US Energy Security Threatened by Looming Climate Change Impacts on Hydroelectric Sector

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Executive Summary

As the US seeks to become more dependent on hydropower as a source of clean energy, a collaborative effort between national and state government is needed to accurately assess the vulnerabilities in the hydroelectric infrastructure that stand to be heavily impacted by climate change. Failing to address these vulnerabilities is a major security risk, as both the Dams Sector and the Energy Sector including hydroelectric plants are designated as critical US infrastructures by the Department of Homeland Security.¹

Hydropower, one of the oldest energy sources for the US, accounts for over seven percent of the nation’s power supply² and is the largest means of energy storage for the US due to its flexible ability for pumped hydroelectric energy storage (PHES) to back up other segments of the energy sector.³ Although development of PHES has largely remained dormant in the US since the 1990s,⁴ there has been a recent revival in the commercial, environmental, and policy interests of increasing PHES facilities.⁵ This, coupled with a hyper-focus on clean energy to reduce carbon emission levels,⁶ has encouraged US policy to lean more heavily on hydropower as a source of electricity.⁷ The existing and anticipated reliance on hydropower in the energy sector may prove problematic as climate change is predicted to fuel inland water scarcity throughout the United States, and specifically in western regions,⁸ where hydroelectric power plays a dominant role.⁹ As water availability decreases, the hydroelectric sector will face a tight strain on maintaining efficiency which may threaten the vital assets, systems, and networks necessary to the physical security, economic security, and public health and safety of the US.¹⁰

If the US maximizes current hydroelectric capacity, refrains from expanding the hydroelectric sector until climate change assessments are included in water management plans, and actively seeks to work with local governments to create viable energy and management solutions, the threats posed by climate change to the hydroelectric sector can be minimized.

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Hydropower has historically been an attractive source of energy for the US because of its ability to provide stability in volatile demands for energy and its capacity to provide essential back-up power to the energy sector. As water fills a dam that is equipped with hydroelectric capabilities, water is pumped uphill to a reservoir at a higher elevation from the second reservoir at a lower elevation. When energy is needed, the water is released and turns a turbine, which generates electricity.\textsuperscript{11} Sudden changes in demand for electricity can be easily met as many hydroelectric facilities can rapidly jump from zero power to maximum output.\textsuperscript{12} Additionally, hydroelectric power is the sole generation type that can resume operations without relying on a kickstart from an outside power source. This creates the ability for a hydroelectric facility to dispatch power immediately to stabilize the electric grid during major disruptions.\textsuperscript{13}

This back-up capacity is further strengthened when pumped hydroelectric energy storage (PHES) acts as a battery to store the electricity generated by other sources of power like solar, wind, and nuclear for later use. Hydro-powered energy storage could prove especially useful if the United States were to face a wide-spread blackout, such as the Northeast blackout of 2003 where 45 million people in 8 states were affected.\textsuperscript{14} During this costly blackout (which incurred $6 billion in damages), hydropower projects in upstate New York continued to run, even as the rest of the energy sector in the region was shut down.\textsuperscript{15} Additionally, hydropower is largely recognized as a form of clean energy “capable of mitigating the greenhouse gas emissions largely responsible for anthropogenic contributions to greenhouse climate change.”\textsuperscript{16} The National Hydropower Association estimates that more than 160 million tons of carbon dioxide emissions were avoided in the US in 2004 because of hydropower generation, which is capable of converting more than 90\% of available energy into electricity, making it the most efficient form of electricity generation. (Fossil fuel plants are only capable of generating 50\% of available energy into electricity as a comparison).\textsuperscript{17} These attractive qualities have led the US to invest in hydropower within the energy sector.

