AVOIDED CARBON DIOXIDE PRODUCTION RATES IN THE NORTHWEST POWER SYSTEM

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Contents

Summary 1
Introduction 2
Methodology 3
Results 4
- Existing Policy 4
  - Annual Comparison 4
  - Monthly Comparison 5
  - Observations 7
- Social Cost of Carbon 12
  - Annual Comparison 13
  - Monthly Comparison 13

Conclusion 14

SUMMARY

The impact of future carbon dioxide (CO_2) regulation is a significant risk in long-term utility resource planning. Improper accounting for this risk when evaluating resources may result in poor resource decisions and higher costs for the region's ratepayers. This study is an examination of the rate of avoided CO_2 emissions over time under different water and CO_2 price conditions.

In comparison to the opportunity to purchase a similar resource on the market, a resource that avoids CO_2 emissions,[1] such as conservation, mitigates risk. The opportunity for risk mitigation depends on what the next available megawatt of generating resource is available and how much CO_2 it emits. The *marginal resource* is the least variable cost resource available and needed to meet the next megawatt of load.

In the Northwest, the average CO_2 production rate from all electricity generation is low in comparison to other parts of the Western Electric Coordinating Council region (WECC). This is

[1] Some other examples of resources that have this risk mitigation attribute are conservation, demand response and renewable generation, like wind or solar.

because there are vast hydroelectric and wind generation resources in the Pacific Northwest. These resources have low operating costs, no CO_2 emissions, and dispatch before coal-fired or natural gas-fired generating units. However, since the next megawatt of generation avoided would be available from the marginal unit, not an average of all the units online, the emissions of the marginal unit would best represent the avoided carbon risk of serving the last unit of load.

INTRODUCTION

During any given hour of the year, there is a diverse mix of generating units supplying power to the regional power system. Some of these units will be hydroelectric, solar, nuclear, or wind generating units that do not emit CO_2 into the atmosphere. At the same time, coal, fuel oil, biomass, or natural gas-fired generating units that do emit CO_2 into the atmosphere will also be generating power for the region. Each type of generating unit emits CO_2 at a distinct rate. For context, a contemporary natural gas-fired combined cycle unit emits roughly 0.8 to 0.9 pounds (lbs.) of CO_2 per kilowatt-hour. A typical conventional coal-fired steam unit emits roughly 2.1 to 2.4 lbs. of CO_2 per kilowatt-hour. Peaker gas units have a larger range of emissions rates 1.1 to 1.7 lbs. of CO_2 per kilowatt-hour. Older units of all classes may have higher emissions rates. One way to measure the CO_2 production rate of the generators in a power system is to average the rates of all the generating units operating during a given time period.

Another way to measure the CO_2 production rate of a power system is to estimate the CO_2 emissions rate of the last resource (or marginal resource) brought on-line to supply power during a given time period. In wholesale power markets for energy, generating resources have typically been brought online in the order of their operating costs. In other words, resources with low operating costs generate power before resources with higher costs. In general, hydroelectric, nuclear, solar and wind generating units dispatch before coal-fired or natural gas-fired generating units. Some units, traditionally considered marginal, might actually be scheduled primarily to provide operating or contingency reserves in addition to energy.

Additionally, at most times, the Pacific Northwest region is an exporter of power to other load centers in the WECC. This means energy avoided in the region may actually translate into higher exports out of the region. This means the avoided emissions rate is likely better represented not as the marginal unit in the Pacific Northwest, but the unit that is marginal for the entire WECC. This determination of a WECC-wide marginal unit is clouded by system constraints such as transmission limitations, line losses, and differing reserve requirements.

While the exact marginal unit is now more complex to determine, the concept of finding the CO_2 emissions rate of the last resources brought to bear to meet system energy needs still seems to be a reasonable proxy of the emissions that can be avoided by adding energy-efficiency measures to the system. This paper describes the methodology for determining this avoided CO_2 production rate for reduced Pacific Northwest net demand, during each hour for four separate years: 2016, 2021, 2026, and 2031 under 80 different hydro conditions. Because there are typically 8,760 hours during a year, the results are summarized by providing the average avoided CO_2 production rates for each year (or each month, in some cases).

METHODOLOGY

Due to the reasons discussed above, the methodology for determining the regional power system's marginal CO_2 production rate is different from the 2008 Council study[2] and from the initial draft of this study. In this paper, we will examine two regional strategies, corresponding with the Existing Policy and Social Cost of Carbon scenarios from the Seventh Power Plan[3], in the following years: 2016, 2021, 2026, and 2031. All 80 hydro conditions[4] considered in the Seventh Power Plan will be tested for each scenario.

Council staff uses AURORAxmp® Electric Market Model (AURORAxmp) to develop its wholesale electricity price forecasts. This model simulates hourly supply and demand to determine a marginal resource and market-clearing price for every hour of the simulation period for each of the load-resource zones in the model. The Council's configuration of AURORAxmp uses 16 load-resource zones to represent the entire Western Electricity Coordinating Council (WECC) power system. Four of these zones represent the Pacific Northwest regional power system. Information about further buildout and retirements outside the region but in the WECC is consistent with the 2026 WECC Common Case.

