pdf.

Types of Hydroelectric

Hydroelectric generating systems are categorized as large and small-scale plants.[60] Large-scale plants, also known as large conventional hydropower, have a generating capacity greater than 30 MW.[61] These systems are much less common in the U.S. than small-scale

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57 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
58 National Academy Press, "Electricity from Renewable Resources."
59 National Academy Press, "Electricity from Renewable Resources."
60 Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power," Cambridge, MA: Union of Concerned Scientists, 2012, accessed April 19, 2016, http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-hydroelectric-power.html.
61 Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."

systems.[62] Small-scale hydropower plants have generating capacities of 30 MW or less.[63] These systems can be further classified into categories. Low-head hydropower means that water falls less than 65 feet before hitting the turbine to generate electricity. Micro-hydropower systems are those that generate capacities of less than 100 kW. Future development of hydroelectricity in the U.S. will be considerably more focused on smaller systems and will increase the number of run-of-river hydroelectric plants.[64] Run-of-river plants are smaller scale hydropower systems that only utilize reservoirs some of the time.[65] They also are known for utilizing a river's natural current to push water through the turbines, allowing for the current below the dam to be similar, if not the same as, the current upstream.[66] Not only do these plants require less land to develop, they also maintain the natural current of the river limiting the impacts on riparian (riverside) habitat.[67]

Land Use

The land use requirements for hydroelectric plants are highly subjective on plant capacity, configuration, and the installation site.[68] The main land impact of hydroelectricity is the inundation of land behind a dam to create a reservoir.[69] When these reservoirs are formed it can dramatically change animals' habitats and the geography of the land.[70] The size of a reservoir can also have a dramatic effect on the carbon emissions created by the biomass that is inundated as it decomposes.[71] Typically hydropower plants located in hilly areas or canyons result in less flooding than those in flat areas.[72] The creation of the Balbina reservoir in Brazil caused flooding of 2,360 km^2; this is considered on of the largest area inundated for hydroelectric generation.[73] The Saskatchewan Energy Conservation and Development Authority estimated that a 10 MW run-of-river system would only require around 1 hectare (approximately 2.5 acres).[74] Studies have found that the potential lifetime carbon emissions from reservoirs located on tropical regions, where the amount of biomass that must be inundated is greater, can reach 2100g CO_2eq/kWh.[75] In comparison a coal system can produce approximately 910g CO_2eq/kWh.[76] Emissions are considerably

62 National Academy Press, "Electricity from Renewable Resources."
63 Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
64 Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
65 Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
66 National Academy Press, "Electricity from Renewable Resources."
67 National Academy Press, "Electricity from Renewable Resources."
68 National Academy Press, "Electricity from Renewable Resources."
69 Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
70 Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
71 Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
72 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
73 Philip Fearnside, "Brazil's Balbina Dam: Environment versus the legacy of the Pharaohs in Amazonia," New York, NY: Environmental Management, 1989, accessed April 20, 2016, http://philip.inpa.gov.br/publ_livres/preprints/1989/balbina-eng2.pdf.
74 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
75 Working Group III, "Climate Change 2014: Mitigation of Climate Change."
76 Working Group III, "Climate Change 2014: Mitigation of Climate Change."

lower for reservoirs in boreal regions, ranging from 15-33g CO_2eq/kWh, according to research done by Hydro-Québec and the University of Québec.[77]

Wildlife and Habitat

Hydroelectric generation can have several impacts on local wildlife and their habitats. One of the most basic issues that these plants can pose to aquatic organisms is the effect on the waterway's current.[78] Not only can hydropower plants affect habitat downstream by changing the flow of water, it can also dramatically change natural habitat behind the dam, especially if a reservoir is being utilized.[79] The creation of a reservoir for hydroelectric generation can lead to water becoming more stagnant as it is held behind a dam. This reservoir water is often rich in sediments and nutrients that were washed downstream.[80] A process known as eutrophication allows for accelerated growth of algae and other aquatic weeds in the reservoir, changing the water's quality and, potentially crowding out native river species.[81] If plant growth is too excessive as a result of eutrophication, plants can be removed manually by dredging the reservoir or introducing new species to eat them. The water held in reservoirs evaporates at a much quicker rate than in regularly flowing rivers.[82] It can also vary in temperature and dissolved oxygen content from top to bottom as it has little current. This can pose issues for wildlife downstream by subjecting them to abnormal conditions.[83] Another major issue associated with the damming of rivers is concern for migratory fish species.[84] Migratory fish can be classified as either *anadromous*, (migrating upstream from the sea to spawn, such as salmon) or *catadromous* (migrating downstream to the sea to spawn, such as eels).[85] As these species attempt to migrate either upstream or downstream during spawning season, hydroelectric dams can be a major issue for their travel. For fish moving downstream, being caught or injured by the turbine is a serious threat and can cause "physical stress including disorientation, physiological stress, injury and mortality."[86] To combat this, many hydroelectric plants have built in fish ladders, or passages, to allow fish to safely bypass the turbine and hydroelectric system.[87,88] One solutions designed to help migratory fish move past dams is trap and haul operations. This is a process where fish are caught and transported downstream to be

