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COMMENTARY

The Geopolitics of "Cleaner" Energy Series

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Environmental Concerns: How Clean Is Clean?[1]

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Concern regarding the environmental impacts associated with conventional energy has been increasing, prompting governments and the private sector to promote clean energy technologies as a way to mitigate these concerns. Indeed, environmental benefits have become a major justification for switching to cleaner energy sources; however, similar to conventional energy sources, clean energy technologies also have environmental and social externalities (along with previously mentioned economic, technology, and scalability issues[2]) that must factor into decisions regarding their use. Yet, relative to the incumbent fuel mix, the shift toward cleaner technologies will have a lower impact on the environment than a business-as-usual scenario.

Each technology has potential positive and negative externalities that could stem from its widespread use, and cleaner technology is no different. As with all technologies, there are trade-offs, and the use of a cleaner energy technology to improve one problem may inadvertently cause another. Therefore, understanding both the positive and negative impacts over the full lifetime of the technology is important in order to adequately compare and contrast cleaner technologies with conventional technologies and ultimately choose what to transition to and what to implement where.

While cleaner energy sources in general produce fewer emissions and reduce air pollutants, their impacts on water and land resources are highly variable. There are a variety of analyses used to measure the "footprint" of energy technologies. While many claim to measure the life cycle of energy technologies, the use of the term life cycle can be misleading due to the range of boundary conditions for various studies. So-called life-cycle studies have erroneously reported only the impact of energy generation, while others have reported only the upstream impact of energy and forgo the downstream impacts, while others evaluate the entire fuel cycle but draw narrow boundaries and thus do not account for critical inputs and outputs that are byproducts of the fuel cycle.[3] This wide range in approaches has led to a need for unbiased comparative studies, such as those by Heath et al.[4] Rigorous life-cycle analysis (LCA) evaluates the entire system, measuring upstream, direct (generation), and downstream impacts, as well as inputs and

[1] This commentary is part of a series that will evaluate major trends shaping the shift toward or away from cleaner energy sources, as well as some of the emerging geopolitical dynamics arising as part of the push for cleaner energy. More information about this series can be found on the CSIS Energy and National Security Program website, http://csis.org/node/37613.
[2] See Molly A. Walton and Leigh E. Hendrix, "The Promise of Renewables: Recent Success and the Challenge of Getting to Scale," CSIS, June 2012, http://csis.org/files/publication/120605_Walton_Renewables.pdf, and Leigh E. Hendrix, "Competition for Strategic Materials," CSIS, July 2012, http://csis.org/files/publication/120713_Hendrix_CompetitionStrategicMaterials_Commentary.pdf.
[3] Ethan Warner, Garvin Heath, Patrick O'Donoughue, *Harmonization of Energy Generation Life Cycle Assessments (LCA): FY2010 LCA Milestone Report* (Golden, CO: National Renewable Energy Laboratory [NREL], November 2010), http://www.nrel.gov/docs/gen/fy11/47492.pdf.
[4] Ibid.

outputs associated with each stage, and provides the best understanding of the impact (both positive and negative) that cleaner energy technologies might have on the environment and society.[5]

This section analyzes the existing literature (both LCA and other impact analyses), analyzes the environmental and social impact of cleaner energy, and provides a clearer understanding of the positive and negative co-impacts associated with a switch to one of the cleaner technologies.

Impacts by Type

The impact on air/climate, water, land, and the benefits accrued to society from a switch to cleaner energy technologies depends on a variety of inputs including but not limited to the geography and geology of a region,[6] the climate, the type of technology utilized, and the operational procedures implemented during generation.[7] Moreover, achieving the most environmentally friendly option can produce trade-offs. For example, technologies that reduce water consumption (e.g., dry cooling) are more expensive and result in lower efficiency rates and decreased reliability.[8]

Air/Climate

Overall, clean energy technologies offer a reduction in air pollution compared with their conventional counterparts. However, LCAs that include emissions from upstream manufacturing and fuel production show a wide variation in the magnitude and type of reductions created by the different types of technologies within a clean energy type. According to the Intergovernmental Panel on Climate Change (IPCC) Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN), the maximum life-cycle greenhouse gas (GHG) emissions estimate for concentrated solar power (CSP), geothermal, hydropower, ocean, and wind energy is less than 100 gCo2e-/kWh with median ranges falling between 4 and 46 gCO2e-/kWh.[9, 10] Including bioenergy, where a majority of emissions comes from feedstock production; hydropower, where emissions stem from decomposition in reservoirs; and nuclear power, where fuel processing, construction, and decommissioning also contribute to emissions, the IPCC reported that compared to conventional energy sources, renewables were 400 to 1,000 g CO2eq/kWh lower than fossil counterparts (without carbon capture and storage [CCS]).[11]