In order to identify a marginal CO_2 production rate for the region, for each hour of the simulation period, Council staff considered the simulated operation of each generating unit located in the WECC from the AURORAxmp hourly output databases. Staff and the System Analysis Advisory Committee, in light of the more complex calculations of determining a regional or WECC-wide marginal unit and burdensome time and data requirements to ensure accuracy, developed a more simple methodology to approximate the "marginal" CO_2 production rate for the region.

The method is as follows:

1. Run two AURORA simulations, one as a base case and one with a reduction of 100 MW[5] over all hours of the year.
2. Calculate the WECC-wide change in emissions and change in power generated. Then,

Equation 1: Equation for Avoided CO_2 Emissions Rate

$$Avoided\ Emissions\ Rate = \frac{Emissions_0 - Emissions_{100}}{Output_0 - Output_{100}},$$

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[2] See the "Marginal Carbon Dioxide Production Rates of the Northwest Power System" at https://www.nwcouncil.org/media/29611/2008_08.pdf.

[3] See the Seventh Power Plan.

[4] The hydro conditions represent the result of a GENESYS run using modified streamflows of hydro years 1929 through 2008 to develop hourly boundaries to put into AURORAxmp. These boundaries limit the monthly hydro availability, and the minimum and maximum hourly generation capability of the hydro system in AURORAxmp.

[5] This was tested with 1, 10, 100 and 250 MW reductions, and it was determined that 1 and 10 MW showed volatility in model results that could be considered noise when allowing for the mathematics behind the simulations' solution strategy. One hundred MW reduction in load was determined to be a reasonable sized signal when considering the number of units in the WECC.

Where $Emissions_{100}$ is emissions in the WECC after 100 MW load reduction in the region, $Emissions_0$ is emissions in the WECC in the base run, where $Output_{100}$ is power generated in the WECC after 100 MW load reduction in the region, and $Output_0$ is power generated in the WECC in the base run. Note that two intermediate definitions are

$$Avoided\ Emissions = Emissions_0 - Emissions_{100} \text{ (Equation 2)}$$

And

$$Avoided\ Output = Output_0 - Output_{100} \text{ (Equation 3)}$$

Note that the above methodology was checked against the actual marginal unit calculations and found to have comparable results but was more time intensive and required more data.

RESULTS

In general, the annual average avoided CO_2 emissions rate decreases over time from 1.83 (in 2016) to 0.97 lbs. per kWh (in 2031) for the Existing Policy scenarios. The avoided CO_2 emissions rate was lower in the Social Cost of Carbon scenarios than in the Existing Policy scenarios, and decreased similarly from 1.4 to 0.55 lbs. per kWh.

The reduction in CO_2 intensity of the WECC fleet of resources (coal plant retirements, etc.) seems to be the main driver in the avoided emissions rate decrease.[6]

Existing Policy

Annual Comparison

This comparison examines the annual average changes in the avoided CO_2 emissions rate.

Table 1: Annual Average Avoided CO_2 Emissions Rate

Scenario	Average Annual Avoided Emissions Rate (lbs. of CO2 per kWh)
2016	1.83
2021 Plan DR	0.91
2026	0.93
2031	0.97

[6] Note that due to a different method of calculation, the results reported out of this study are going to be presented in an alternative format.

As coal plants retire, the CO_2 intensity of all generation sources decreases over time. Some of those plants are expected to be replaced with natural gas plants in other parts of the WECC.[7] There may be a slight increase in the avoided CO_2 emissions rate after 2021, after the significant decrease between 2016 and 2021 when over 6100 MW of coal are scheduled to be retired (including Boardman and Centralia 1 in the region). After 2021 considerably more WECC coal plants[8] are retired both within and external to the region. While this may cause the average carbon intensity of the WECC to decrease, most of those coal plants scheduled to be retired are not on the margin as often as natural gas combined cycle units and thus, the avoided carbon emissions rate goes up slightly between 2021 and 2031.

Monthly Comparison

This comparison examines seasonal changes in emissions rate. While there is some variation in the avoided marginal emissions rate from -0.83 to 2.63 lbs. per kWh, there is not a significant pattern associated with seasonality. The two periods that seem to have distinctive characteristics are as follows: 2016 summer and fall higher avoided emissions rates, and 2021 late spring, early summer shows an average emissions rate increase.