[77] Alain Tremblay, Louis Varfalvy, Charlotte Roehm and Michelle Garneau, "The Issue of Greenhouse Gases from Hydroelectric Reservoirs: From Boreal to Tropical Regions," Montréal, Canada: United Nations, 2004, accessed April 21, 2016, http://www.un.org/esa/sustdev/sdissues/energy/op/hydro_tremblaypaper.pdf.
[78] Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
[79] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[80] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[81] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[82] Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
[83] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[84] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[85] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[86] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[87] Grant Public Utility District, "Fish Survival," Ephrata, WA: Public Utility District No. 2 of Grant County, 2016, accessed April 19, 2016, http://grantpud.org/environment/fish-wildlife/fish-survival.
[88] Idaho National Laboratory, "Advanced Turbine Systems," Idaho Falls, ID: Idaho National Laboratory, 2007, accessed April 19, 2016, http://hydropower.inel.gov/turbines/index.shtml.

released. Improved turbine design can also increase dissolved oxygen content and allow fish to pass through with a reduced chance of being harmed.[89]

Table 4: Environmental Barriers to Hydropower

Environmental and Siting	Barrier	Representative Responses
Dam and Reservoir	Inundation of wetlands and terrestrial vegetation	Reduce the size of the storage reservoir; create alternate wetlands
	Emissions of GHGs from flooded vegetation at some sites	Reduce the size of the storage reservoir; clear vegetation from flooded area
	Conversion of a free-flowing river to a reservoir	No mitigation available
	Replacement of riverine aquatic communities with reservoir communities	No mitigation available
	Displacement of people and terrestrial wildlife	Relocation
	Retention of sediments and nutrients in the reservoir	Periodically flush or dredge the reservoir
	Interference with upstream and downstream passage of aquatic organisms	Install fish ladders or elevators for upstream passage
		Improve downstream passage survival with screens, bypasses, or fish-friendly turbines
River	Alteration of river flow patterns below the dam	Release environmental flows in a natural seasonal pattern, and avoid rapidly varying flow releases
	Loss of river-based recreation and fisheries in impounded area	No mitigation available; enhance reservoir fisheries and recreation
	Desiccation of streamside vegetation below the dam	Release environmental flows in a natural seasonal pattern
	Development of aquatic weeds and eutrophication	Employ herbivorous fish, herbicides, mechanical removal, light-blocking dyes, and other vegetation-control measures
		Reduce sediment and nutrient input to the reservoir
	Alteration of water quality and temperature	Reduce the size and depth of the storage reservoir
		Control the depth from which water is released by multiple outlets
		Employ aerating turbines

Data from: National Renewable Energy Laboratory, "Renewable Electricity Futures Study," Golden, CO: U.S. Department of Energy, 2012, accessed April 19, 2016, http://www.nrel.gov/docs/fy12osti/52409-2.pdf.

[89] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."

Effects on the Community

Often times reservoirs are designed to be able to store excess water, which can be released when demand for electricity is highest. These systems can also raise the water level behind the dam to increase the current of the water as it hits the turbines to create more electricity.[90] Reservoirs can be used for purposes other than electric generation such as flood protection, irrigation water supply, recreation. and navigation.[91] Additionally, the eutrophication of reservoirs can limit the effectiveness for these purposes if the water quality becomes poor enough.[92] Reservoirs that are used for multiple purposes can diminish overall generating capacity of the system because some water must be allocated for other purposes.[93] Table 4 outlines potential barriers to the construction and production of hydroelectricity.

