The Heritage Foundation

SPECIAL REPORT

No. 298 | DECEMBER 6, 2024

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CENTER FOR ENERGY, CLIMATE, AND ENVIRONMENT

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This paper, in its entirety, can be found at **https://report.heritage.org/sr298**

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The Climate Shift: How Changing Weather Patterns Will Enhance Hydropower

Todd Myers

Inadequate water supply for hydropower is cited by some members of the media, government agencies, and politicians as a risk of climate change. Climate models, however, project an increase *in streamflow for hydropower generation across North America in the upcoming decades. Models have a large margin of error, but all agree that as temperatures increase, so will precipitation and power generation. The net effect is a significant increase in total hydropower generation, increasing the ability to meet growing electricity demand. This additional generation will be necessary for backing up intermittent sources of electricity and filling in gaps when energy from wind and solar disappears, making hydropower more valuable as electricity demand increases, and the mix of electricity generation changes.*

In 2023, as the Pacific Northwest faced a dry summer and the region's snowpack diminished, hydropower production declined to one of the lowest levels in decades. Reporters and politicians were quick to point to climate change as a contributing factor in the reduced power generation.

In an article titled "Climate Change Is Throwing the Water Cycle into Chaos Across the U.S.," NBC News reporters claimed: "Warm spring and summer temperatures in the Pacific Northwest hastened that region's meltout, leaving the water supply short in fall and straining the region's capacity to generate hydropower."[1] Noting that hydropower across the Northwest declined by about 23 percent in 2023, Seattle's local NPR radio station KUOW linked the result to a reduction in snowpack "as the global climate has warmed."[2]

These stories are part of a larger narrative about the effect of climate change and rising temperatures on the viability of hydropower as a reliable source of energy over the next several decades. In 2009, both the Environmental Protection Agency's (EPA's) "Endangerment Finding for

Greenhouse Gases" and a report from the U.S. government on climate cited reductions in hydropower generation as one of the potential harms from climate change.

The authors of the 2009 *Global Climate Change Impacts in the United States* argue that "[c]limate change is likely to affect some renewable energy sources across the nation, such as hydropower production in regions subject to changing patterns of precipitation or snowmelt" like the Pacific Northwest.[3]

The technical document for the EPA's 2009 endangerment finding also warned that climate change could significantly reduce the availability of hydropower in some parts of the country. The authors claimed that in California, "diminished snow melt flowing through dams will decrease the potential for hydropower production by up to 30% if temperatures rise to the medium warming range by the end of the century (~5.5 to 8°F [~3.1 to 4.4°C] increase in California) and precipitation decreases by 10 to 20%."[4]

If climate change does, in fact, reduce hydropower generation, it would add pressure to the North American electrical system precisely as the U.S. and Canada are looking to electrify energy demand. Although hydropower is not a major source of electrical generation for most of the United States, it plays a significant role in the Western U.S. and provides valuable peak energy generation—power that is available during peak demand hours typically in the evening—in Southern states. As intermittent sources of energy like wind and solar power become prevalent, hydropower's flexibility will become increasingly valuable to fill in when renewables are not available.

Despite those predictions, research from national labs, regional energy managers, and utilities indicate that increasing temperatures are likely to *increase* total hydropower generation, even during the summer when electricity demand is expected to increase the most. Although there are regional differences, production is expected to increase in key regions of North America. The models also show that while generation will shift toward winter and spring, the change is driven primarily by increased production in winter and spring rather than significant declines in summer and fall.[5] In fact, storage behind dams will allow dam managers to increase summer power generation even where there are reductions in streamflow.

Other factors may have a greater influence on the future availability of hydropower than climate change. As intermittent sources of energy become more prevalent, dam operators are likely to change how they manage generation, holding water in reservoirs as a backup for periods when wind and sun are not available. Using dams for peak generation capacity might make hydropower more valuable, but it could also make dams less efficient.

This *Special Report* examines the claims made in the 2009 endangerment finding and subsequent national climate assessments about the effects of climate change on hydropower. Using updated climate models and reports from several sources, the author examines the current projections for future precipitation, streamflow, and hydropower generation in several regions of the United States and Quebec, where hydropower is the primary source of electrical generation. However, this *Special Report* concludes that there will be more hydropower, not less.

This report makes some choices about timelines and future climate scenarios. The accuracy of these choices may or may not influence its conclusions, but they are beyond the scope of this study.

First, this author has chosen to focus on projections up to the year 2050. This timeframe is consistent among the studies produced by national labs, utilities, and others modeling potential hydropower effects. Some of the claims made in the endangerment finding are for the end of the century. As the authors of *The Third Assessment of the Effects of Climate Change on Federal Hydropower* note, "future precipitation projections are quite uncertain," so this report focuses on potential influences over the upcoming decades.[6]

Second, any projection that uses climate modeling is influenced by the choice of future scenarios used by researchers. Scenarios for climate projections, ranging from low to high, were previously called Representative Concentration Pathways (RCP) and are now referred to as Shared Socioeconomic Pathways (SSP). Projections are based on theoretical increases in emissions of carbon dioxide (CO_2), methane, and nitrous oxide and, as the name suggests, SSPs are based on projected economic and social changes that result in differing levels of greenhouse gas emissions.