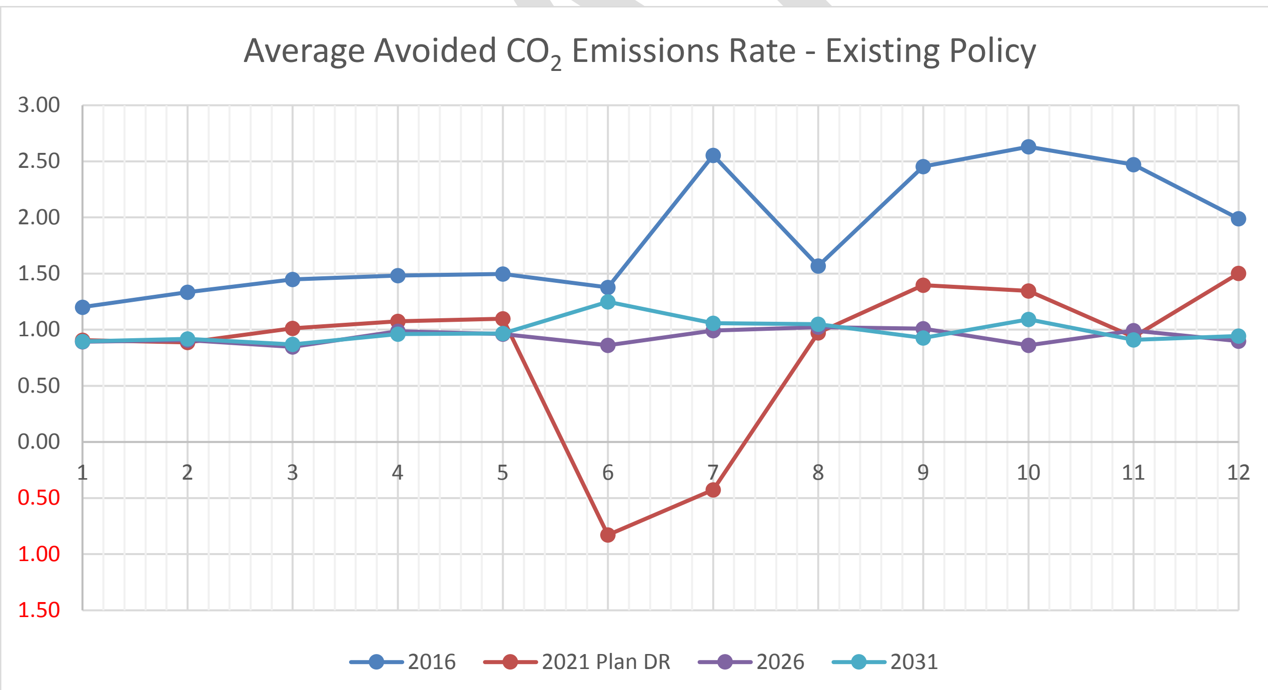

Figure 1: 2016, 2021, 2026 and 2031 monthly Avoided Emissions Rates for the Region

[7] Per information from the WECC 2026 Common Case and AURORAxmp buildout external to the region, some additional generic CCCT renewables are added to maintain reliability.
[8] Over 3100 MW of nameplate coal resource is scheduled to be retired between 2021 and 2026, and over 2200 MW of coal is scheduled to be retired from 2026 to 2031.