Water

The implementation of cleaner energy technologies could either increase or decrease water use, depending on the type of technology and cooling options used. In general, non-thermals, such as solar and wind, have the lowest water consumption, though they too consume water during manufacturing and construction, which should be accounted for in analysis.[12] Biofuels, because of extensive irrigation, are the most water-intensive alternative, though a shift to

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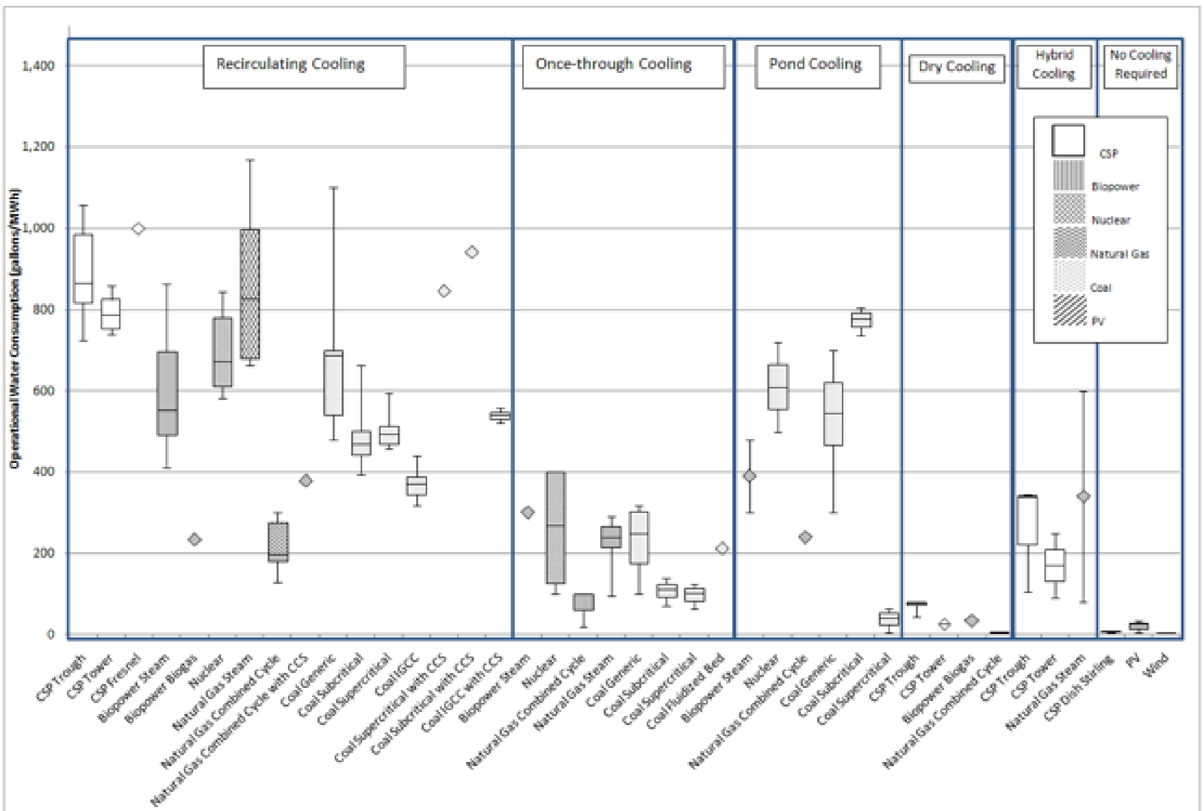
[5] Jayant Sathaye et al., "Renewable Energy in the Context of Sustainable Development," in *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change,* ed. Ottmar Edenhofer et al. (New York: Cambridge University Press, 2012), 730, http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch09.pdf.
[6] The geography and geology of a region is vital because it influences what technology is suitable for each region. Because the type of technology implemented is highly dependent on the availability of inputs, such as land and water, which vary depending on location, some technologies may have a greater negative environmental impact than benefit if implemented in an unsuitable location. For example, often the best locations for CSP coincide with water supply constraints, therefore despite ample sun, CSP may have a greater negative impact than positive impact as it may place undue strain on a finite water supply.
[7] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 730.
[8] Electric Power Research Institute (EPRI), *Use of Degraded Water Sources as Cooling Water in Power Plants* (Palo Alto, CA: EPRI, October 2003), chapters 1, 2, http://www.energy.ca.gov/reports/2004-02-23_500-03-110.PDF.
[9] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 733.
[10] Range for life-cycle GHG estimates are the result of methodological differences and different types of technology.
[11] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 733.
[12] Erik Mielke, Laura Diaz Anadon, and Venkatesh Narayanamurti, "Water Consumption of Energy Resource Extraction, Processing, And Conversion: A review of the literature for estimates of water intensity of energy-resource extraction, processing to fuels, and conversion to electricity," Energy Technology Innovation Policy Discussion Paper No. 2010-15, Belfer Center for Science and International Affairs, Harvard Kennedy School, October 2010, 35, http://belfercenter.ksg.harvard.edu/files/ETIP-DP-2010-15-final-4.pdf.