While many, but not all, of the studies cited here use RCP 8.5 and SSP 585—which are the most extreme scenarios with the highest emission levels and temperature increases—this author does not contest or adjust their projections.[7] Although other scenarios may produce slightly different outcomes, there is little difference among scenarios for the 2050 timeframe.

The Intergovernmental Panel on Climate Change (IPCC) now considers these scenarios unlikely, writing in the most recent assessment that it is "considerably less likely that emissions could end up as high as RCP8.5."[8] The IPCC also notes that "[h]igh-end scenarios (like RCP8.5) can be very useful to explore high-end risks of climate change but are not typical 'business-as-usual' projections and should therefore not be presented as such." As a result, these assessments offer the worst-case scenario in many cases for the effect on hydropower. Since even these scenarios show increased hydropower generation, it is unlikely that any reasonable climate scenario would contradict the findings in this *Special Report*.

Ultimately, the fact that projections from so many independent sources all point to increased hydropower generation in the upcoming decades indicates that the claims included in the endangerment finding, national climate assessments, and recent media reports do not reflect the reality that dams will likely increase total energy production and continue to play an important role in North American electricity generation.

The Role of Hydropower in the United States and Quebec

Dams that generate hydroelectric power play a relatively small role in total energy production in North America but are important in the Western United States and the northeastern Canadian province of Quebec due to the large number of dams built in these regions. In their study of the influence of future climate change on hydropower generation, researchers at the Oak Ridge National Laboratory wrote: "As of 2019, there were 2,270 conventional (i.e., once-through) hydropower plants in the United States with a total of 80.25 GW of generating capacity producing 6.6% of all electricity and 38% of electricity from renewables."[9]

In the U.S. Pacific Northwest and in Quebec, hydropower plays a much more significant role in total electrical generation. Hydro-Québec notes that it is "one of the largest producers of hydroelectricity in the world, with an installed capacity of over 37,000 MW," accounting for 94 percent of total generation in the province in 2021.[10] In the three U.S. states of the Pacific Northwest, there are about 34,400 installed megawatts of hydropower, accounting for about one-third of total U.S. hydro generation and more than two-thirds of the electricity generated in Washington state.[11] In 2023, about 13 percent of electricity generated in California came from hydropower.[12]

Although only 13 percent of California's electricity generation comes from hydroelectric dams, the state is a major importer of electricity from the Bonneville Power Administration in the Pacific Northwest during the summer months when demand is low in Idaho, Oregon, and Washington.

Hydropower can also be dispatched quickly, responding to changes in generation elsewhere on the grid. Hydro-Québec's 2035 plan argues that hydropower will continue to play an important role, even as other sources of energy are built. The "Toward a Decarbonized and Prosperous Quebec: Action Plan 2035," argues: "We must also balance wind power with firm generation to ensure optimal balance in the energy system at all times. In Québec, hydropower is the best option for firming up intermittent wind power."[13] The U.S. Department of Energy echoed this sentiment in its 2016 report on the future of hydropower, writing:

> An increasing need to integrate variable generation resources, such as solar and wind, will lead to greater demand for grid flexibility and balancing services. Hydropower generation and [pumped hydro] provide these needed services due to their consistent availability and their capability for rapid response to changes in demand.[14]

Batteries can also provide this function, typically storing solar power in the middle of the day and releasing it during peak demand hours in the evening. However, battery power is currently expensive and represents a small percentage of electricity supply.[15] Unlike hydropower generation, but similar to pumped hydropower, batteries do not generate electricity but simply shift power from other sources to different times of the day when demand is greater.

Lastly, hydropower's flexibility allows it to "load follow," increasing or decreasing production to meet the changing level of demand during the day. As electricity demand increases in the morning and evening, dams can increase the amount of water running through the turbines. The Department of Energy notes that "[m]ost U.S. hydropower units are able to and do effectively provide load following to an hourly schedule, as well as following ramps that occur within the hour time scale."[16] Across the Southern United States, this is the primary function that hydropower serves.[17]

Thus, although hydropower is a relatively small source of electricity across the United States, the flexibility it provides to back up intermittent sources of power and meet hourly changes in demand make it an increasingly important source of electricity.

Claims that Climate Change Will Harm Hydropower Production

Concern that increasing temperatures will reduce the amount of water available to generate hydropower features regularly in government and media reports highlighting the effects of climate change. By altering the timing and amount of runoff from mountain snow, the concern is that reduced streamflow will decrease hydropower production or limit availability when demand is highest, especially in the summer when temperatures are predicted to increase.