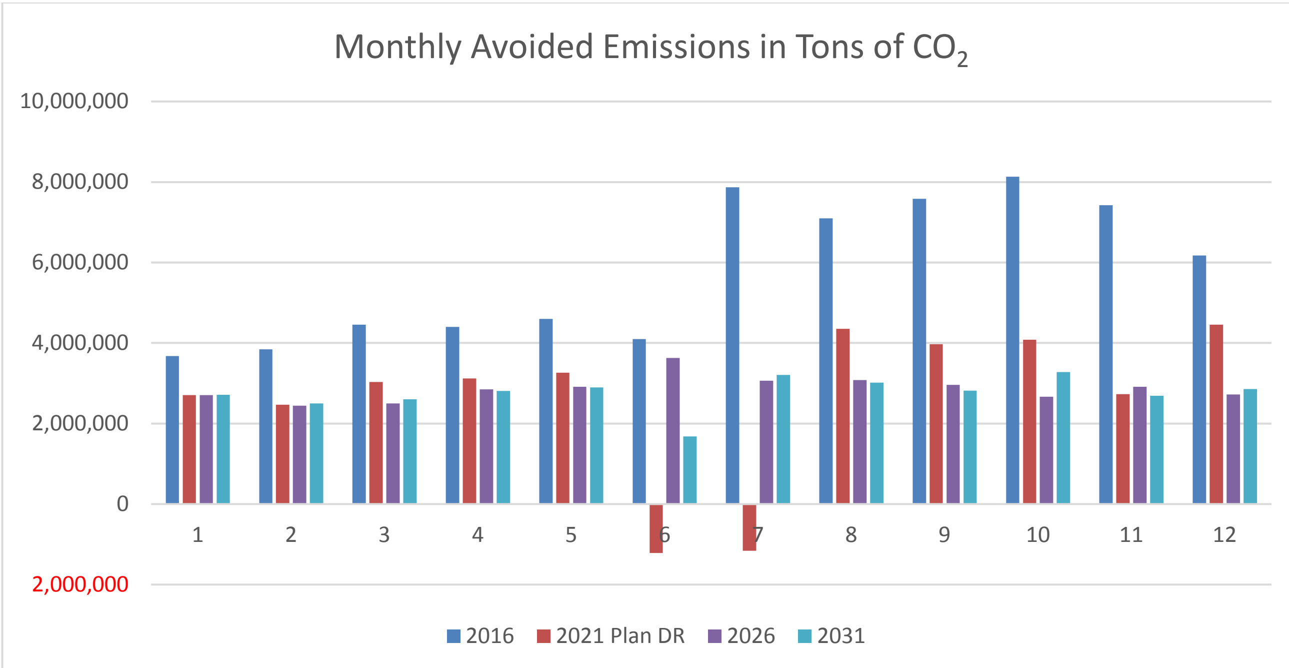

Figure 2: 2016, 2021, 2026 and 2031 Monthly Avoided Emissions (in tons of CO_2)

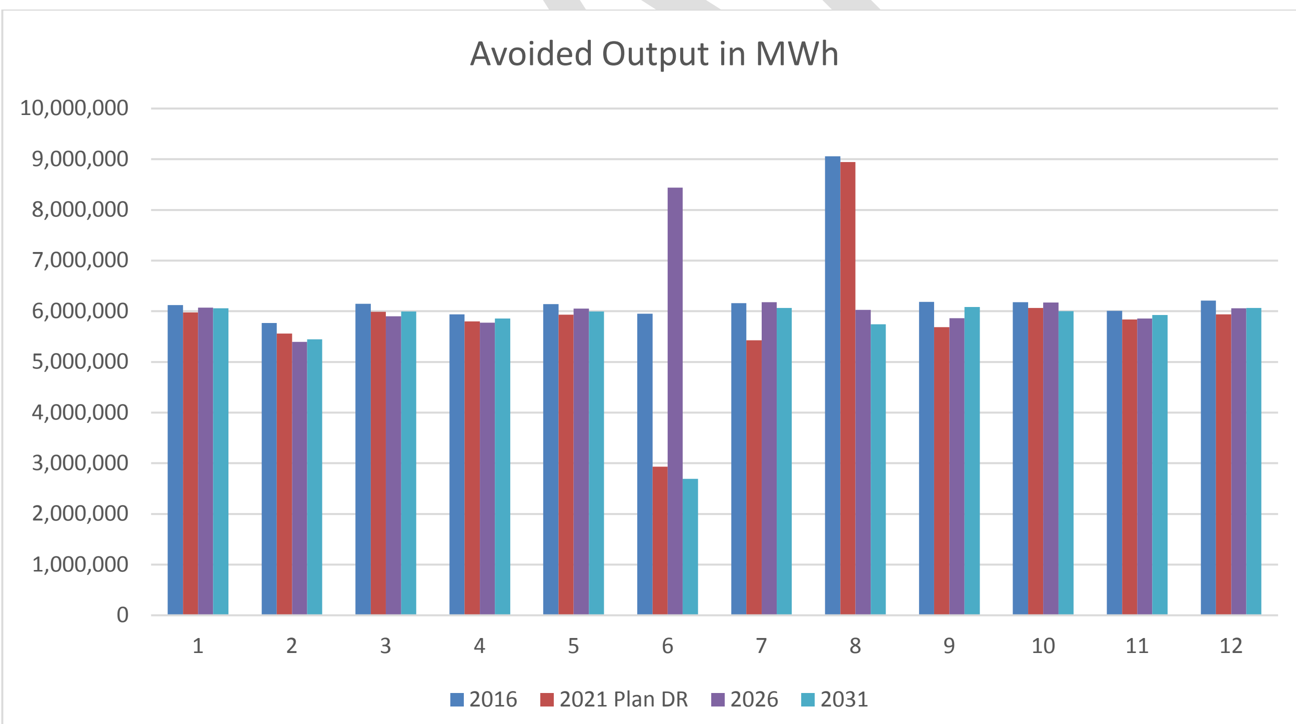

Figure 3: 2016, 2021, 2026 and 2031 Monthly Avoided Output (in MWh)

Observations

In Figure 2, notice that the monthly average avoided emissions in 2016 nearly double in summer and fall while the monthly average avoided output, shown in Figure 3, stays the same.[9] Per Equation 1, it makes sense that the emissions rate would nearly double as well. If the output avoided mostly stays the same, then there is a change in the type of plant providing the electricity from a lower emitting plant to a higher emitting plant.

Also in Figure 2, notice that the average monthly avoided emissions in 2021 drop below zero (i.e. emissions increase) in late spring and early summer, while the monthly average avoided output, shown in Figure 3 is nearly halved. Per Equation 1, it makes sense that the emissions rate would be negative. It does not seem intuitive that emissions would increase for a whole month while load decreases, but it is certainly possible. What actually occurs is that during many days of the month, emissions are still avoided, but during some days, emissions increase due to the load decrease in the region.

