Energy Supply Readiness Across Climate Change and Energy Demand Scenarios in Columbia River Basin

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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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Optimization of Ten Reservoirs in Columbia River Basin

This technical report will talk about the optimization of ten reservoirs with the Columbia River Basin. The Columbia River Basin is a network of 1,243 miles of rivers running into the Pacific Ocean and provides electricity, water, navigation, habitats and other resources to the many people of the region. The system crosses over six US states (Washington, Oregon, Idaho, Montana, Nevada, and Wyoming) and two Canadian provinces (British Columbia and Alberta) with over 400 dams (NPCC, 2016). A system of this size affects a variety of people and wildlife, thus we must consider multiple objectives to optimize all functions. The multi-objective nature of this system creates a large degree of uncertainty due to the unknown impacts of climate change on the physical environment and more (IPCC, 2013).

The Columbia River Basin serves many functions for the people that live in the area, but our efforts will focus on certain areas. The basin contributes a large amount of electricity to many of its residents with its dams being considered the foundation of the Northwest's power supply (NPCC, 2016). The system is also used to help control flooding, where damming and the subsequent reservoirs created are used to store water due to the river's flow variations throughout the year. This storage of water is also used as a supply of drinking water. The basin is also home for many types of aquatic life that need to be protected, specifically the valuable salmon population (BPA, 2001). We also need to take into consideration how the system receives funding to run smoothly even though the economic aspects of the basin can be hard to predict . Important considerations in optimizing for this system include balancing private/public interest, indigenous lands, demographic and population shifts and climate change effects (Grizzetti et. al, 2016). Prioritizing these other demands could reduce hydropower production, creating cascading impacts on the energy system. These impacts include reducing generation from renewable energy, changing the price of electricity in the Pacific Northwest's Mid-Columbia energy market and the adjacent California Independent System Operator (CAISO) market. Changing climate conditions could also influence future hydropower production potential, causing cascading impacts on these energy systems.

One way of understanding these multi-sectoral impacts is through integrated water-energy system models such as the California and West Coast Power Systems (CAPOW) model. CAPOW uses stochastic simulation to generate possible temperature and streamflow time series that feed a reservoir operations model and unit commitment/economic dispatch model (UC/ED). The outputs of the UC/ED model include system costs and energy prices (Su et al, 2020). This paper uses CAPOW to analyze the potential benefits and consequences of alternative development pathways in the region under possible future climate scenarios for the years 2050-2059, representing a mid-century scenario for the CA and PNW region. These scenarios are represented by climate projections from the Coupled Model Intercomparison Project 5 (CMIP5) Representative Concentration Pathways (RCP) (Brekke et al, 2014), and population and energy growth scenarios informed by Shared Socioeconomic Pathways (SSP) (Riahi et al, 2017). This paper's research has focused on altering the CAPOW model to reflect scenarios combining a specific climate change and energy demand future and understanding the impact each potential scenario has on the basin. The goal is to understand how these two sets of scenarios interact in shaping future socioeconomic benefits and consequences in the region with the goal of informing regional energy development.

Modelling of the basin and its expected changes was achieved using the CAPOW systems model, sourced from https://github.com/samarthsing/CAPOW_Capstone, climate projection data sourced from CMIP5 RCPs, and energy demand frontiers sourced from SSPs.

The CAPOW framework was designed to simulate the operations of the West Coast power grid of the United States, where electric power is delivered to majority of the Columbia River Basin. There are two major markets for wholesale electricity on the West Coast, the Mid-Columbia (Mid-C) covering most of the Pacific Northwest (PNW), and the California Independent System Operator (CAISO). Mid-C corresponds directly to the Pacific Northwest (PNW), while the major utility company service areas in California correspond to five zones (CA) in CAISO. This is a unit commitment and economic dispatch (UC/ED) model, which finds the cost-minimizing dispatch of electric generators in CA and the Pacific Northwest to meet both system's energy demands, assuming all available solar and wind energy is first dispatched, and all reservoirs obey federal operating guidelines. Primary inputs are hourly electricity demand, wind and solar power production, and daily available hydropower production. For this project, the modified environmental parameters were wind speed, streamflow, ambient air temperature, supply of solar and wind power, and regional demand for electricity to represent nine possible future societal and climate scenarios. Each variable was changed with mathematical multipliers or delta shifts, showing the expected relative change in these inputs between the present year and 2050-2079.