The 2009 endangerment finding from the EPA highlights these exact risks. The finding notes that lower snowpack due to higher winter temperatures would mean lower levels of runoff. "In California," the authors write, "diminished snow melt flowing through dams will decrease the potential for hydropower production by up to 30% if temperatures rise to the medium warming range by the end of the century."[18] The finding does offer a significant hedge against that projection, noting, "it is possible that precipitation may increase and expand hydropower generation." The authors also worry that in the Pacific Northwest, dams may have to release "large amounts of runoff during the winter and early spring to fulfill flood protection objectives, leaving the region without a reliable water supply for hydroelectric power production in summer and early fall when temperatures reach their peak and electricity demand for air conditioning and refrigeration is greatest."

The national climate assessments in 2009 and 2023 both echo the concerns about reduced snowpack and increased risk of flooding.

According to the authors of the 2009 report, "[h]ydropower production is reduced due to low flows in some regions," due to "to changing patterns of precipitation or snowmelt."[19] The authors go on to say that "[w]armer summers will increase electricity demands for air conditioning and refrigeration at the same time of year that lower streamflows will lead to reduced hydropower generation."

In addition to changes in the amount of snowpack and the timing of runoff, the authors report that large reservoirs behind the dams will suffer from increased evaporation, "meaning less water will be available for all uses, including hydropower."

Fourteen years later, the authors of The Fifth National Climate Assessment in 2023 wrote bluntly that in the Western United States, "[i]ncreasing energy demand due to higher summer temperatures, coupled with a projected decrease in summer hydropower generation, will magnify the potential for energy shortfalls."[20] For the Pacific Northwest in particular, the authors warn that "[h]ydropower generation is currently meeting the number of cooling degree days but might not continue to do so as temperatures and heatwaves increase in the future."

In many—but not all—cases, the language of the 2023 National Climate Assessment (NCA) is careful, using words like "might" and "potential for," but the message is clear that climate change will result in less energy from hydropower, making it less reliable especially in the summer.

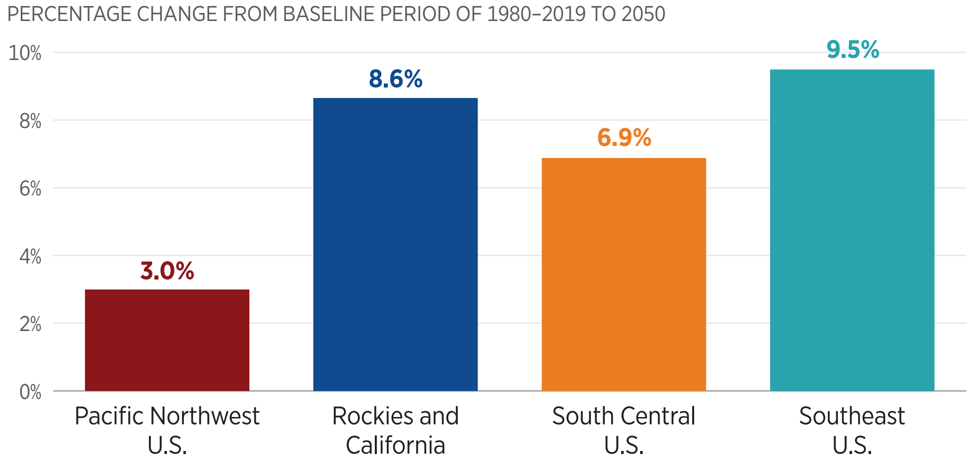
This *Special Report* now assesses how accurate the claims that are already measurable have been, and looks at the future projections, in some cases using the same sources.

Projections for Future Precipitation and Streamflow

Many of the claims about the decline in future hydropower focus on reduced snowpack and increased drought causing lower streamflow during critical parts of the year and less hydropower.

CHART 1

Median Increase in Hydropower Generation by 2050



SOURCE: Author's calculations.

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Several organizations have modeled national and local results of future climate change to assess their effect on power generation. For its projections of reduced hydropower, the 2023 NCA uses studies from researchers at Oak Ridge and Pacific Northwest National Laboratories. This author uses those studies and spoke with the lead authors of the Third Assessment to compare the language in the NCA to the underlying research.

This author also examined research from the Northwest Power and Conservation Council and the National Renewable Energy Laboratory, a study prepared for Hydro-Québec, and other papers.[21] He interviewed researchers, utility managers, and energy experts about the projections of changes in the climate on hydropower.