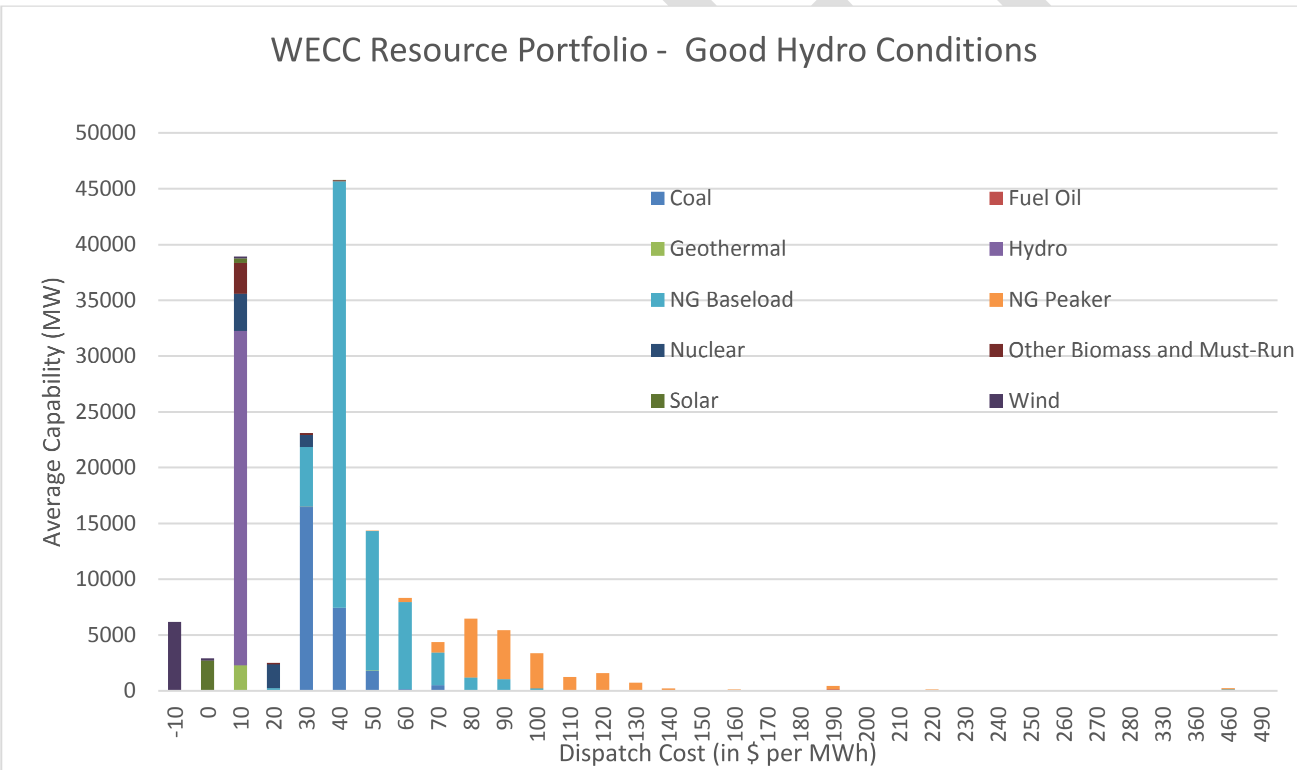

Figure 4: WECC Resource Portfolio in 2021 under 1996 Hydro Conditions

[9] With the exception of August where the output also goes up.