This continuing investment has made the US the fourth largest hydropower nation in the world (behind China, Brazil, and Canada) with the seventh largest PHES pipeline.\textsuperscript{18} At the end of 2015, the US hydropower generation fleet included 2,198 active power plants with a total capacity of 79.6 GW and 42 pumped-storage hydropower (PHES) plants totaling 21.6 GW, for a total installed capacity of 101 GW.\textsuperscript{19} This compounds into a generation share of hydropower at 7\% in 2017, with the US Energy Information Administration expecting similar, or slightly higher, generation shares in the next few years.\textsuperscript{20} This percentage is comparably small within the energy sector as the US largely depends on natural gas, coal, and other nonhydropower renewables for the majority of their electricity dependence.\textsuperscript{21} However, the size and influence of hydropower in the US energy sector can be best assessed by looking at US dependence on pumped hydroelectric energy storage, which comprised the vast majority (97\%) of all utility-scale electricity storage in the United States at the end of 2015.\textsuperscript{22} In 2018, hydropower is the leading renewable energy source for the US, contributing approximately 85\% of the nation’s total renewable electricity generation.\textsuperscript{23}
Despite the reliance on hydroelectric power and its inclusion in conventional energy development policy, progress in the hydroelectric sector remained largely dormant in the US during the 1990s. Policy restraints created by inefficiencies and concerns surrounding hydroelectric dam industrialization stagnated major progress in this portion of the energy sector.\textsuperscript{24} Despite their clean energy generation and storage benefits, dams used for hydroelectric energy have historically displaced people, significantly exceeded initial cost projections, accelerated some negative ecological impacts, and sometimes failed to deliver on predicted benefits in terms of electricity production, irrigation, and flood control.\textsuperscript{25} Once a hydroelectric dam is built, operating costs remain constant and typically result in long operational lives;\textsuperscript{26} however, up-front costs are very high and many existing hydropower facilities fail to maximize their full energy-producing capacity.\textsuperscript{27} Thus, although hydropower is still the main contributor to grid stability and utility-scale electricity storage in the US, PHES development has remained slow over the past few decades.\textsuperscript{28} These negative implications have led to reliance on other sources of energy as the main contributors to the total percentage of energy production and consumption in the US.\textsuperscript{29}

In recent years, however, pressure to pursue clean energy to reduce carbon levels has revived US commercial interest in developing PHES facilities.\textsuperscript{30} Over the past 65 years (1950–2015), hydropower has provided a cumulative 85% of US renewable power generation, making it the first sector the US is scouting to increase reliance on renewable energy and reduce carbon emissions.\textsuperscript{31} The Affordable Clean Energy (ACE) Rule, as proposed by the US Environmental Protection Agency, seeks to establish guidelines for states to address greenhouse gas emissions and has proposed hydropower as the primary renewable source of power.\textsuperscript{32} With national interest to pursue renewable energy in mind, the Office of Energy Efficiency and Renewable Energy (EERE) projects that US hydropower could grow from 101 gigawatts (GW) of capacity in 2015 to nearly 150 GW by 2050.\textsuperscript{33} If this amount of GW increase is achieved, $209 billion in savings from avoided global damages from greenhouse gas emissions is possible, including $185 billion from continuing to operate the existing hydropower fleet. Complete in this vision of hydropower-fueled renewable energy is the capacity for 35 million average US homes to be powered by hydroelectric facilities by 2050.\textsuperscript{34} Further progress could be made as hydropower is used to meet grid flexibility needs and support increased integration of variable generation sources. Overall, the EERE recommends capturing the great potential of hydropower to help the US reach its goal of reducing carbon emissions and embracing clean energy.\textsuperscript{35}

To achieve this potential, the EERE first suggests the value of existing hydropower facilities as low-cost, low-carbon options for renewable energy with flexible grid support services. EERE recognizes that if the use of the existing hydropower infrastructure is optimized to generate economically and environmentally sustainable growth, hydropower has significant near-term potential to increase its contribution to the nation’s goal regarding clean energy.\textsuperscript{36} To make a long-term contribution, however, potential sites that are not yet developed will need to be strategically added to the current infrastructure in a way that maximizes innovative technologies to address environmental impacts and economic constraints.\textsuperscript{37} The 300 experts from over 150 organizations tasked to assess the future potential of hydropower power in the US concur that it will be unlikely to develop effective hydropower further than the predicted amount listed above without transformational, significant innovation in technology designed to lower costs.\textsuperscript{38}
However, even to reach the lofty economic and environmental long-term potential of hydropower in the US, there is a major assumption that the volume of water necessary to power the current and new infrastructure recommended will remain unaffected by climate change. In a report largely dedicated to highlighting the positive potential hydropower has on influencing the US energy sector, experts in the Water Power Technologies Office within the EERE recognize the vulnerabilities hydropower faces when confronted by climate change:

Climate change creates uncertainty around water availability for hydropower generation, and this uncertainty can affect the long-term outlook of the hydropower industry. Water availability—including more water in some areas and less in others—affects the energy production potential of hydropower resources, which in turn influences their economic attractiveness in the electric sector. A changing climate may also potentially impact water quality (e.g., temperature) and availability of water for thermal power plant cooling, while changing temperatures may impact electricity demand.39

Despite this recognition that the long-term outlook of the hydropower industry may be threatened by water scarcity/volatility created by climate change, vulnerabilities in hydropower are largely unexplored due to the uncertainty and political contention surrounding climate change and the attractive potential hydropower has as a renewable resource.40 Many plans for expanding hydropower facilities fail to factor in climate change when creating assessments and the US government is currently promoting expansion projects despite climate change concerns that have been raised.41 Currently, the House Committee on Natural Resources is focused on expanding hydropower independent of potential climate impacts: “Republicans in Congress support expanding the use of hydropower and it is an essential part of an all-of-the-above energy approach to improve the environment and to meet our country’s energy needs.”42 The committee is working to make all hydropower recognized as a renewable source by any legal standard established by the federal government. In June 2018, House Natural Resource Committee Chairman Rob Bishop issued a statement following the passage of the 2019 Energy and Water Development and Related Agencies Appropriations bill, designed to “assist bolstering hydropower markets and promoting stable, affordable energy for millions of Americans.”43 This bill, among other hydropower promoting projects, is projected to be finalized in 2019.44 If US policy follows the current trend, it can be expected that hydropower will expand and US dependence on hydropower will grow, making the threat climate change will pose to hydroelectric energy even more relevant.

Climate change, in conjunction with the anticipated expansion of future human populations, is likely to increase regional and global fresh water scarcity considerably.45 With water as a critical resource for most electric power generation technologies, there are a growing number of vulnerabilities in the energy sector as thermal power plants typically require a large amount of cooling water.46 In addition to using water as the primary resource to produce energy, hydropower plants also experience evaporative water loss from the large surface areas of the storing reservoirs.47 This could prove especially problematic as water stress and scarcity is expected to rise due to rising temperatures fueled by climate change. The exact implications are unclear as a complex geography of water use and supply makes the future accessibility of water
resources difficult to determine. However, climate models, water budgets, and socioeconomic information along river networks all suggest that rising water demands will outweigh concerns of atmospheric warming in defining the state of global water systems through 2025.

A significant proportion of the world’s population is already experiencing water stress, a phenomenon that will worsen as future population growth increases the pressure on available resources. According to the Western Climate Initiative (WCI), there are an expected 1.6 billion people estimated to be currently living within watersheds exposed to water scarcity with an additional 0.5 to 3.1 billion people worldwide expected to be exposed to an increase in water scarcity due to climate change by 2050. Other environmental specialists project that planetary warming of 2°C above present temperatures will result in an additional 15% of the global population experiencing a severe decrease in water resources. Likewise, this projection of atmospheric warming will increase the number of people living under absolute water scarcity (<500 m3 per capita per year) by another 40% (according to some models, more than 100%) compared with the effect of population growth alone. On a national level, rising air and water temperatures and changes in precipitation are intensifying droughts, increasing heavy downpours, reducing snowpack, and causing declines in surface water quality, with varying impacts across US regions.

The Fourth National Climate Assessment, published by the US Global Change Research Program in 2018, assesses that expected future warming will add to the stress on water supplies and adversely impact the availability of water in parts of the US. Climate change is expected to increase groundwater depletion, changes in relative amounts and timing of snow and rainfall, rising sea levels, and temperature increases in the US. Although these patterns put many parts of the US at risk for groundwater depletion, drought, flooding, saltwater contamination, and dependable safe water supply, the southwest and northwest regions of the country are particularly at risk for the future reliability of hydropower production. Changes in the timing and quantity of snow and rainfall, severe drought, and extreme weather conditions are all expected to persist in the future and will negatively affect US hydropower production, especially if the predicted level of dependence on hydropower as a source for electricity is achieved.