advanced biofuels could reduce this footprint. Geothermal (depending on what is measured as water)[13] and nuclear (especially inland) withdraws and consumes large amounts of water depending on the type of cooling technology used.[14] CSP, because it utilizes steam turbines, has water consumption levels comparable to that of conventional power plants.[15]

Water is used throughout the life cycle of cleaner energy technologies, from fuel acquisition and treatment, plant construction, operation, decommission, and disposal.[16] While many studies only evaluate the water impact from generation, the water used upstream for energy and material inputs at each of these stages should also be factored in. Unfortunately, reliable data for many of these phases is limited, especially on a global level, and is subject to measurement and geographical differences. Figure 1 summarizes water metrics on comparative LCA bases for power generation technologies.[17] The figure emphasizes the impacts that the type of cooling system and the incremental requirements for CCS have on water consumption, underscoring the increasing importance of water resource availability, costs, and management in power system decisions.

Figure 1: Operational Water Consumption



Source: Jordan Macknick, Robin Newmark, Garvin Heath, and KC Hallett, *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies* (Golden, CO: NREL, March 2011), 7, http://www.nrel.gov/docs/fy11osti/50900.pdf.

[13] See Impacts by Technology section (geothermal), below, for a more detailed explanation.
[14] Vasilis Fthenakis and Hyung Chul Kim, "Life-Cycle Uses of Water in U.S. Electricity Generation," *Renewable and Sustainable Energy Reviews* 14, no. 7 (September 2010): 2039–2048.
[15] Ashlynn S. Stillwell et al., "The Energy-Water Nexus in Texas," *Ecology and Society* 16, no. 1 (2011): 16, http://www.ecologyandsociety.org/vol16/iss1/art2/.
[16] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 741.
[17] Jordan Macknick, Robin Newmark, Garvin Heath, and K.C. Hallett, *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies* (Golden, CO: NREL, March 2011), 7, http://www.nrel.gov/docs/fy11osti/50900.pdf.

Land

The evaluation of land use impacts must extend beyond the land on which a technology is situated for generation and should include land used for mining of materials used in manufacturing each technology, supply, and infrastructure, as well as land required for the disposal of waste or decommissioning of a technology. Land use impacts vary widely between and within technologies studied. For most clean energy technologies (except nuclear and bioenergy), the generation stage is responsible for a majority of the technologies' land use requirements.[18, 19] Depending on regional and technological considerations, solar photovoltaic (PV) requires the least amount of land among renewables.[20] Wind's land use requirements are reported as direct and indirect.[21] Direct land use (pads for towers and roads) may be quite small in comparison to indirect use, including the land between turbines, which offers opportunities for dual use.[22] Geothermal has a limited above-ground footprint, but due to risks of land subsidence, the entire field is normally included in analysis.[23] Hydro's footprint is dependent on the type of hydropower utilized and the topography of the site, and thus can either have a large footprint (if land needs to be flooded for a reservoir) or a minimal footprint (run of the river).[24] Bioenergy requires the most land because of the need to cultivate feedstock.[25] The nuclear fuel cycle also has large land intensity due to mining, generation, and waste disposal.[26]

Social Impact Studies

Social impacts that extend across the clean energy technologies discussed in this report include health benefits from fewer emissions and reduced air pollutants,[27] increased energy diversity and a buffer from price volatility, energy supply where one might not have existed (e.g., utilizing energy for development), and employment and investment opportunities.[28] Moreover, each technology affords its own unique co-benefits. However, just as there are positives, so too are there negatives associated with a potential shift toward cleaner sources. Many of these negatives are technology specific, including the displacement of people and communities from hydropower projects,[29] the impact on birds and bats from wind turbines,[30] and the foul-smelling odors from geothermal. Each of these, along with the "not-in-my-back-yard" (NIMBY) problems that also confront conventional sources must be addressed before a rapid scale up of use of cleaner sources of energy.[31]

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[18] PV and wind's land use is often described as static because once the infrastructure is built in an area, there is no further land footprint outside of decommissioning, as there is no need for further extraction of resources for that particular site, compared to conventional energy where fuel must constantly be replenished.

