ADAPTING HYDROPOWER OPERATIONS TO SUPPORT RENEWABLE ENERGY TRANSITIONS AND FRESHWATER SUSTAINABILITY

HOW DOES SUSTAINABLE INFRASTRUCTURE LIKE HYDROELECTRIC POWER PLANTS AND THEIR OPERATION IMPACT UNDERREPRESENTED COMMUNITIES?

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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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INTRODUCTION

Meeting global carbon mitigation targets will require a rapid transition to more renewable energy sources, but doing so will make our energy supply more variable and out-of-phase with demand. One approach to balancing supply and demand is to use existing hydropower and pumped storage facilities, which can reduce needed investments in developing battery storage technologies by pumping water back up to a reservoir at night to prepare for peak power demands (USGS, 2018). Hydroelectric power plants are an example of sustainable infrastructure, which refers to "the designing, building, and operating of structural elements in ways that do not diminish the social, economic, and ecological processes required to maintain human equity, diversity, and the functionality of natural systems." (Sustainable Infrastructure | CRC Research. (n.d.)). However, adapting hydropower operations for greater load balancing could come at the expense of sustaining environmental flows for wildlife and ensuring sufficient water supply and flood protection (Rahman, Baseer, & Rehman, 2015).

As part of the Department of Energy's Hydropower Collegiate Competition (2022), the capstone team's technical project seeks to find how the operations of hydropower systems can be adapted to complement the decarbonization of the electricity sector while mitigating the impacts of floods, droughts, and regulated flows on freshwater sustainability. The team will design reservoir operating rules to balance conflicting economic and ecological objectives to derive a hydropower-based solution that enables 100% clean energy within a defined region. This project will focus on the Columbia River Basin (CRB) in the Pacific Northwest and explore how alternative hydropower operations (specifically the Grand Coulee Dam) could balance increasing supply intermittency from the penetration of renewables throughout the West Coast while mitigating impacts on flood control and freshwater sustainability for salmon.

There are stakeholders involved in every facet of this problem – the public sector, the private sector, and citizens, to name a few – and they are oftentimes in conflict with each other. The multi-objective optimization solution can guide the discussion between actors like power companies that want to maximize hydropower production and eco-advocacy groups that push back for increased salmon protection (via spillways or fish ladders). Unlike the groups with prominent voices in the discussion behind infrastructure development, there will be groups that are inadvertently and disproportionately impacted. The analysis of hydroelectric power plants as sustainable infrastructure will be conducted using the ethnographic framework described by Star and Ruhleder (1999), which explains that infrastructure appears as a relational property that differs in meaning for different groups of people. Thus, as we adapt hydropower operations to support renewable energy transitions and freshwater sustainability, it is crucial to investigate the social and human connections as well, especially regarding how they impact underrepresented communities.

CAPOW: A MODELING FRAMEWORK FOR BULK POWER SYSTEMS

In recent years, interest has grown in exploring the effects of hydrometeorological variability on the operations of bulk power systems. Hydrometeorological processes such as droughts, floods, air temperatures, wind speeds, and solar irradiance have direct impacts on the supply and demand of electricity, and consequently on pollution, electricity prices, and the financial standing of electricity suppliers and consumers (Hill et al., 2021). Previous investigations have fallen short in their assessments, due to either limited testing or context. Bulk power systems span areas so large that models need system topologies that allow extension beyond a single watershed, state, and region. Hydrometeorological uncertainty and power system risks can also manifest on different time scales, with hydrometeorological conditions that have durations on the order of days up to years, and power system modeling that requires an hourly or sub-hourly time step (Su et al., 2020). Few (if any) models capable of performing analysis on the scale necessary are publicly available. The California and West Coast Power (CAPOW) systems model is a generalizable and open-source framework for simulating the influence of correlated hydrometeorological processes on power system dynamics at decision-relevant scales (see Figure 1). It is comprehensive in its treatment of stochastic weather and streamflow, simulation of relevant infrastructures like reservoir networks and power systems, and evaluation of outcomes such as system costs, prices, etc. (Su et al., 2020).