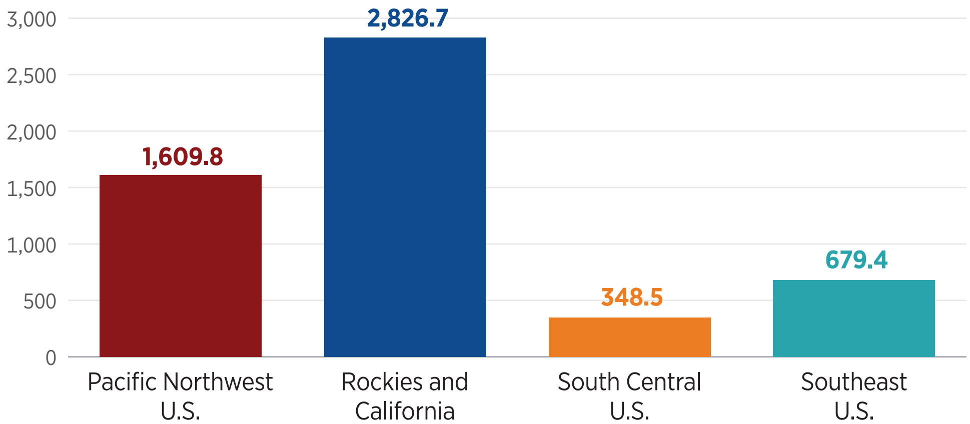
All studies agree on three basic findings. First, total streamflow will increase in the upcoming decades as temperatures increase. Warmer air can hold more moisture, leading to increased precipitation. The models all show that the amount of water available for hydropower generation will increase. The increases grow over time with the temperature. Evaporation from reservoirs behind dams also worsens but does not offset increases in precipitation and streamflow.

Rather than reducing the amount of hydropower, the models indicate that climate change will increase generation. Researchers at the Oak Ridge National Lab found that across the regions they examined in the United States, annual streamflow is projected to increase by 9 percent, creating a 4 percent increase in total hydropower generation by the middle of the century.[22]

CHART 2

Projected Increase in Total Hydropower Generation by Region in 2050

CHANGE FROM BASELINE PERIOD OF 1980–2019 TO 2050 IN GIGAWATT HOURS PER YEAR



SOURCE: Author's calculations. SR298 heritage.org

Second, there is a shift in power generation toward the winter and spring months. This shift is largely a product of increased streamflow in winter and spring rather than a significant reduction in summer streamflow. There are regional differences, and in some parts of the country there may be less water available for hydropower during summer, primarily in the Western United States (and, in Quebec, Canada). Although summer generation will be lower in those regions, climate change is likely to diminish the risk of energy shortages by reducing the number of heating degree days (when cool temperatures increase demand for heating) during the winter, which is the time of highest demand in those areas. The number of cooling degree days (when warm temperatures increase demand for cooling) will increase in those regions but will create a smaller risk of energy shortages.

In other regions, like the Southern United States, generation is expected to increase during the summer, but because these regions generate much less hydropower, the effect on total energy generation is small.

Because hydropower plays a different role in each region, a closer look at each region helps in understanding the effects and risks more clearly. For example, changes in streamflow do not necessarily correlate directly to changes in hydropower generation. Some dams have storage capacity, meaning they can absorb seasonal changes better than run-of-river (ROR) dams that have smaller reservoirs.

Third, increases in one region can offset changes in demand or generation in other parts of the country as long as transmission capacity exists. In the Western United States, the highest demand for electricity is during the winter in the Pacific Northwest but during the summer in California. As a result, some of the hydropower generated in the Columbia River Basin is sent south during the summer to meet increased demand in California. Although this report focuses on regional changes, much of the electricity can be sent where it is needed—from region to region—at different times of day or the year.

The Pacific Northwest

The dams in Idaho, Oregon, and Washington state produce more hydropower than any other region in the United States.[23] For that reason, potential reductions in hydropower could have greater effects in the Northwest than elsewhere.

The 2009 National Climate Assessment noted that "[h]ydropower is a major source of electricity in some regions of the United States, notably in the Northwest," going on to claim that "[i]t is likely to be significantly affected by climate change in regions subject to reduced precipitation and/or water from melting snowpack."[24] The authors of the 2023 National Climate Assessment echoed those claims, writing: "Less snow, earlier snowmelt, and more frequent and intense droughts will alter the seasonal capacity of hydropower, a primary source of regional energy, to meet electricity demand."[25]

To assess the accuracy of these claims, this author examined the projections of the Northwest Power and Conservation Council (NWPCC) in its 2021 Northwest Power Plan, and The Third Assessment of the Effects of Climate Change on Federal Hydropower released in 2022 by researchers at the Oak Ridge National Lab. Both of those reports model the influence of climate change on hydropower for the middle of the century, and The Third Assessment is cited by the 2023 National Climate Assessment.

Contrary to the concerns, The Third Assessment projects that annual runoff is likely to increase in the Pacific Northwest. Its models show a potential increase between 3.9 percent and 6.5 percent in runoff in the next decade, and between 1.9 percent and 9.4 percent in the middle of the century. The prime drivers are increases in runoff during the winter and spring. Summer runoff is expected to decline between 3.5 percent and 6.6 percent in the near term and between 8.6 percent and 18 percent in the middle of the century.