The Representative Concentration Pathways (RCPs) are put forth by the IPCC Fifth Assessment Report from 2014 that describe potential climate scenarios by their respective radiative forcing value, a higher concentration of carbon dioxide means more forcing, a more radiation is absorbed by the Earth instead of radiated out into space. Possible socio-technical developments will alter emissions and reductions in carbon dioxide, so these RCPs can generally inform the expected temperature increase based on possible CO2 concentration. We feel the RCPs most relevant to the CRB system are 2.6, 4.5 and 8.5 for modelling. Scenario 3.4 is unfeasible due to the difficulty associated with removing greenhouses gases directly from the atmosphere. Similarly, the United States has resigned from the Paris Agreement as of 2016, so RCP 1.9 will not be analyzed as well. RCP 7 and 8.5 both act as the scenario to describe no reduction or mitigation strategies being taken, and will serve as the "worst case," as even though it is not as extreme in global temperature changes there, climate change is expected to have many negative effects on the CRB, so no remediation is the baseline "worst case." Therefore, we have three main scenarios, a low, middle, and high-end amount of greenhouse gas concentrations with their respective increases in temperature. To reflect these RCPs within CAPOW, multipliers and delta shifts were derived from requests on https://gdo-dcp.ucllnl.org/. Multipliers and delta shifts were computed by finding the quotient or difference between the average (and for some variables, standard deviation) of climatic variables over the time period 2050-2079 and the period 1990-2019. The final results yielded multipliers on the mean and standard deviation of streamflow in the CRB, an expected additive shift in temperature change for the region, as well as a multiplier for annual temperature standard deviation. Streamflow projections were utilized instead of precipitation to more directly model the volume flowing through CRB reservoirs.

Energy supply and demand scenarios are informed by the Shared Socioeconomic Pathways (SSP) database, including 5 SSP scenarios. SSP's are a "set of baselines, with future developments in absence of new climate policies beyond those in place today" (Erying, et al, 2018). These qualitatively summarize different scenarios in societal developments from which changes in emissions and therefore temperature can be drawn. There are 35 combinations of SSP and RCP that can quantitatively project the temperature increase and degree of climate change. Some configurations of SSP and RCP are unlikely to occur and will not be considered when finding inputs for our model. This study will focus on SSP5, SSP3, and SSP1 for these simulations since they represent the overall best, worst, and average scenarios. Collectively, this creates nine major possible future conditions to gather projections from for which the CAPOW model will simulate, summarized in the matrix in Appendix A.

For the analysis of our results, we started with the investigation of the RCPs and SSPs among the energy prices for the future. Appendix B shows the average energy price on each calendar day of the 10-year simulation for the state of California and Appendix C shows the same for the Pacific Northwest according to the different combinations of RCPs and SSPs. The RCPs among various pathways show little impact on the price, while the SSPs have a significant impact. SSP1 is considered as a sustainable approach for the future and the price effects on energy are more cost effective per megawatt hour compared to the other SSPs. SSP2 is the middle ground pathway and the prices for energy are found to be closer in line with SSP5 but slightly lower. While SSP5 is considered the path with continued heavy reliance on fossil fuels, this pathway has the most expensive prices for energy usage. The appendices also show the price seasonality changes among the SSPs. Both region of California and Pacific Northwest have similar trends in the seasonality price changes. In SSP1, prices begin rising in August, while in SSP2 and SSP5 they start rising in June. Under SSP5, some of the highest prices occur in the summer, when they are highest in the winter for SSP1 and SSP2. SSP5 also shows more variance in prices from June to September, regardless of the associated RCP. While one might hypothesize that this is because higher and more variable summer temperatures lead to cooling demands exceeding heating demands, this effect should be captured by the RCPs not the SSPs. Further investigation would be needed to understand this response, but design implications could include a need to adapt hydropower operations to store more water for the drier summer to meet rising summer demands, allowing for lower prices.