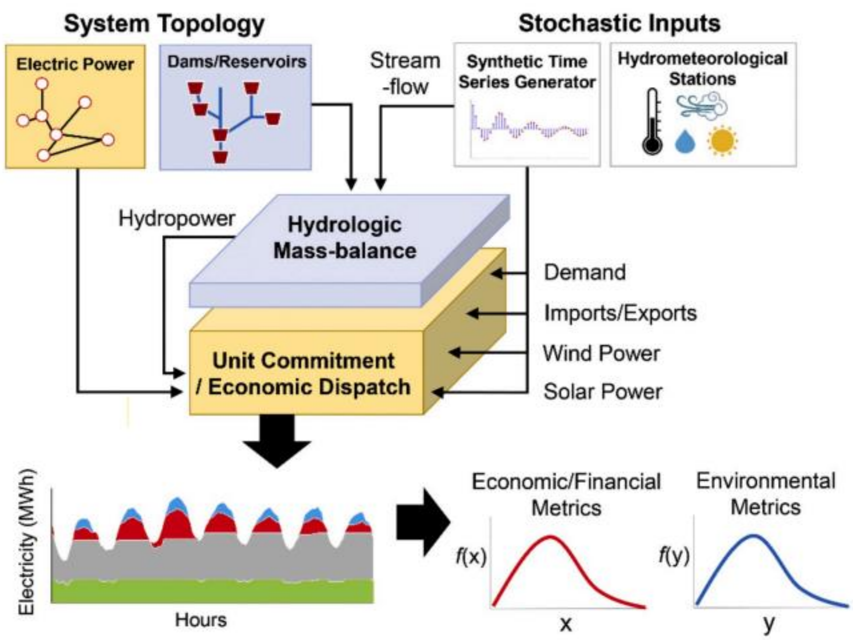

Figure 1: CAPOW model workflow. First, define topologies of relevant electric power and surface water infrastructure, then use synthetic time series inputs to drive the stochastic simulation of a power system (UC/ED) model. Model outputs include the least cost generation schedule, total system costs, estimated wholesale prices, and emissions. (Image source: Su *et al*., 2020)

The capstone team will refine and improve the CAPOW model for pumped storage, a method of keeping water in reserve for peak period power demands by pumping water that has already flowed through the turbines back up to a storage reservoir during a time when energy demand is low. The reservoir acts like a battery, storing power in the form of water, which allows generating units to start up and make output adjustments quickly ("Hydroelectric Power: How It Works | U.S. Geological Survey," 2018). The existing model and workflow provide the foundation for the optimization. This project further utilizes reservoir simulation and water level models (see Figure 2). The project also uses direct policy search, which is a solution to the limitations that traditional optimization methods have with the type and scale of problems they can solve (Quinn et al., 2017).

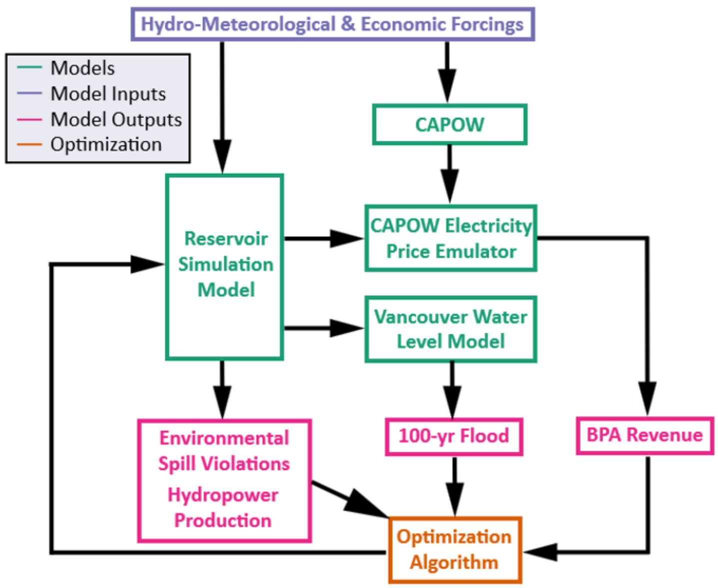

Figure 2: Flow diagram of the models, inputs, outputs, and optimization process. Hydro-meteorological and economic forcings are inputs for the CAPOW, Reservoir Simulation, CAPOW Electricity Price Emulator, and Vancouver Water Level models. The parameters for each of the objectives (environmental spill violations, hydropower production, 100-year flood protection, and Bonneville Power Administration (BPA) revenue) are run through the optimization algorithm. (Image source: Quinn, 2022)

However, adapting hydropower operations for greater load balancing by adding pumped storage could come at the expense of sustaining environmental flows for wildlife and ensuring sufficient water supply and flood protection. Just as reducing downstream water flow can cause a loss of habitat and reduce available water supply, creating reservoirs for pumped storage hydropower systems often cause upstream flooding that destroys wildlife habitats and agricultural land (Environmental Impacts of Hydropower | EnergySage. (n.d.)). Hydroelectric power plant operation has hydro-ecological effects that disproportionately impact native tribes in the area. These communities suffered a loss of salmon populations, flooding, and displacement. Pumped storage in the Grand Coulee Dam needs to be factored into the reservoir simulation model to accurately evaluate the extent of these impacts.