The research included in the Northwest Power Plan largely agrees with those projections. NWPCC researchers project that streamflow from October through May is likely to be significantly higher than the historical record.[26] And while the report projects a decline in streamflow in the summer, the authors note that the model may exaggerate those reductions. Comparing streamflow from 1929 to 1958 to streamflow from 1979 to 2008, the model used in the Northwest Power Plan accurately projected the observed increase during the spring. However, the projected decrease in the summer did not occur. The authors noted that, "the trend of decreasing flows for summer months is not evident in the historical data." They go on to note that observed streamflow during the most recent 30 years ending in 2018 is closer to the modeled projections.

Although streamflow affects hydropower generation, there is no direct correlation between the two. The Third Assessment notes that in the Northwest, "hydropower generation has a smaller response to climate change relative to increases in runoff, indicating that much of the flow increases may bypass turbines via spill, or that reservoir storage systems may be able to absorb part of the runoff variability."[27]

Overall, hydropower production is expected to increase modestly in both the near term and the middle of the century. Seasonal changes are more pronounced, with winter generation increasing by up to 20 percent by mid-century and generation declining by up to 9 percent during the summer.

Despite the changes, the risk of severe energy shortages is likely to decline. Demand for electricity across the Northwest is driven by cold weather in winter. Summer temperatures are typically mild, so demand for cooling will continue to be relatively low. The risk of serious electricity shortfalls, which typically occur during the winter, is smaller and is replaced by a risk of less severe shortfalls during the summer. Researchers at the Pacific Northwest National Laboratory projected an increase in the number of electricity shortfall events but found that the events would be less serious. "We find that whilst shortfall events occur more frequently under climate change, the nature of those events is more amenable," they wrote. "The average event lasts about half as long (~13±1 to ~7±1 h) and is significantly less intense."[28]

As a result, the combination of changes in hydropower generation and electricity demand due to climate change *increases* total production and reduces the risk of serious energy shortages in the middle of the century.

California

Projections of the results of climate change have focused particularly on California because the state has faced repeated droughts, and the large population contributes to water scarcity. Additional reductions in streamflow would exacerbate that scarcity, leaving hydropower competing with other priorities for water.

In 2023, hydropower accounted for about 13 percent of California's total electricity generation.[29] It also plays an important role in balancing California's electricity, ramping up as solar power disappears in the evening and ramping down in the midday when solar power is prevalent. The only other significant energy source that plays a similar role in the state is natural gas–generated power.

The endangerment finding specifically mentions the effect of climate change on hydropower in California. The authors claimed that "diminished snow melt flowing through dams will decrease the potential for hydropower production by up to 30% if temperatures rise to the medium warming range by the end of the century."[30] Additionally, California's peak demand for electricity occurs during the summer. If streamflow declines in the summer, increased temperatures would exacerbate the reduction in hydropower.

Researchers at Oak Ridge National Laboratory modeled the potential influence of climate change on streamflow and hydropower generation in Northern California—region 6 of the Western Area Power Administration (WAPA-6)—and the lower Colorado River (WAPA-4), which provides electricity to Southern California.

Contrary to the fear that climate change would lead to a reduction in hydropower, the researchers found that by the middle of the century, both California and the lower Colorado River would see an increase in both precipitation and streamflow. They wrote in the Third Assessment: "A comparison of the probability distribution between the baseline and future periods indicates a statistically significant increase in precipitation" in both California and the lower Colorado River, which translates to increased total streamflow.[31] The models show a slight decrease in streamflow in California in the next decade, but an increase of 11.3 percent by the middle of the century. Streamflow in the lower Colorado River increases in both the near term and in 2050.[32]

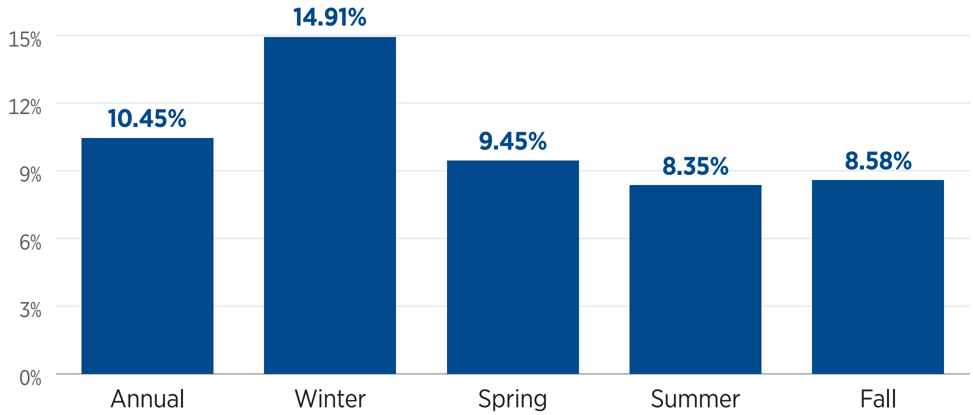
There is seasonal variability, with a significant increase in California's streamflow in all seasons except summer. By way of contrast, the researchers project increased streamflow in all seasons in the lower Colorado River. In particular, summer runoff on the lower Colorado River is projected to increase about 8 percent by the middle of the century.[33]