We also looked into changes within energy production in both regions. Appendix D shows average daily generation from fossil fuels in each region and SSP and RCP combinations. In general, the research found that the PNW region generates less electricity using fossil fuel generators than the CA region. Sources include natural gas, oil, and imports from fossil fuel generators across regions. As population increases from SSP1 to SSP5, demand for electricity and thus power generated from these sources also increases. Within a given SSP, fossil fuel generation across the three RCPs does not vary significantly in either region, at least for this projected decade of 2050-2059. The results from price fluctuations and fossil fuel generation show that the model is less sensitive to climate change than expected.

Appendix E shows the sum of daily generation from hydro, solar and wind power across the two regions in the simulated decade. Note the range on the y axis differs across SSPs, with SSP1 generating about twice as much from renewables as SSP2 and SSP5. All SSPs primarily increase their production from wind power, with the role of hydropower as baseload becoming less crucial in SSP1. Even in the most pessimistic SSP5, the total energy generation from renewables exceeds that of fossil fuels, showing that renewable energy has the potential to remain the dominating producer in the region regardless of population change. Once again, the climate scenarios are less influential, with no noticeable differences in renewable generation across RCPs.

Energy demand projections from population growth and energy supply projections in both renewables and fossil fuel sources have shown to be more impactful on energy prices and generation in CAPOW than climate projections. Certain values in price per MWh and total MWh generated show little variation across the RCPs, while energy prices and generation increase as socioeconomic conditions move towards more unsustainable development. However, because we only considered a short segment of time, it is important to consider that climate change scenarios may be more important later in the century despite seeming insignificant in this research. The future energy production also shows that regional reliance on hydroelectric energy may diminish over time as wind produced energy, and to a lesser extent solar, become more prevalent. The pricing for energy usage for California and the Pacific Northwest has shown that regardless of climate change scenarios, the SSPs have a larger impact on the cost than RCPs. Future work that can be completed are direct policy research to look into optimizing reservoir operations by looking at policies being used within the basin and further investigating the SSP and RCPs combinations since not all of the combinations were looked into for this project.