Increasing temperatures and decreasing water availability attributed mainly to climate change are expected to affect US power plants which rely on a steady supply of water for cooling and hydropower dams that rely on effective water storage. In recent years, increased temperatures, especially the earlier occurrence of spring warmth, have significantly altered the water cycle in the US southwest and northwest. These changes include decreases in snowpack and its water content, earlier peak of snow-fed streamflow, and rises in the proportion of rain to snow. This record-low snowpack has resulted in water scarcity and large wildfires that, in addition to negatively affecting farmers, drinking water, air quality, fish populations, and recreation, has harmed the steady source of water that hydropower relies on to maximize efficiency across the western US. Furthermore, this variability in run-off from snow and water availability is likely to persist in the northwest and southwest and could expand to other segments of the energy sector. Rising temperatures could reduce total energy efficiency up to 15% across the southwest US by 2050, because “the efficiency of all water-cooled electric power plants that burn fuel depends on the temperature of the external cooling water.”
There is an increased regional risk of droughts also caused by these rising temperatures. For example, in the winter of 2014-2015, above freezing temperatures led to the lowest snowpack in California on record. This may have accounted for one-tenth to one-fifth of the reduced soil moisture during the recent California drought. Lower runoff caused by higher temperatures in the ongoing Colorado River Basin drought led to 17%–50% of the record-setting streamflow reductions between 2000 and 2014. With continued greenhouse gas emissions, higher temperatures could cause more frequent and severe droughts in the southwest and lead to drier future conditions for the region. From 2011 to 2015, hydroelectric generation was reduced by two-thirds because of the severe drought in California which was intensified by climate change. As droughts increase in the US, political and industry leadership should expect similar reductions in hydroelectric generation capacity.

Climate change is also driving a rising number of severe weather events that present challenges for hydroelectric power to reach its greatest capacity. Existing energy and water infrastructure already face challenges from heat waves, drought, wildfires, landslides, and flooding. Volatile conditions produced by climate change are projected to increase the risks to critical infrastructure from many extreme weather events. Hydropower could potentially be compromised in pockets of these regions where dependence on hydropower is high and preparation against random weather events is not emphasized. The risk of severe weather on hydropower has been evident in the severe flooding of California caused by the increase in severity and frequency of atmospheric rivers under climate change—channels in the atmosphere that carry water vapor from the tropics to other regions. In the winter of 2016–2017, a series of strong atmospheric rivers generated high runoff in northern California and filled reservoirs. However, at Oroville Dam, unexpectedly high flows eroded the structurally flawed emergency spillway, caused costly damage, and led to the preventive evacuation of people living downstream. In addition to the immediate threat to human life and property, this incident revealed that deteriorating dams, spillways, and other infrastructure require substantial maintenance and repair. This is a costly implication tied to much of the existing hydropower infrastructure in the US that should be considered when planning for infrastructure expansion.

Overall, variability in mountain snowpack runoff, severe drought, changes in evaporation, and severe weather is projected to significantly reduce hydropower production. According to some estimates, for vulnerable power stations, climate change may reduce average summertime generating capacity by 1.1–3.0%, with reductions of up to 7.2–8.8% under a ten-year drought. These estimations do not account for future hydropower expansion, nor do they account for water supply in the hydroelectric sector being used for other purposes in response to water scarcity such as water table support. Aside from detrimental economic implications, these reductions are problematic to US energy security because the national infrastructure is closely linked to hydropower success. On a national level, one of the largest vulnerabilities posed by climate change to the hydropower industry is the nature of hydropower power generation resources to be spread unevenly across North America. While hydropower accounts for a negligible portion of power generation in some portions of the US, other regions like the Pacific Northwest generate a significant amount of their electricity from hydropower. This means that the regions that rely heavily on hydropower to generate electricity are also the regions that are most vulnerable to water scarcity and other climate change-induced risks. As the ability to
produce hydroelectric energy relies on the very hydropower storage that is declining due to water scarcity, regional pockets of the US may start to face extreme energy challenges. Additionally, if the electric grid becomes compromised due to a severe weather event or a foreign cyberattack and the hydroelectric system is not prepared to navigate growing climate challenges, US dependence on hydropower storage energy will result in a threateningly slow recovery time.