Biomass Energy

Biomass energy or "bioenergy" refers to energy derived from plant and animal based materials.[94] Biomass can come from several different sources including: wood, grass, oilseeds, small grains, animal waste, and oil-rich algae, as well as municipal and industrial wastes with organic matter.[95,96] Bioenergy is the third largest form of renewable generation after hydroelectric and wind generation.[97] Biomass energy can also be stored as liquid fuel (biofuel) in addition to generating electricity. This allows biomass to be a more versatile energy option compared to other renewables.[98] Plant-derived biomass is often classified under five categories, "urban wood wastes, mill residues, forest residues, agricultural residues, and dedicated herbaceous and woody energy crops."[99] Table 5 describes what each of these categories entails. The National Renewable Energy Laboratory has found that, "generally, urban wood wastes are the least expensive biomass resource, followed by mill residues, forest residues, agricultural residues, and energy crops."[100]

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[90] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[91] National Academy Press, "Electricity from Renewable Resources."
[92] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[93] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[94] National Renewable Energy Laboratory, "Biomass Energy Basics," Golden, CO: National Renewable Energy Laboratory, accessed April 21, 2016, http://www.nrel.gov/learning/re_biomass.html.
[95] National Renewable Energy Laboratory, "Biomass Energy Basics."
[96] National Renewable Energy Laboratory, "Biomass Energy Basics."
[97] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[98] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[99] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
[100] National Renewable Energy Laboratory, "Renewable Electricity Futures Study."

Table 5: Plant Derived Biomass

Characteristics and Regional Distribution of Biomass Resources in United States

Biomass Resource	Characteristics	Comments
Urban waste	Woody materials, such as yard and tree trimmings, site-clearing wastes, pallets, packaging materials, clean construction, and demolition debris	Concentrated at single source; diverted from landfills; and, possibly, composting facilities
Primary mill residues	Bark stripped from logs, coarse residues (chunks and slabs) and fine residues (shavings and sawdust) from processing of lumber, pulp, veneers, and composite wood fiber materials	Concentrated at single source; clean; ~20% moisture; most material used as fuel or inputs in manufacture of products
Forest wood residues	Logging residues (small branches, limbs, tops, and leaves); rough, rotten, and salvable dead wood	Much of the rough, rotten, and salvable dead material is inaccessible due to the absence of roads or access, is not economically retrievable with current technology, or is located in environmentally sensitive areas
Agricultural residues	Primarily corn stover[a] and wheat straw; other grain crops are limited in acreage or the amount of residue is small	Approximately 30%–40% (actual amount is site-specific and the subject of studies) of corn stover and wheat straw residues may be removed to maintain soil quality (i.e., nutrients and organic matter) and limit erosion; limited collection season—usually a couple of months following grain harvest; year-round use may require storage of up to 10 months
Dedicated energy crops	Short rotation woody crops such as hybrid poplar and hybrid willow, and herbaceous crops[b] such as switchgrass	Management practices for each crop are regionally dependent; ability to use existing on-farm equipment is a potential advantage of switchgrass[c] over tree crops

[a] Stover is the dried stalks and leaves of a crop remaining after the grain have been harvested. Corn stover is the refuse of a corn crop after the grain is harvested.
[b] Herbaceous energy crops are perennial non-woody crops that are harvested annually, though they may take 2–3 years to reach full productivity.
[c] Switchgrass is a tall North American panic grass (*Panicum virgatum*) that is used for hay and forage.

Data from: National Renewable Energy Laboratory, "Renewable Electricity Futures Study," Golden, CO: U.S. Department of Energy, 2012, accessed April 19, 2016, http://www.nrel.gov/docs/fy12osti/52409-2.pdf.

Land Use

While some sources of bioenergy are byproducts of other industries, such as mill residues or wood waste, others such as corn and oilseeds require large amounts of land dedicated to them.[101] This can become an issue when energy and food crops need the same piece of land. Another issue is what is so-called the "food-vs.-fuel" debate.[102] Many traditional food crops are also used for biomass energy including: corn, sugar cane and vegetable oils. Agricultural crops may be shifted from producing food crops to producing crops dedicated to energy needs. Similar to food crop production, run off from synthetic fertilizers and pesticides can enter the environment if overused. This can negatively impact soil quality, water resources, biodiversity and ecosystems in surrounding areas.[103]

101 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
102 Environmental and Energy Study Institute, "Bioenergy (Biofuels and Biomass)," Washington, DC: Environmental and Energy Study Institute, accessed April 21, 2016, http://www.eesi.org/topics/bioenergy-biofuels-biomass/description.
103 Environmental and Energy Study Institute, "Bioenergy (Biofuels and Biomass)."