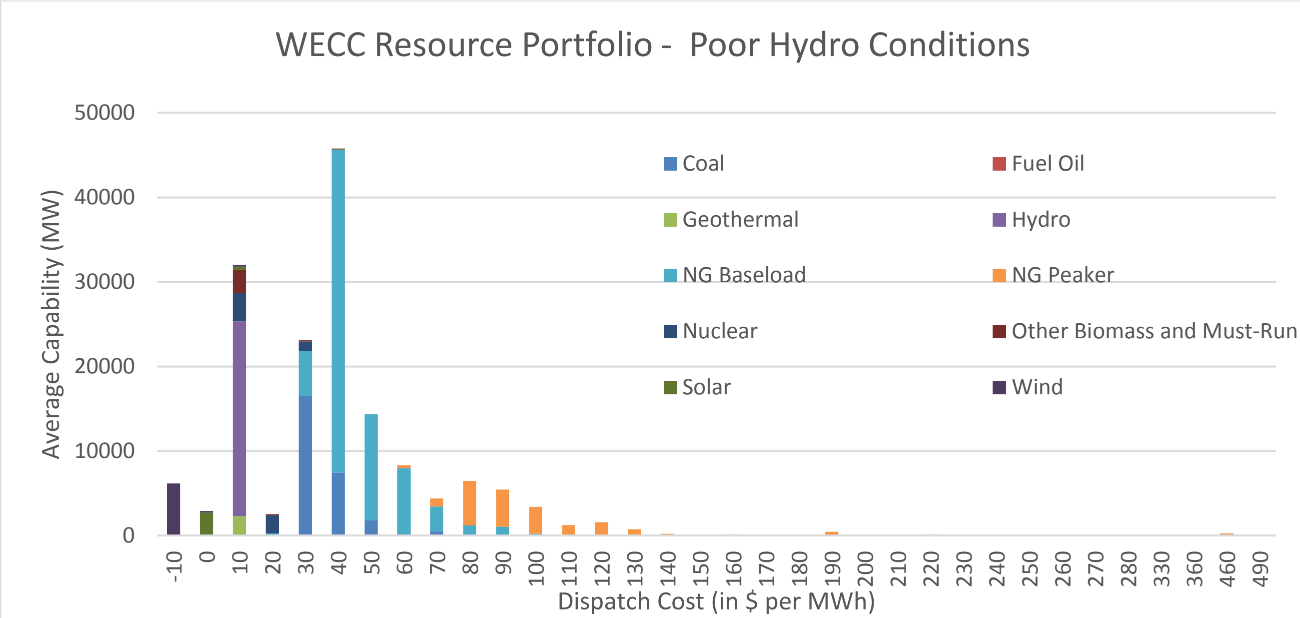

Figure 5: WECC Resource Portfolio in 2021 under 1937 Hydro Conditions

A common reason these sort of scenarios occur is that relatively low emitting combined cycle units in the Northwest are not on, since there is less local demand. In other words, with transmission losses and fees the combined cycle unit would not necessarily be economic for just exporting power elsewhere. These sort of combined cycle units are generally 300 to 400 MW in size. This means there might have been 200 to 300 MW more demand served in the region during some hours of the day. Simple cycle gas units serve some of the residual local demand, but the effect on emissions really stems from the region exporting less power to California. Since California relies heavily on northwest and southwest imports, when the northwest imports less, the southwest often makes up the difference. The difference tends to be made up by coal or natural gas units, especially when the price is between 25 and 45 dollars, as can be seen in Figure 4 and Figure 5. In the case discussed here, where emissions go up during certain days, it is usually a larger response from the desert southwest and mountain west coal fleet that causes emissions to go up.

This effect of increased emissions after a load decrease in the region does tend to happen more in the early summer months of 2021, but it seems to be mostly due to the make-up of the WECC portfolio at that particular time in conjunction with the volatility of hydropower in the Pacific Northwest. Over time, as more coal plants are scheduled for retirement, this seasonal effect of emissions going slightly up for a whole month disappears. However, on an hourly basis the phenomena where emissions are increased due to a decrease in load, still occurs, as can be seen in Figure 6. Additionally, Figure 6 and Figure 7 show that most of the emissions changes, whether they are avoided or exacerbated by lessening regional demand, are in parts of the WECC with significant coal resources, or they are in California.