[19] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 744.

[20] Vasilis Fthenakis and Hyung Chul Kim, "Land Use and Electricity Generation: A Life-Cycle Analysis," *Renewable and Sustainable Energy Reviews* 13, no. 6–7 (August-September 2009): 1465–1474. The authors in this study considered two metrics: land transformation (land altered) and land occupation (area occupied and duration) when looking at the life-cycle impact of energy technologies on land. While the size of the array area may occupy a lot of land (unless they are placed on preexisting infrastructure or on marginal lands), the study's conclusions regarding solar were that when the entire life cycle was taken into account (materials acquisition, module production, operation and maintenance, and material disposal) solar PV transforms the least amount of land per GWh of electricity generated.

[21] Paul Denholm, Maureen Hand, Maddalena Jackson, and Sean Ong, *Land-Use Requirements of Modern Wind Power Plants in the United States* (Golden, CO: NREL, August 2009), http://www.nrel.gov/docs/fy09osti/45834.pdf.

[22] Fthenakis and Kim, "Land Use and Electricity Generation," 1469.

[23] Annette Evans, Vladimir Strezov, and Tim J. Evans, "Assessment of Sustainability Indicators for Renewable Energy Technologies," *Renewable and Sustainable Energy Reviews* 13, no. 5 (June 2009): 1082–1088.

[24] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 744.

[25] Fthenakis and Kim, "Land Use and Electricity Generation," 1469–1470.

[26] Ibid., 1465.

[27] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 739–740.

[28] A.K. Akella et al., "Social economical and environmental impacts of renewable energy systems," *Renewable Energy* 34, no. 2 (February 2009): 391, http://greenenv.blog.com/files/2009/06/akella_2009_renewable-energy.pdf.

[29] World Commission on Dams (WCD), *Dams and Development: A New Framework for Decision-Making* (London: Earthscan Publications, November 2000), 102, http://www.unep.org/dams/WCD/report/WCD_DAMS%20report.pdf.

[30] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 745.

[31] Ibid., 757.

Impacts by Technology

An assessment of clean energy technologies finds that there are variations both between and within energy technologies in regards to their impacts on water, land, air/climate, and the benefits accrued to society. Thus, it is useful to compare among technologies to assess their relative potential positive and negative environmental and social externalities.

Wind

Many studies identify wind as having the lowest air pollution, water consumption demands, and most favorable social impacts of all the clean energy technologies.[32] Wind's water consumption and emissions during operation are negligible; however, its upstream impacts, while minimal compared to other technologies, must be accounted for. Wind has a large indirect land footprint over its entire life cycle[33] compared to other clean technologies, and the magnitude of impacts varies between onshore and offshore.

Impact	Key Findings
Air/Climate[34]	• Most emissions come from energy used in infrastructure phase of turbines and towers (material production, processing, transport, assembling, installation, and waste disposal) and grid-mix used to produce energy in this phase • Negligible emissions from generation; however, because it is intermittent, the source of energy that provides backup/peak reserves might alter wind's total emissions • Size of turbine (small turbines produce more emissions than large turbines due to economies of scale), and location (off-shore turbines have higher emissions because of infrastructure requirements) account for variations in emissions
Water[35]	• Indirect, upstream water impact from production of turbines—water withdrawn for steel, iron, glass fiber • Minimal water impact during generation • Wind's minimal water footprint makes it ideal for water scarce regions with ample wind resources
Land[36]	• Large indirect footprint over course of lifetime in part due to ample space needed between turbine blades; however, it's direct footprint (surface area disturbed by infrastructure) is minimal • Offers opportunity for dual siting with agriculture and grazing land; can be sited on degraded land • Offshore footprint includes transmission lines to shore; face competition for sea space (shipping, bird migration pathways, fishing, recreation)
Social[37]	• Positive: health impact from decreased emissions • Negative: noise pollution, aesthetic degradation
Other[38]	• Installation of turbines can impact ecosystem from clearing of vegetation, potential erosion • Turbines may interfere with flight path of birds and bats; offshore may also negatively impact ocean ecosystem surrounding it