Appendices

Appendix A
Table Mapping RCP and SSP Combinations for Use

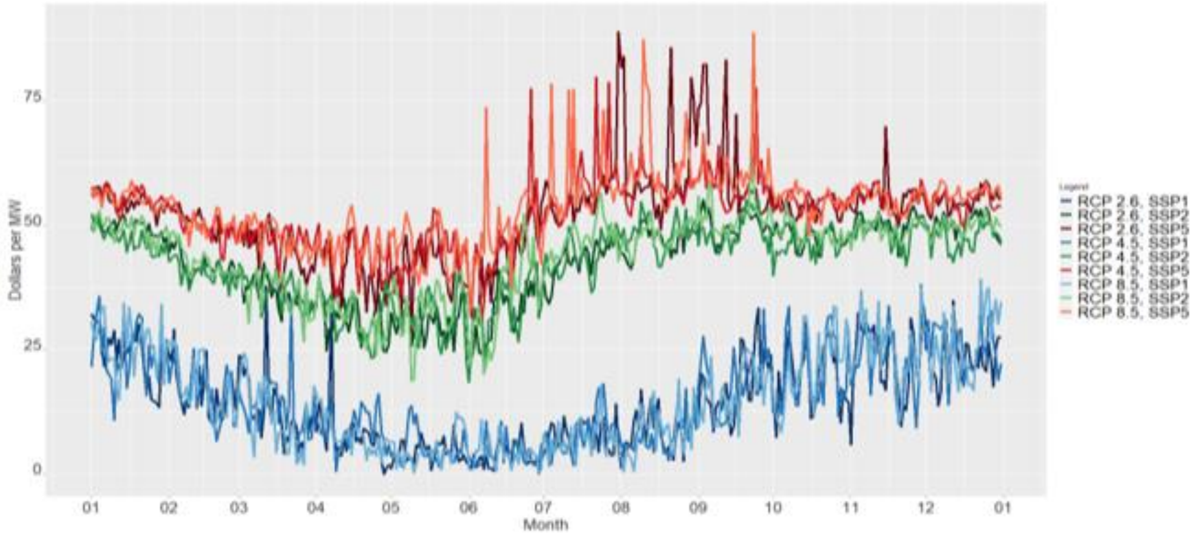
	Energy Scenario

Climate Scenario		SSP1	SSP2	SSP3	SSP4	SSP5
	RCP 1.9	🟥	🟥	🟥	🟥	🟥
	RCP 2.6	🟩	🟩	🟩	🟩	🟩
	RCP 3.4	🟥	🟥	🟥	🟥	🟥
	RCP 4.5	🟩	🟩	🟨	🟩	🟨
	RCP 6	🟨	🟨	🟨	🟨	🟨
	RCP 7	🟥	🟥	🟥	🟥	🟥
	RCP 8.5	🟩	🟩	🟩	🟩	🟩

Key: 🟩 Combinations for Use
🟨 Combinations for Use Conditional on Time/Complexity
🟥 Combinations Not Considered