Greenhouse Gas Emissions

Land uses including the shift in agricultural areas to produce biomass crops have both direct and indirect impacts on greenhouse gas emissions. Emissions related to bioenergy include: CO2, carbon monoxide, methane (CH4), volatile organic compounds, and nitrogen oxides.[104,105] Wood combustion, the most common form of biomass energy, ideally recycles carbon that was already in the natural carbon cycle creating a net effect and therefore producing no new carbon.[106] The U.S. Environmental Protection Agency reports, "CO2 from this source [biomass] is generally not counted as greenhouse gas emissions because it is considered part of the short-term CO2 cycle of the biosphere."[107] However, this is only true for wood sources that are harvested using sustainable forestry practices that stimulate the regeneration of what is being harvested.[108] Biomass can also be burned in coal boilers as an additive to coal, which is called co-firing.[109] This option is the least expensive for producing biopower as it does not require any additional machinery to produce.[110] Co-firing with biomass also reduces emissions from coal generation.[111] Burning municipal waste "produces nitrogen oxides and sulfur dioxide as well as trace amounts of toxic pollutants such as mercury compounds and dioxins."[112] The lifetime emissions for bioenergy can be seen in Table 1 above.

Water Usage

Waste-to-energy power plants use water in both boilers and cooling systems.[113] This water is then discarded and can contain pollutants, which may harm aquatic life and reduce water quality depending on the location of the power plant.[114] The majority of water use in bioenergy generation comes from cooling systems, but energy crops also require large amounts of water to grow.[115] Biomass feedstock is most often grown in areas where irrigation is not required to keep costs down. Additionally, most feedstock requires low inputs of fertilizers, minimizing the chance of runoff issues. Good agricultural practices such as, "irrigation practices, soil erosion prevention, nutrient pollution reduction, and precision agriculture" are also encouraged.[116]

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104 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
105 Environmental and Energy Study Institute, "Bioenergy (Biofuels and Biomass)."
106 Biomass Energy Resource Center, "Carbon Dioxide and Biomass Energy," Montpelier, VT: Biomass Energy Resource Center, 2008, accessed April 2016, https://www.biomassthermal.org/resource/PDFs/FSE_Biomass%20C02.pdf.
107 Biomass Energy Resource Center, "Carbon Dioxide and Biomass Energy."
108 Biomass Energy Resource Center, "Carbon Dioxide and Biomass Energy."
109 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
110 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
111 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
112 Texas Comptroller of Public Accounts, "Chapter 18, Municipal Waste Combustion," Austin, TX: 2008, accessed April 21, 2016, http://comptroller.texas.gov/specialrpt/energy/pdf/18-MunicipalWasteCombustion.pdf.
113 Texas Comptroller of Public Accounts, "Chapter 18, Municipal Waste Combustion."
114 Texas Comptroller of Public Accounts, "Chapter 18, Municipal Waste Combustion."
115 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
116 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."

Geothermal

Geothermal energy exists in the form of underground reservoirs of steam, hot water, and hot dry rocks in the Earth's crust.[117] Hydrothermal energy plants are typically located near "hot spots where hot molten rock is close to the earth's crust and produces hot water."[118] Other areas where geothermal energy can be produced require drilling into earth's surface to reach deeper geothermal resources.[119] The U.S. Energy Information Administration (EIA) states that "geothermal power plants require high-temperature (300°F to 700°F) hydrothermal resources that come from either dry steam wells or from hot water wells."[120] Once these resources are accessed, wells can be drilled into the earth and can use the hot water or steam to operate a turbine that generates electricity.[121]

Types of Geothermal Energy

The environmental impacts of geothermal energy can vary depending on how it is transformed into electricity. There are three different types of technology used to convert geothermal energy into electricity: dry steam power, flash steam power, and binary steam power plants.[122] Dry steam power is produced where natural steam erupts from the earth and can be directed to turn generator turbines. Flash steam power plants use hot water from Earth's crust and convert that to steam. Then, once the steam is cooled and condensed to water again, it is recycled into the ground and used once more. Flash steam plants are the most common form of geothermal energy in the U.S. Binary steam power plants use geothermal heat to turn water into steam that is used to turn generator turbines.[123]

Water Usage

Geothermal energy plants often use "between "1,700 and 4,000 gallons of water per MWh" depending on the cooling system.[124] The hot water that is pumped from reservoirs underground often contains large quantities of sulfur and other minerals. Steel casings are used to prevent water contamination at U.S. geothermal facilities.[125]

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[117] National Academy Press, "Electricity from Renewable Sources."