Solar (PV & CSP)

The environmental impacts of solar vary depending on the type of technology utilized. Emissions from generation for both PV and CSP are negligible, though each produces indirect emissions from activities that occur in their upstream

[32] Manfred Lenzen, "Current State of Development of Electricity-Generating Technologies: A Literature Review," *Energies* 3, no. 3 (March 2010): 470, http://www.mdpi.com/1996-1073/3/3/462/pdf.
[33] Denholm et al., *Land Use Requirements of Modern Wind Power Plants in the United States*.
[34] Hanne Lerche Raadal et al., "Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power," *Renewable and Sustainable Energy Reviews* 15, no. 7 (September 2011): 3419; Daniel Weisser, "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies," *Energy* 32, no. 9 (September 2007): 1552; Lenzen, "Current State of Development of Electricity-Generating Technologies," 536.
[35] Fthenakis and Kim, "Life-Cycle Uses of Water in U.S. Electricity Generation," 2042.
[36] Fthenakis and Kim, "Land Use and Electricity Generation,"1469; Denholm et al., *Land Use Requirements of Modern Wind Power Plants in the United States*.
[37] International Energy Agency (IEA), *Energy Technology Perspectives 2010: Scenarios & Strategies for 2050* (Paris: IEA, 2010), 632, http://www.iea.org/Textbase/nppdf/free/2010/etp2010_part2.pdf.
[38] Brain Snyder and Mark J. Kaiser, "Ecological and economic cost-benefit analysis of offshore wind energy," *Renewable Energy* 34, no. 6 (2009): 1567–1578, http://course.bnu.edu.cn/course/hjdx/JXZY/dixuewenxian/2.pdf.

fuel cycles.[39] The water footprint of PV is minimal; however, depending on the type of cooling system utilized, CSP can have a water footprint along the same order as conventional power plants. Both types of solar have small land requirements compared to conventional fuels, and solar PV, if incorporated in buildings has the smallest footprint among all renewables.

Impact	Key Findings
Air/Climate-PV[40]	• Most emissions stem from upstream electricity and fuel used during manufacturing (and the grid-mix used to produce electricity) and quantity and grade of silicon used and installation (slanted, flat rooftop, façade) • Negligible emissions from generation; however, because it is intermittent, the source of energy that provides backup might alter PV's total emissions
Air/Climate-CSP[41]	• Upstream emissions from manufacturing and production, similar to PV • Negligible emissions from generation; however, because it is intermittent, the source of energy that provides backup might alter CSP's total emissions
Water-PV[42]	• Indirect upstream water impact from mining of materials, electricity used to purify silicon and other semiconductor materials, production of silicon and single crystals, manufacturing, and construction • Minimal water used in generation, some for cleaning and cooling wafers/mirrors • Thin PV requires less water (less materials)
Water-CSP[43]	• Indirect upstream water impact similar to PV, water inputs for manufacturing and construction • Most water consumed for cooling, about 10% is used for mirror washing • Type of cooling technology used impacts water consumption: dry-cooling technology reduces water consumption by 90% but is more expensive upfront and decreases efficiency by 1% to 5% • Often the best locations for CSP coincide with water-supply constraints
Land-PV[44]	• Fuel cycle transforms least amount of land per GWh of electricity of renewable, but mining and processing of materials does transform land and create toxic waste • Integrating PV within/onto buildings or structures decreases its footprint, leaving only the land impacted by materials and energy usage for producing PV modules
Land-CSP[45]	• Linear Fresnel have smallest land requirement • Best sites for CSP often isolated and unsuitable for agriculture
Social[46]	• Positive: good option for development; easily installed to power rural communities and individual homes; positive public health impact from decreased emissions • Negative: depending on type of solar technology used, possible conflict with other sectors over water, especially if sited in dry area
Other	• Disturbance from construction and installation; removal of vegetation (fire hazard if left unclear)