The increase in total streamflow in California and the lower Colorado River translates into an increase in hydropower generation of about 8 percent and 1 percent, respectively.[34] Although the projections of a significant

CHART 3

Projected Seasonal Increase in Hydropower Production in California in 2050

PERCENTAGE CHANGE FROM BASELINE PERIOD OF 1980–2019 TO 2050



NOTE: Winter months include December, January, and February; spring months include March, April, and May; summer months include June, July, and August; and fall months include September, October, and November.
SOURCE: Author's calculations.

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reduction in hydropower included in the endangerment finding are for the end of the century, it would require a dramatic decrease in total production during the second half of the century for that projection to be accurate.

The models show reduced streamflow in California during the summer but indicate that hydropower generation during the summer will increase. The authors of the Third Assessment explain that "[s]imilar to annual generation, seasonal generation in WAPA-6 in California is expected to remain relatively stable in the near-term future period (ranging from -1% in spring to 3% in summer). In the mid-term future period, generation is expected to increase in all seasons (ranging from 8% in summer to 15% in winter)."[35] They note that large reservoirs behind California dams "substantially smooth the seasonal variability in natural runoff and projected changes in seasonality."[36]

Large reservoirs allow dam managers to hold water until it is needed—either seasonally, or to meet changing demand during the day. Holding water can lead to increased evaporation, reducing the amount of water available for generation. The net effect found in models indicates that evaporation does not outweigh the ability to store water for when it is needed.

The same trend of increased generation across all seasons is true on the lower Colorado, for which the authors note: "The stable seasonal generation response is likely because of the large storage capacity provided by Hoover Dam and Lake Mead, and because this region receives a substantially managed upstream flow."[37] Generation in spring, summer, and fall is expected to increase between 8 percent and 15 percent in the middle of the century.[38]

Finally, Oak Ridge researchers compared the potential increase in hydropower generation to an expected increase in electricity demand as summer temperatures rise in California. They project that demand will grow by 3.6 percent in the middle of the century.[39] That relatively modest increase, along with increases in hydropower generation in California, the lower Colorado, and neighboring states, led researchers to conclude that power generators "will on average be able to fulfill the capacity and energy allocations in its current long-term contracts" in the upcoming decades.[40]

California's water problems are frequently cited as a potentially serious result of climate change. The projections for mid-century, however, indicate that hydropower generation will increase, helping to meet the increased demand for electricity and keep homes cool during the summer.

Quebec

Although neither the endangerment finding nor the National Climate Assessments mention Quebec, hydropower production provides nearly all the electricity for the province and supplies energy to the Northeast United States. In their assessment of "The Future of Hydropower in the Northeastern United States," researchers at the National Renewable Energy Laboratory note that the interconnections "were built to facilitate New England access to abundant low-cost hydropower from Quebec, and the expectation is that there will be sufficient hydropower resources in Quebec to maintain energy exports to New England."[41]

As noted, Hydro-Québec is one of the largest hydropower generators in North America. The utility has studied the potential effect of climate change on the availability of water to continue to generate the power needed by the province and commissioned a study of the changes in precipitation and streamflow through 2050.[42] The results are similar to other studies and show that total streamflow is likely to increase over the next several decades, leading to an increase in hydropower generation.

The climate scenarios modeled by the researchers are less extreme than those used by the studies in the United States, but the results are consistent since the variation between the models through the middle of the century is relatively small.

Researchers found that precipitation would increase by about 15 percent in northern Quebec and 10 percent in the south of the province by 2050.[43] Additionally, because winter temperatures in the north will remain freezing, the increase in precipitation will mean more snow. The researchers wrote: “The northern part of Québec will also see a decrease in the number of days with snow on the ground, but total snow accumulation will be greater.”[44]

As a result, annual streamflow will increase for the province as a whole. “Simulations results indicate that increases in mean annual streamflow are projected for the whole province, with greater changes (up to 14%) in the north.” The models show a slight decrease in summer streamflow. “Summer months show an overall very probable decrease in their contribution to the annual volume, ranging from –0.5 to –3%.” However, the changes are limited, and the researchers point out that “although median values of changes in monthly contributions are rather small, the consensus with respect to the direction of change is strong.”[45]

As with California, large reservoirs allow Hydro-Québec to store runoff during the winter and spring to mitigate the small decrease during the summer. Hydro-Québec staff told this author in an email that “[i]n the long term, climate change could favor northern hydro systems, increasing the water available for hydropower production” by between 6 percent and 8 percent.[46] “This is especially true where very large upstream reservoirs are available to hedge against inflow variability.”