[118] Union of Concerned Scientists, "Environmental Impacts of Geothermal Energy," Cambridge, MA: Union of Concerned Scientists, 2016, accessed April 22, 2016, http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-geothermal-energy.html#.Vxvz68dxvww.

[119] Union of Concerned Scientists, "Environmental Impacts of Geothermal Energy."

[120] U.S. Energy Information Administration, "Geothermal Power Plants," Washington, DC: U.S. Energy Information Administration, 2015, accessed April 22, 2016, http://www.eia.gov/energyexplained/index.cfm?page=geothermal_power_plants.

[121] U.S. Energy Information Administration, "Geothermal Power Plants."

[122] U.S. Energy Information Administration, "Geothermal Power Plants."

[123] U.S. Energy Information Administration, "Geothermal Power Plants."

[124] Union of Concerned Scientists, "Environmental Impacts of Geothermal Energy."

[125] Union of Concerned Scientists, "Environmental Impacts of Geothermal Energy."

Air Emissions

When heat is extracted from geothermal energy plants gases such as hydrogen sulfide, CO2, ammonia, CH4, and boron can be emitted into the atmosphere. Sulfur dioxide (SO2) in the atmosphere forms "small acidic particulates that can be absorbed by the bloodstream and cause heart and lung disease."[126] It is also responsible for acid rain that can damage crops, forests, lakes and infrastructure.[127] However, "SO2 emissions from geothermal plants are approximately 30 times lower per MWh than from coal plants, which is the nation's largest SO2 source."[128] See Table 1 above for life-cycle emissions of geothermal generation.

Land Use

Many geothermal sites are located in sensitive geological "hot spot" areas that are often high earthquake centers. When water is pumped at high pressures underground in geothermal systems, there is a possibility of disturbing faults in earth's crust, which can lead to small earthquakes.[129] Additionally, geothermal plants use a large amount of land. For example, the Geysers in California is the largest geothermal plant in the world. It has a capacity of ~1,517 MW and takes up 13 acres per MW.[130]

Greenhouse Gas Emissions

Most hazardous chemicals in geothermal fluids are in aqueous phase and can be potentially harmful to ecosystems if released at the surface. With current technology, however, harmful chemicals are more easily protected against contamination by using cemented casings and impermeable linings that provide protection from temporary fluid disposal ponds.[131] If excess surface disposal is leaked, there can be adverse effects on the ecology of rivers, lakes or marine environments. [132]

Conclusion

Renewable energy is a considerably more environmentally friendly alternative than fossil fuel generation. Like all energy production options, however, renewable energy carries the risk of harming the natural environment. These impacts are wide ranging, extending from land and water use to public health and animal habitat concerns. In order to accurately judge the environmental impacts of any specific renewable energy project, it is important

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[126] National Research Council, "Hidden costs of energy: Unpriced consequences of energy production and use," Washington, DC: National Research Council, 2010, accessed April 22, 2016, http://www.nap.edu/catalog.php?record_id=12794.
[127] National Research Council, "Hidden costs of energy: Unpriced consequences of energy production and use,"
[128] Union of Concerned Scientists, "Environmental Impacts of Geothermal Energy."
[129] Union of Concerned Scientists, "Environmental Impacts of Geothermal Energy."
[130] California Energy Commission, "The Geysers," San Francisco, CA: California Energy Commission, 2016, accessed April 24, 2016, http://www.energy.ca.gov/geothermal/background.html.
[131] Working Group III, "Climate Change 2014 Mitigation of Climate Change."
[132] Working Group III, "Climate Change 2014 Mitigation of Climate Change."

to consider siting.[133] Poorly sited renewable generation systems can rank even higher than fossil fuel generation in terms of GHG emissions and other environmental impacts, if the surrounding environment is not properly considered.[134,135]

This report was completed on May 2, 2016 by Frances Workman, Jackson Berman and Chris Thomas under the supervision of Professors Jack Gierzynski, Robert Bartlett and Eileen Burgin in response to a request from Senator Rogers and Senator Bray.

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133 National Renewable Energy Laboratory, "Renewable Electricity Futures Study."
134 Philip Fearnside, "Brazil's Balbina Dam."
135 Working Group III, "Climate Change 2014: Mitigation of Climate Change."