[39] There have been isolated instances of pollution from the production of PV equipment, most notably in China's Jinko Solar Plant; however, in general, emissions are negligent. See "China villagers protest solar plan pollution—Xinhua," Reuters, September 18, 2011, http://af.reuters.com/article/commoditiesNews/idAFL3E7KI01B20110918.
[40] IEA, *Energy Technology Perspectives 2010*, 631.
[41] L. Stoddard et al., *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California* (Golden, CO: NREL, April 2006); IEA, *Energy Technology Perspectives 2010*, 630.
[42] Mielke et al, "Water Consumption of Energy Resource Extraction, Processing, and Conversion," 37; U.S. Department of Energy (DOE), *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water* (Washington, DC: DOE, December 2006), http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf; Fthenakis and Kim, "Life-Cycle Uses of Water in U.S. Electricity Generation," 2042.
[43] Nicole T. Carter and Richard J. Campbell, "Water Issues of Concentrative Solar Power (CSP) Electricity in the U.S. Southwest," Congressional Research Service, June 8, 2009, http://www.circleofblue.org/waternews/wp-content/uploads/2010/08/Solar-Water-Use-Issues-in-Southwest.pdf; U.S. Department of Energy (DOE), *Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation: Report to Congress* (Washington DC: DOE, 2010); Mielke et al, "Water Consumption of Energy Resource Extraction, Processing, and Conversion," 36.
[44] IEA, *Energy Technology Perspectives 2010*, 632.
[45] Ibid., 631.
[46] Ibid., 631.

Hydropower/Ocean Power

Hydropower's emissions and land requirements depend on the type of technology, size of the reservoir, and the topography. Hydropower's water use is characterized as in-stream water use; however, some water is consumed by evaporation from the reservoir though the amount varies depending on topography and climate. Hydropower has both positive and negative externalities that accrue to society. The nascent development and utilization of ocean and tidal power[47] means that there exists limited data regarding its environmental and social impacts.[48] Thus far, only speculative conclusions can be drawn regarding the extent of tidal/wave's impact on air/climate, land, and water resources. As the technology develops, more work needs to be done to fully understand the potential implications of development. Therefore the table below will focus primarily on hydropower.

Impact	Key Findings
Air/Climate[49]	• Emissions depend on size of reservoir (flooding land with vegetation creates decay) and age of plants (newer plants emit more because vegetation decay is in early stages); most emissions are methane from anaerobic decomposition of biomass at depth • Cooler climates, lower biomass intensities, and dams with high power densities have lower emissions/kWh • Upstream emissions for all types from manufacturing and construction phase
Water[50]	• Indirect upstream water impact from construction and infrastructure materials • Characterized by high withdrawals but low consumption; USGS characterizes as in-stream water use • Some water is lost from reservoirs from evaporation, but rates vary by reservoir location and volume • Can alter water quality downstream by changing sediment flows, hydrology of river, temperature, and dissolved oxygen content
Land[51]	• Large projects with reservoirs require more land, which land may be cleared and then flooded • Water reservoirs in flat contours need more land, while higher shorter dams in mountains need less • Run-of-river power plants have limited footprint • Downstream impacts: erosion and changes in sedimentation deposits can alter land • Total ocean area required for wave, ocean, tidal is dependent on spacing needed between facilities, but can be used for other purposes
Social[52]	• Positive: flood control; driver of economic growth; water in reservoir can be used in times of drought, for irrigation, leisure • Negative: adverse downstream impacts on riparians and communities dependent on the river for livelihoods (fishing, transport, farming); forced relocation from reservoir flooding; potential to increase seismic activity
Other[53]	• Potential adverse effects for alteration of hydrology of river; impacts on ecosystem and floodplains; impact on fish migration/spawning routes

[47] As of December 2010, only tidal barrage systems were at a commercial scale and accounted for a majority of global installed ocean energy capacity. See Renewable Energy Policy Network for the 21st Century (REN21), *Renewables 2011: Global Status Report* (Paris: REN21 Secretariat, 2011), 26, http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR2011.pdf.

[48] DOE Wind and Hydropower Technologies Program, *Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies* (Washington, DC: DOE, December 2009), http://www1.eere.energy.gov/water/pdfs/doe_eisa_633b.pdf.

[49] Raadal et al., "Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power," 3420; Weisser, "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies," 1553; Lenzen, "Current State of Development of Electricity-Generating Technologies," 521.

[50] Henriette I. Jager and Brennan T. Smith**, "**Sustainable Reservoir Operation: Can We Generate Hydropower and Preserve Ecosystem Values?" *River Research and Applications* 24, no. 3 (2008): 340–352, http://www.esd.ornl.gov/~zij/mypubs/Waterpower/RRA08-SustainableReservoir.pdf; Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 741; DOE, *Energy Demands on Water Resources*; P. Torcellini et al., *Consumptive Water Use for U.S. Power Production* (Golden, CO: NREL, December 2003), http://www.nrel.gov/docs/fy04osti/33905.pdf.