That flexibility means that “[p]eriods of low runoff have no impact on the energy supply of our customers in Quebec or on long-term contractual commitments in neighboring markets.” This is also good news for states in the Northeast U.S. that rely on Canadian hydropower. Hydro-Québec staff told this author that they “have sufficient reserves to meet Québec demand and honor our export contracts.”

The increase in winter and spring generation may be beneficial as states in the Northeast move away from natural gas to electric heat in the winter. A study published by the National Renewable Energy Laboratory found that under a high-electrification scenario, “nearly all states in the Northeast join the northwestern states and become winter peaking.”[47] Even in medium-electrification scenarios, demand shifts toward winter. Unlike the Northwest, where increases in winter generation are counter to the trend in demand, electrification in the Northeast would create demand that is aligned with an increase in winter generation.

Other Regions in the United States

Although other regions of the U.S. rely less on hydropower, it still plays an important role in meeting demand and managing the grid. In the Southern United States, hydropower provides electricity when it is most needed during peak demand hours. Dams on the upper Missouri River provide a fair amount of electricity, accounting for nearly a quarter of power generation in South Dakota.[48]

Despite the regional differences, the pattern of the influence of climate change on hydropower is similar to that of other regions. By the middle of the century, the total amount of streamflow and hydroelectric generation in all regions is expected to increase.

In the upper Missouri and upper Colorado regions, researchers at the Oak Ridge National Laboratory project that streamflow will increase between 12.5 percent and 14.6 percent by the middle of the century.[49] Although streamflow increases in winter, spring, and fall, and decreases slightly in the summer months, electrical generation is expected to increase in all seasons.[50] For example, the upper Missouri is expected to see generation increase the most in spring, growing by about 14 percent, and the least in the summer, but still increasing by 8 percent.[51]

The amount of hydropower generated across the Southern United States is relatively small and is used primarily to help meet peak demand in the morning and evenings.[52] Generation is driven primarily by rainfall. Both streamflow and power generation are expected to increase in the upcoming decades. For example, the Third Assessment notes that in the region that encompasses Arkansas, Missouri, Nebraska, and Oklahoma, "[t]he annual hydropower generation is projected to increase significantly," growing between 5 percent and 11 percent across the region.[53]

In the Southeastern United States, streamflow is expected to increase between 13.7 percent and 18.4 percent, with the largest growth coming during the summer months, in contrast to the pattern in the Western United States and Quebec.[54] The models show an increase in electricity generation between 3 percent and 19 percent in the middle of the century, depending on the state.[55]

The hydro systems in the South are small, generating an average of about 17 percent of what dams across the Pacific Northwest produce, so even with these increases, hydropower will still play a small role in regional electrical generation.

There will be some shift in total generation from summer to other seasons. The summer reductions, however, are relatively modest, and in many regions the storage capacity offsets the reductions, resulting in increased power generation during the summer.

Increases in Wind and Solar Power Make Hydropower More Valuable as a Backup

Hydropower's flexibility will make it a particularly important source of energy in the future. It is the only significant, low-carbon energy source that can adjust to meet changes in demand and fill in the gaps left by other sources of energy. There are some new and promising nuclear technologies. However, nuclear power generally provides consistent base-load at near maximum output that, while providing reliable generation, generally does not leave generation capacity to respond to changes in supply or demand.[56]

Conversely, hydropower's important role in flexible generation was consistently highlighted in this author's interviews with system planners and researchers.[57] The Western Area Power Administration, which covers much of the area along the Rocky Mountains, noted that the Colorado River "hydropower system will be pressed to provide more and more 'back-up' power for a non-dispatchable renewable generation such as wind and solar."[58]

Hydro-Québec's 2035 Action Plan highlighted the burdens that renewables place on hydropower management. Plan authors wrote: "During less windy periods, however, hydropower facilities—which provide reliable, firm generation—must take over to meet demand. Although adding new wind generation is a key component of our strategy to meet Québec's growing demand, it will not be enough."[59]