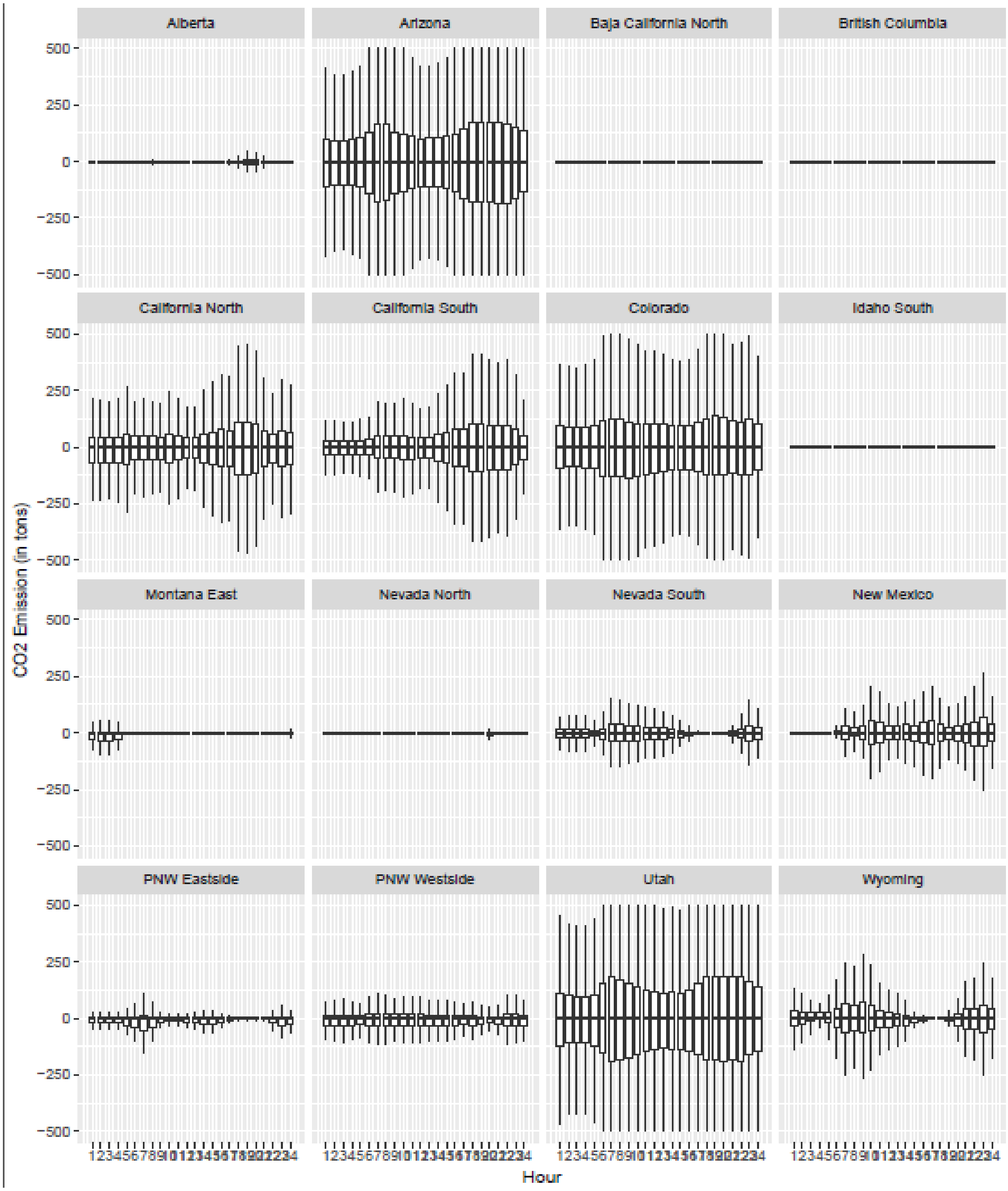

Figure 6: Distributions of Avoided Emissions by Hour in Different Parts of the WECC in 2021 over all 80 Hydro Conditions

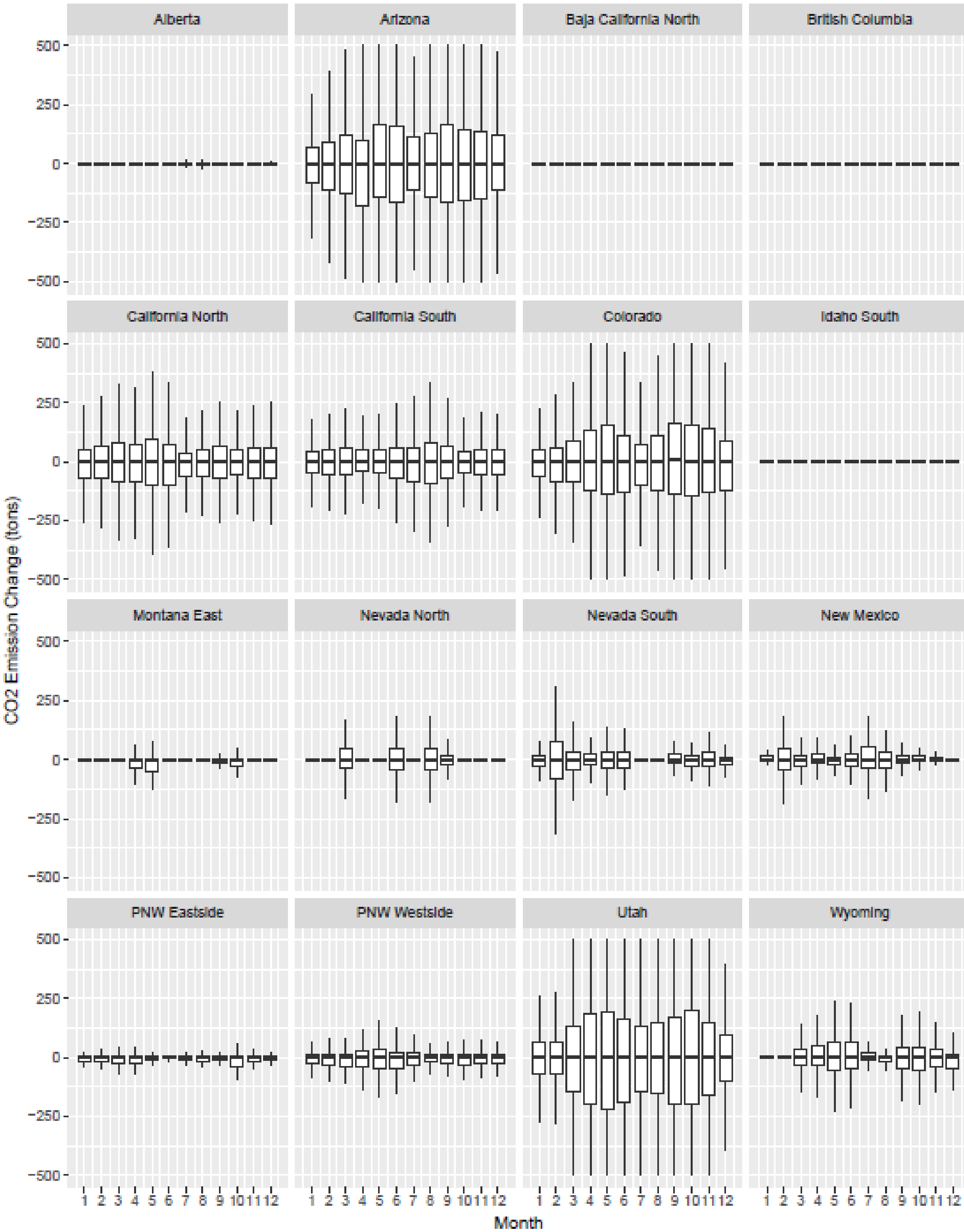

Figure 7: Distributions of Avoided Emissions by Month in Different Parts of the WECC in 2021 over all 80 Hydro Conditions