THE ETHNOGRAPHY OF INFRASTRUCTURE

Infrastructure, by definition, is the basic physical and organizational structure needed for the operation of a country, city, or area (Masterclass, 2022). Hydroelectric power plants are designed and operated with the goal of not diminishing social, economic, or ecological processes. Of course, it is not as simple in application as may be in theory, as the functionalities of the natural, built, and social environment are interconnected in ways that make it extremely difficult to appease all actors involved. According to “Ethnography of Infrastructure,” by Star and Ruhleder (1999), infrastructure appears as a relational property, as it differs in meaning to different groups of people. For example, the construction of the Grand Coulee Dam blocked spawning salmon from the upper Columbia River, which drastically changed the fish-based culture of the native peoples in the area (“Grand Coulee Dam Construction History | Bureau of Reclamation,” 2021). However, many others, like the workers, contractors, and government bodies, are supported by the economy of the Grand Coulee Dam area, which is dependent on the dam for its power and irrigation. The nine properties of infrastructure defined by Star are: embeddedness, transparency, reach or scope, learned as part of membership, links with conventions of practice, embodiment of standards, built on an installed base, becomes visible upon breakdown, is fixed in modular increments (Star, 1999).

In this case, the Grand Coulee Dam can be best investigated using "embeddedness", "reach or scope", and "built on an installed base". Infrastructure is sunk into and embedded inside other structures, social arrangements, and technologies, with people seldom distinguishing the coordinated components of the infrastructure (Star, 1999). The dam's facilities are embedded in the power grid and irrigation systems. The sheer size of the dam means that the builders, operators, managers, and/or citizens only see what they are directly interacting with. The reach or scope of the infrastructure can be spatial or temporal, extending beyond a single event or one-site practice. As the largest hydropower producer in the United States, the Grand Coulee Dam supplies electricity to 8 western states (Bureau of Reclamation, 2021). Lastly, the nature of infrastructure means that it inherits the strengths and limitations of the existing installed base it is built upon or within (Star, 1999). The concrete dam was modeled after the path nature took during the last Ice Age over 13,000 years ago. The Cordilleran Ice Sheet blocked the Columbia River where the dam sits today, diverting the Columbia River to cut a new channel that would then become a huge canyon. This canyon is where the Grand Coulee Dam pumps water for irrigation today ("Grand Coulee Dam FAQ | Bureau of Reclamation," 2021). Since its completion in 1942, the Grand Coulee Dam has undergone several additions, including a pump-generating plant, another power plant, and another dam ("Grand Coulee Dam: History and Purpose," n.d.).

RESEARCH QUESTION AND METHODS

To investigate how sustainable infrastructure like hydroelectric power plants and their operation impact underrepresented communities, data will be collected for a case study analysis of the Grand Coulee Dam and the native tribes in the surrounding area. The analysis of the dam using the ethnographic framework considers how decisions made regarding economic, environmental, and institutional metrics excluded underrepresented communities like the native tribes or disproportionately impacted them. This work will facilitate the ethnographic analysis by providing evidence of the properties of the dam, as well as how they mesh with different social groups. Social impacts must be measured, especially because they are consequential to the effects of dam operations like environmental flows, flooding, and economic growth. To collect data, counts of events will be taken down, detailing every instance in which the effects of hydropower operation caused a displacement or disruption of the native communities in the Upper Columbia River area. Secondary sources are abundant for the construction history of the Grand Coulee Dam, so prior literature, policy documents, and agency reports should provide sufficient supplementary evidence. In addition to the descriptive case study analysis, an evaluative analysis can be done based on sustainability and environmental justice.

The methodology of conducting a case study analysis begins with establishing the broad case to investigate (Davies, 2011). Access to published information about the cultural and construction history of the Grand Coulee Dam is available through the Bureau of Reclamation, the federal department put in charge of the construction project in the 1930s ("Bureau of Reclamation," 2022). After establishing the research question, select cases that represent a variety of impacts will be studied. The parameters of this research will be which tribes were displaced and by what – flooding of their land or burial grounds, disruption of salmon passage, purchase of land by the federal government, etc. To organize evidence systematically, the records will be kept in chronological order. The data will be checked for discrepancies and tabulated for the frequency of events to allow for the evaluative analysis. The evaluative analysis will serve as another lens to investigate the extent of impacts caused by the dam, especially regarding the treatment and involvement of all people in the development, implementation, and enforcement of environmental laws, regulations, and policies ("What Is Environmental Justice?," n.d.).

CONCLUSION

The construction and operation of sustainable infrastructure like hydroelectric power plants have significant and fast-acting effects on its surroundings ("Grand Coulee Dam Facts," 2011). This extends beyond other infrastructure and physical systems, including landscapes, ecosystems, population demographics, and socio-economic arrangements. The Columbia River Treaty, a transboundary water treaty between U.S. and Canada, is up for renegotiation in 2024 (Shrestha, 2021). The technical deliverable will provide an optimized recommendation for operation that balances conflicting objectives like the maximization of hydropower production and economic benefits, and the minimization of flood risks and environmental flow violations. The STS deliverable will be a case study analysis of the impacts of the Grand Coulee Dam on the surrounding native communities. This will bring awareness to the need for the implementation of environmental justice within federal, state, and local governments and operations. Ideally, this work will facilitate the design of more robust reservoir operating policies in the Columbia River Basin that will be able to balance socio-cultural objectives as well as the aforementioned parameters from the technical deliverable.

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