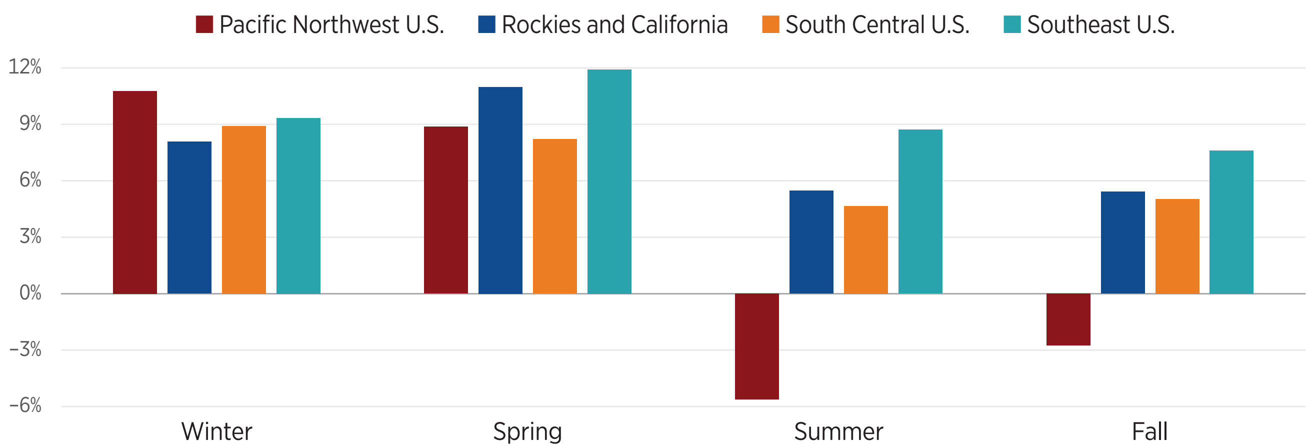
As hydropower is expected to fulfill a variety of roles, it will become more difficult to balance the requirements to provide reliable electricity, flexibility, and demands to provide flood control and meet environmental restrictions. One study on the Columbia River found that a real-world simulation of dam operation could not achieve the desired flexibility due to a range of factors, including "responses to real time information like flow forecasts or hydropower curtailment needs to integrate wind generation resources."[60] As the amount of wind-generated power increases, the difficulty of integrating those resources may become greater.

Hydropower has typically provided some of the lowest-cost electricity in the United States. As the demands on dams increase, it may be that they are unable to balance all the factors they face, making hydropower less efficient and more expensive. Climate change may play a role in these changes, but the need to back up a growing number of intermittent power sources will also make the water behind dams more valuable and expensive.

CHART 4

Projected Change in Hydropower Production by Season and Region in 2050

PERCENTAGE CHANGE FROM BASELINE PERIOD OF 1980–2019 TO 2050



NOTE: Winter months include December, January, and February; spring months include March, April, and May; summer months include June, July, and August; and fall months include September, October, and November.
SOURCE: Author's calculations.

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Flawed Claims About Hydropower

Even with an average increase in hydropower generation, the insinuation of some climate-related critiques is that it will not be able to keep up with the increased demand in electricity due to increased temperatures. Although there is some seasonal variability, this does not appear to be the case.

For example, in California, where projections show a significant increase in cooling-degree days due to warming temperatures, summer generation is projected to increase by more than the increased demand. As a result, the researchers at Oak Ridge National Laboratory note that across the West, federal hydropower generators will "be able to fulfill the capacity and energy allocations in its current long-term contracts."[61] In the Pacific Northwest, which is most reliant on hydropower, total generation will increase more than demand due in part to a significant reduction in demand during winter months.

It is important to remember that these are only projections, and over the next quarter-century a wide range of factors, including modeling errors, technology changes, and public policies, will affect the accuracy of these estimates. The analysis here, and in the sources cited, is designed to provide a basis for a general policy and regulatory direction for the future mix of energy resources. Similarly, the claims made in the endangerment finding and national climate assessments are designed to inform public policy by highlighting theoretical weaknesses in future hydropower generation. The consistent results of the projections demonstrate that hydropower generation is likely to play a larger role both in total generation and as intermittent back-up sources in the future.

Conclusion

Despite claims from the EPA's 2009 endangerment finding, National Climate Assessments, and numerous media stories, it is unlikely that climate change will reduce hydropower generation in the upcoming decades. Consistent with climate models that show that warmer air can hold more moisture, the projections show a likely increase in streamflow and hydropower generation, even in the most extreme climate scenarios.

Additionally, although there is a shift in generation toward winter and spring, that shift can be mitigated (as in Québec), results in fewer serious energy shortages (as in the Pacific Northwest), and may even be positive because it aligns with increased winter demand for electricity (as in the Northeast United States).

Finally, it is worth noting that as the quantity of intermittent sources of electricity are added to the electrical grid, the value of hydropower's flexibility will increase. In short, hydropower will be integral to ensuring that adequate electricity generation is available when intermittent sources decline, but it is also likely to make hydropower less efficient both in terms of cost and the availability of dispatchable resources.

North America will face new challenges in the upcoming decades as it adjusts to shifts in resource availability and new constraints. Fortunately, modeled projections from numerous sources show that hydropower will continue to be a reliable source of flexible electricity, even under the most extreme climate scenarios.

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