[51] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 744.

[52] Lenzen, "Current State of Development of Electricity-Generating Technologies," 470; Nicole T. Carter, "Energy's Water Demand: Trends, Vulnerabilities, and Management," Congressional Research Service, November 24, 2010, 14, http://www.fas.org/sgp/crs/misc/R41507.pdf.

[53] WCD, *Dams and Development*.

Bioenergy (biofuels and biomass)

The type of feedstock and the production and combustion methods greatly influence the amount of emissions.[54] Similarly, bioenergy's water footprint is dependent on several agricultural conditions such as the feedstock, irrigation method, climate and precipitation, and power-generation technologies;[55] however, if irrigated, bioenergy has the largest water footprint of all the clean energy technologies assessed here. Several concerns have been raised regarding bioenergy's competition with agriculture for available arable land, as well as the potential for resource competition (food vs. fuel).

Impact	Key Findings
Air/Climate[56]	• Vary significantly depending on type of feedstock , fertilizer used, locus of production, land productivity, agricultural practices/management, and combustion (combustion efficiency, power rate, plant technology) and processing (gasification and transport)
Water[57]	• Large water footprint from irrigation, evapotranspiration, processing, embedded water (fertilizers, pesticides, herbicides, and fuel and electricity used for cultivation, irrigation, and harvesting) • Use of biomass waste products consumes less water than other harvested biomass materials • Water consumed during processing: grinding, liquefaction, fermentation, separation, and drying
Land[58]	• Widespread utilization can place pressure on available land • Resource competition—fuel vs. food • Land management important to reduce pollution from harvesting and production (fertilizers and farming methods), erosion, nutrient depletion, and expansion onto marginal land and forests
Social[59]	• Positive: job creation (labor-intensive agricultural practices) • Negative: health impacts from pollution from direct combustion of biomass
Other[60]	• Loss of habitats from converted land, soil degradation, eutrophication from agricultural intensification

Nuclear

While nuclear energy has few emissions from generation (dependent on technology used), there are emissions associated with the upstream mining, processing, and transport of uranium. On average, nuclear plants withdrawal more water per unit of energy than coal or natural gas plants. The amount withdrawn is dependent on the type of cooling technology: open-loop cooling systems have a high withdrawal rate and low consumption rate; close-loop systems have lower withdrawals, but higher consumption; and air cooling or indirect dry cooling have negligible water requirements.[61] The main impact on land stems from upstream and downstream processes as the actual nuclear plant takes up little land.[62]

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[54] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 733–736.
[55] Ibid., 743.
[56] Sathaye et al., "Renewable Energy in the Context of Sustainable Development,"733–736; Weisser, "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies," 1553.
[57] Fthenakis and Kim, "Life-Cycle Uses of Water in U.S. Electricity Generation," 2042; Christopher Harto et al., "Life Cycle Water Use of Low-carbon Transport Fuels," *Energy Policy* 38, no. 9 (September 2010): 4933–4944; Carey W. King and Michael E. Webber, "Water Intensity of Transportation," *Environmental Science & Technology* 42, no. 21 (2008): 7866–7872; R. Dominguez-Faus et al., "The Water Footprint of Biofuels: A Drink or Drive Issue," *Environmental Science & Technology* 43, no. 9 (2009): 3005–3010; U.S. Government Accountability Office (GAO), *Biofuels: Potential Effects and Challenges of Required Increases in Production and Use* (Washington, DC: GAO, August 2009), http://www.gao.gov/assets/160/157718.pdf.
[58] Carter, "Energy's Water Demand," 19.
[59] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 740.
[60] IEA, *Energy Technology Perspectives 2010*, 624.
[61] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 741–742.
[62] Fthenakis and Kim, "Land Use and Electricity Generation," 1468.

Impact	Key Findings
Air/Climate[63]	• Upstream emissions stem from uranium mining and milling—similar to those for coal mining, processing, and transport • Emissions depend largely on enrichment technology used and type of nuclear energy technology, ore grade, re-load frequency, burn-up • Generation emits virtually no NOx, SO2, PM, or GHG
Water[64]	• Upstream water impact from uranium mining varies depending on type of mine (underground or surface); water used for dust control, ore benefaction, and re-vegetation of mined surfaces • Water quality impacts from underground/open pit mining—effluent from mining can increase concentrations of uranium, radium, selenium, molybdenum, and nitrate in surrounding surface and groundwater • Processing (milling, enrichment, fabrication into fuel) requires water and energy • Water loss from evaporation from tailing ponds
Land[65]	• Large total land transformation due to mining and fuel waste storage requirements • Small generation footprint: siting of plant; land use predominantly from upstream/downstream processes (type of mining/extraction, supply infrastructure, disposal sites)
Social[66]	• Positive: health benefits from decreased emissions • Negative: public perception—especially post-Fukushima; NIMBY; accident could have major consequences for human health; high-level radioactive waste is a byproduct
Other	• Negative impacts depending on type of mining—may require surface vegetation restoration