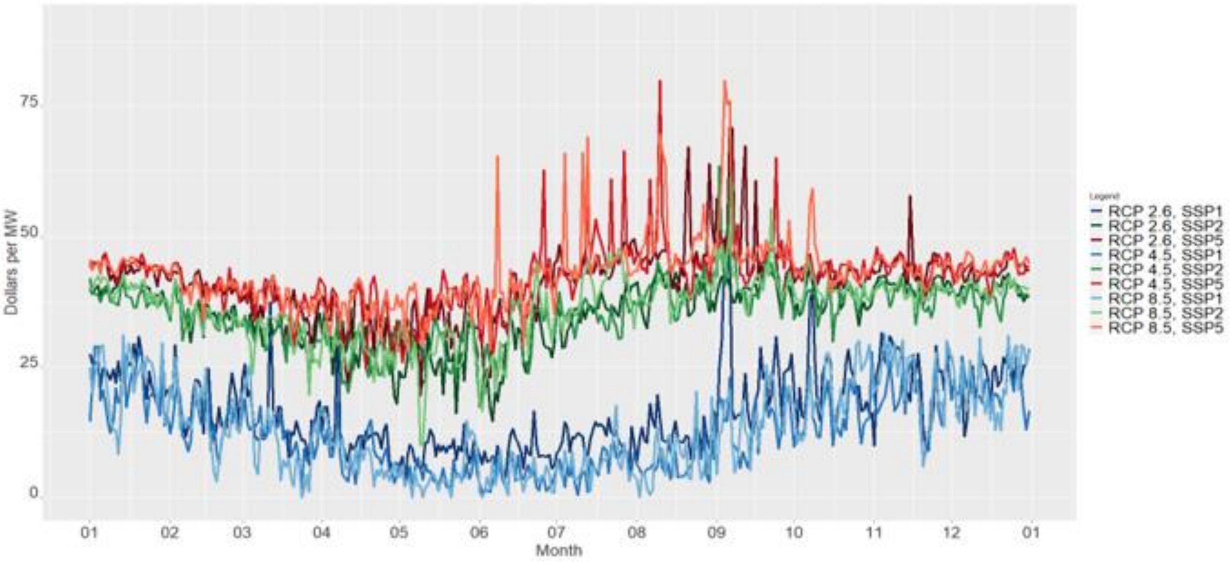
Appendix B

CA Region Daily Dollars per MW Averaged over 2050-2059



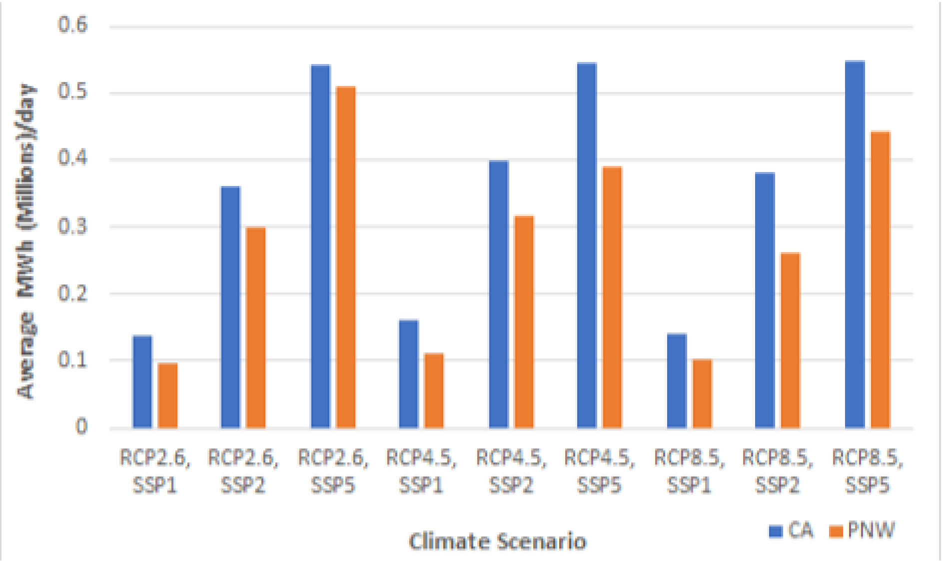
Appendix C

PNW Region Daily Dollars per MW Averaged over 2050-2059



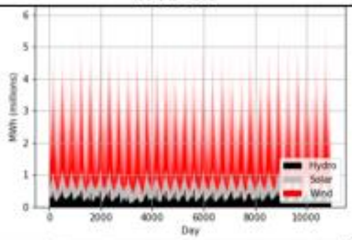
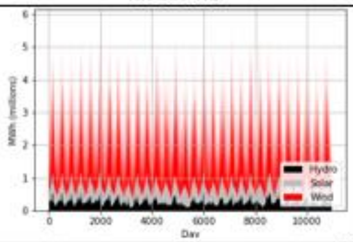
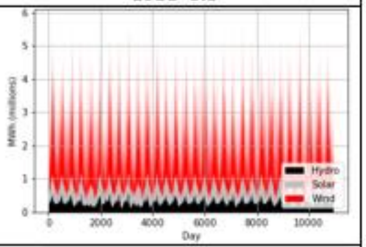
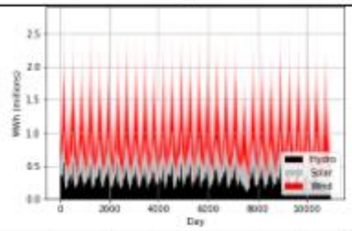
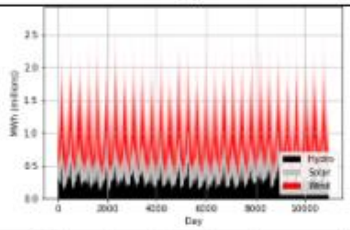
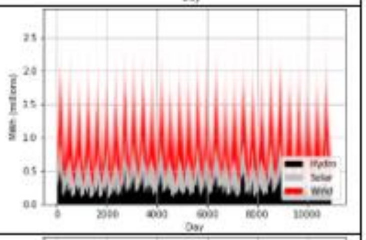
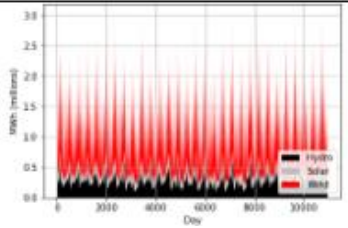
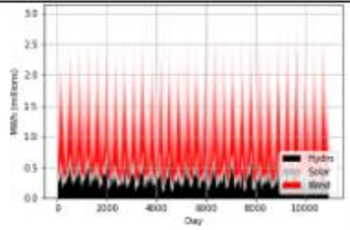
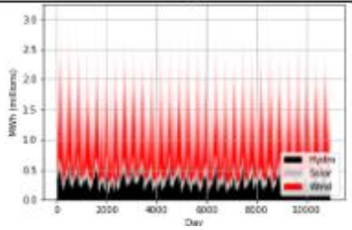
Appendix D

Fossil Fuel Consumption by Region and Scenario



Appendix E

Hydro, Solar, and Wind Production Across Scenarios

	RCP 2.6	**RCP 4.5**	**RCP 8.5**
SSP 1			
SSP 2			
SSP 5			

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