In addressing the current vulnerabilities present in the hydroelectric sector, and in defending against future threats posed by climate change and the expected increased dependence on hydroelectric energy, it is important to note that drastic action to cut reliance on the hydroelectric industry would prove detrimental. More practical recommendations currently being explored by the EERE and Congress would focus on reducing carbon emissions and attacking the source of the largest threat hydropower faces in the form of water scarcity and climate change. Whatever the policy directions pursued, it is not in the best interests of the US to ignore the growing implications climate change poses to hydroelectric energy, to fail to account for these implications when planning the future of hydroelectric energy, and to neglect making conscious preparations to defend against the future threats of climate change against hydroelectric power and the larger energy sector. To successfully solve current and future vulnerabilities within US hydro-electric infrastructure, the US could account for climate impacts while planning water management and expansion strategies, focus on conserving water to protect water supply, and consider other forms of renewable energy that are not affected by water availability.

The recent resurgence of hydroelectric dams, spurred by their promise of clean energy, has inspired a surge in funding for sustainable development initiatives but may hold unforeseen negative consequences for particular issues that are marginalized within the climate change discussion (or may actually run counter to climate change concerns). This pattern is evident when presenting plans to further hydroelectric development in the US. At present, power providers do not account for climate impacts in their development plans, meaning that they could be overestimating their ability to meet future electricity needs. If power providers were required to account for climate impacts when assessing future development opportunities, a more accurate projection of hydropower’s capacity to assist the US energy sector could be provided. Additionally, the nature of planning water management and expansion strategies may change when climate change is factored in. For example, the intensifying droughts and occasional large floods exacerbated by climate change in combination with critical water demands from a growing population, deteriorating infrastructure, and groundwater depletion suggest the need for flexible water management techniques that address changing risks over time. Strategic planning could help balance the expected declining supplies of water with greater demands.

Although water management strategies that account for changing climate conditions can help reduce present and future risks to water security, the implementation of such practices remains limited mainly due to an imbalance of attention on implications. Those groups that are promoting an increase in hydroelectric power are hyper-focused on all the positive implications hydropower could have on the US economy and “clean energy” policy. They are not wrong to recognize this potential, nor is promotion of hydropower inherently detrimental. One key element proposed by the EERE is to maximize the energy-wielding and producing capacity of the
US hydroelectric sector. This could be a cost-efficient way to expand energy production, rely more on the renewable resource capabilities already present in US infrastructure, and meet some goals in combatting climate change. However, expanding the hydroelectric energy sector by investing in infrastructure development as currently proposed by the EERE and congressional committees could prove costly, inefficient, and ultimately detrimental to both the environment and the economy. If experts wait to expand infrastructure until there is a better understanding and prediction of how climate change will affect water scarcity in direct relation to hydropower capabilities, the US could avoid investing in a sector whose potential may decrease in response to climate change. The US should encourage and fund research to reach these accurate predictions, better understand climate change to combat water scarcity, and maximize energy generation by other renewable sources (solar or wind). Although other renewables may not have the same storage capabilities of hydroelectric power, their future potential may be less affected by accelerating climate change. The US could also explore the potential for stationary energy storage batteries that would fill the role of hydro-powered storage. If hydroelectric power is expanded independent of consideration of the negative implications, a greater focus on water conservation could help prepare against water scarcity.