Geothermal

The level of CO_2 emissions depends on the type of technology used; however, geothermal generation emits little NOx or SO_2.[67] Geothermal's water impact depends on the type of cooling used, although consumption can be managed through wastewater reinjection.[68] Concerns exist regarding the potential for surface water contamination from geothermal fluids spilled during operation or if surface storage impoundments leak, though proper management should abate risk.[69] The risk of land subsidence increases geothermal's total impact on land, though, its footprint remains limited.

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[63] IEA, *Energy Technology Perspectives 2010*, 628–629; Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 733, 738.

[64] DOE, *Energy Demands on Water Resources*; Mielke et al, "Water Consumption of Energy Resource Extraction, Processing, and Conversion," 22.

[65] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 744; Fthenakis and Kim, "Land Use and Electricity Generation," 1468.

[66] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 740.

[67] Alyssa Kagel, Diana Bates, and Karl Gawell, *A Guide to Geothermal Energy and the Environment* (Washington, DC: Geothermal Energy Association, April 2007), http://geo-energy.org/reports/environmental%20guide.pdf.

[68] International Finance Corporation (IFC), World Bank Group, "Environmental, Health, and Safety Guidelines for Geothermal Power Generation," April 30, 2007, http://www1.ifc.org/wps/wcm/connect/329e1c80488557dabe1cfe6a6515bb18/Final%2B-%2BGeothermal%2BPower%2BGeneration.pdf?MOD=AJPERES&id=1323161975166.

[69] C.E. Clark et al., *Water Use in the Development and Operation of Geothermal Power Plants: Draft* (Argonne, IL: Argonne National Laboratory, September 2010), http://www1.eere.energy.gov/geothermal/pdfs/geothermal_water_use_draft.pdf.

Impact	Key Findings
Air/Climate[70]	• Emissions impacted by technology choices (type of plant and composition of reservoir fluid) • Binary plants have no CO2 emissions; dry steam and flash steam have minimal CO2 emissions • Generation emits no NOx or So2, reducing local acid rain
Water[71, 72]	• Wide range due to definition of water—some estimates include geothermal fluid (which is not drawn from freshwater sources) • Water consumption can be controlled by the total reinjection of wastewater, non-evaporative cooling, pressure management, and closed-loop recirculating cycles[73] • Waste water contains small amounts of boron and arsenic and H2S and CO2 requiring proper management • Surface spills or leakage from surface storage impoundments of geothermal fluids could contaminate nearby freshwater wells
Land[74]	• Small above-ground footprint • Due to risk of land subsidence, the entire field is used to calculate footprint
Social[75]	• Negative: potential hydrogen sulphide emissions create a sulfur smell; emissions vary widely • Potential for induced seismic activity

Environmental Impacts: Looking Ahead

Moving forward, it is crucial to recognize the inherent environmental and social benefits of a switch to cleaner energy sources, but it is also important to understand the potential risks and impacts associated with the implementation of cleaner technologies. The advent of advanced technology and appropriate policy can mitigate the environmental impacts of cleaner energy technologies. The standardization of a robust and uniform LCA would aid this process by allowing for complete and nuanced comparisons between fuel types. Such uniform measurements would highlight existing gaps where technology could advance as well as provide policymakers the clearest picture so as to understand what technology is best suited for what region given the benefits/impacts and the specific nuances of a region.

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[70] Kagel et al., *A Guide to Geothermal Energy and the Environment.*
[71] Most facilities are able to use either geothermal fluid or freshwater for cooling.
[72] Clark et al., *Water Use in the Development and Operation of Geothermal Power Plants*; Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 741–742.
[73] IFC, World Bank Group, "Environmental, Health, and Safety Guidelines for Geothermal Power Generation."
[74] Evans et al., "Assessment of sustainability indicators for renewable energy technologies," 1082–1088; Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 744.
[75] Sathaye et al., "Renewable Energy in the Context of Sustainable Development," 740, 747.