To ensure that the existing vulnerabilities of hydropower are considered and accounted for through the methods listed above, a collaborative effort will be necessary across multiple US institutions, with a possible expansion of effort to state and local governments to provide a stronger defense against the negative implications of climate change. Currently, Congressional planning to expand renewable energy sources is relying on energy production reports devoid of an in-depth assessment of climate change implications. To remedy this, Congress can work with the Department of Energy to draw on timely and accurate predictions of climate change in direct relation to considerations involving hydropower infrastructure. Congress could also consider crafting new legislation that would require energy providers to build environmental defense mechanisms into their growing hydropower infrastructure, incorporate greater flexibility to meet changes in water availability, and craft reports assessing the impact climate change may have on their current and future infrastructure stability. The administration can help guide this effort by directing key members of the cabinet, especially the heads of the Department of Energy, Department of the Interior, and the Department of Homeland Security to direct resources and staffing toward accurately predicting, defending, and reacting to threats to the energy sector posed by increased variability in climate change. These efforts can work to define the balance of maximizing current hydropower infrastructure, focusing on expanding the ability for hydropower storage capabilities (rather than electricity-generating capabilities), and research areas that could improve US current ability to combat vulnerabilities in the hydroelectric sector. It would also be a worthwhile investment for these teams, especially members of FEMA within the Department of Homeland security, to articulate action plans in the event of a national emergency in the western regions of the US. A deeper understanding of climate change, US expansion of hydroelectric power, and levels of regional dependence on hydropower could help mitigate the damages of future natural disasters—acute or chronic—within these regions.

In managing the current levels of hydropower dependence and in seeking solutions to potential negative implications of a shifting climate, the State Department may be called on to employ strategic climate diplomacy with the United States’ northern neighbor. A large portion of
the power currently imported to the US from Canada is hydro-generated.\textsuperscript{91} Hydropower from Quebec and Ontario is particularly important in serving northeastern US markets, while a transmission line delivers hydropower from Manitoba to the midwestern US, with minimal contact with the rest of the Canadian grid along the way.\textsuperscript{92} Climate change may create tension surrounding current US-Canadian trade of hydropower and stall potential progress in this area. The State Department could be proactive in taking on these looming challenges by bolstering a strategic relationship with Canada to include using Canadian resources in assessing and defending against vulnerabilities facing the hydropower supply in response to climate change on both sides of the northern border.

Although a national effort will prove essential in the long term, immediate defense against climate threats can be, and have been, handled at a local level. Many state and local governments have already issued climate change assessments and action plans. In response to California droughts, the state government was able to reduce water use by 25\% from 2014 to 2017.\textsuperscript{93} The Southern Nevada Water Authority used similar measures to reduce water use per person 38\% from 2002 to 2016 and the Colorado Front Range reduced water use more than 20\% in the early 2000s.\textsuperscript{94} Other local action includes voluntary water conservation and management, restoring cultural fire management, rooftop solar policies, and exploration of water diversion and desalination techniques to combat water scarcity across California, Nevada, Utah, and Colorado.\textsuperscript{95} In addition to relying on state climate change assessments and action plans as a starting point in crafting policy, the national government could assist state water resource planners and scientists in their efforts to test new techniques to combine results from climate and hydrology models, downscale climate model output to finer geographic scales, calculate changing water demands, and accurately forecast flood control.\textsuperscript{96} Gaps in the ability to integrate data from satellites, climate and hydrology models, and field observations that may prove essential in crafting the necessary assessments could be funded by Congressional committees and overseen by the Department of Energy or the Department of the Interior.\textsuperscript{97}

As the national government works in close collaboration with state and local efforts, it may be possible to curtail the vulnerabilities that currently exist in the critical infrastructure of hydropower and defend against negative implications of climate change. While these efforts will help minimize threat exposure in the hydroelectric energy sector, severe weather driven by climate change has the potential to disrupt other critical infrastructures (such as transportation, energy, and water) and threaten multiple arenas of national security.\textsuperscript{98} The volatile and growing nature of climate change makes it impossible to fully defend against, or even recognize, all its potential threats to US security. Even as the US pours resources into defending against a segment of the perceived threats posed by climate change, other vulnerabilities may be left in blind spots of unforeseen consequences and misunderstood implications. In some cases, the US may accurately predict a threat posed by climate change but may not have enough time or resources to defend entirely against it. In addition to a focused approach to specific threats posed by climate change, such as vulnerabilities in the hydroelectric energy sector, the US needs to build up general resilience in its preparation against climate change threats. Many of the research and assessment recommendations outlined in this report can give US institutions a better understanding of the environment they, in unison with state governments, will navigate in combatting climate change implications for US national security.
Endnotes


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