Another observation is when regional demand goes down by 100 MW in every hour, that demand drop does not necessarily correspond to exactly 100 MW less generation from either the region, or elsewhere in the WECC. This phenomenon seems to be influenced by hydro availability in the region in Figure 8 and has some seasonality in Figure 9. Some counterintuitive avoided emissions rate results are due in part to this phenomenon.

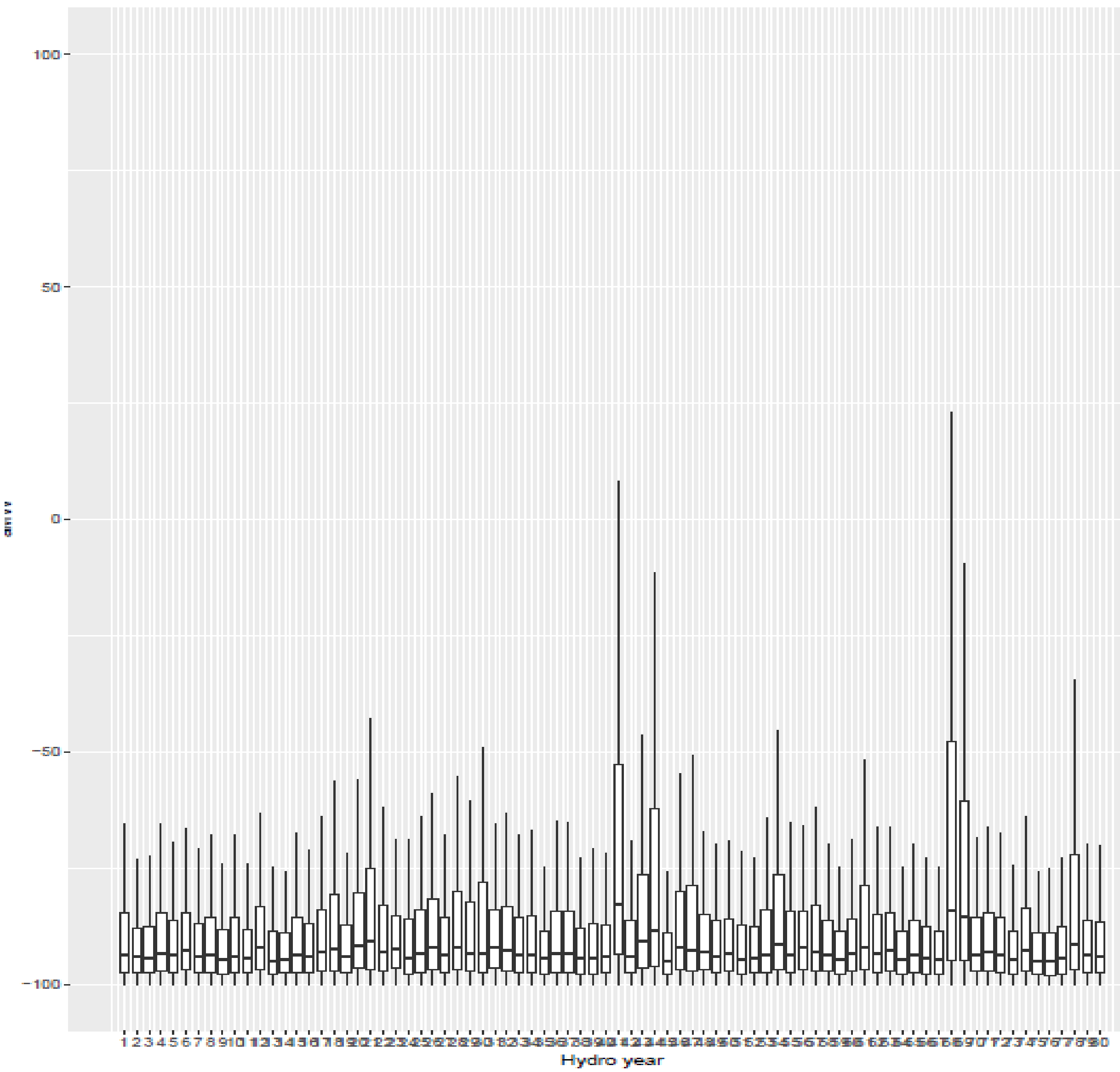

Figure 8: Avoided Generation by Hydro Condition in the WECC in 2021 for all Hours

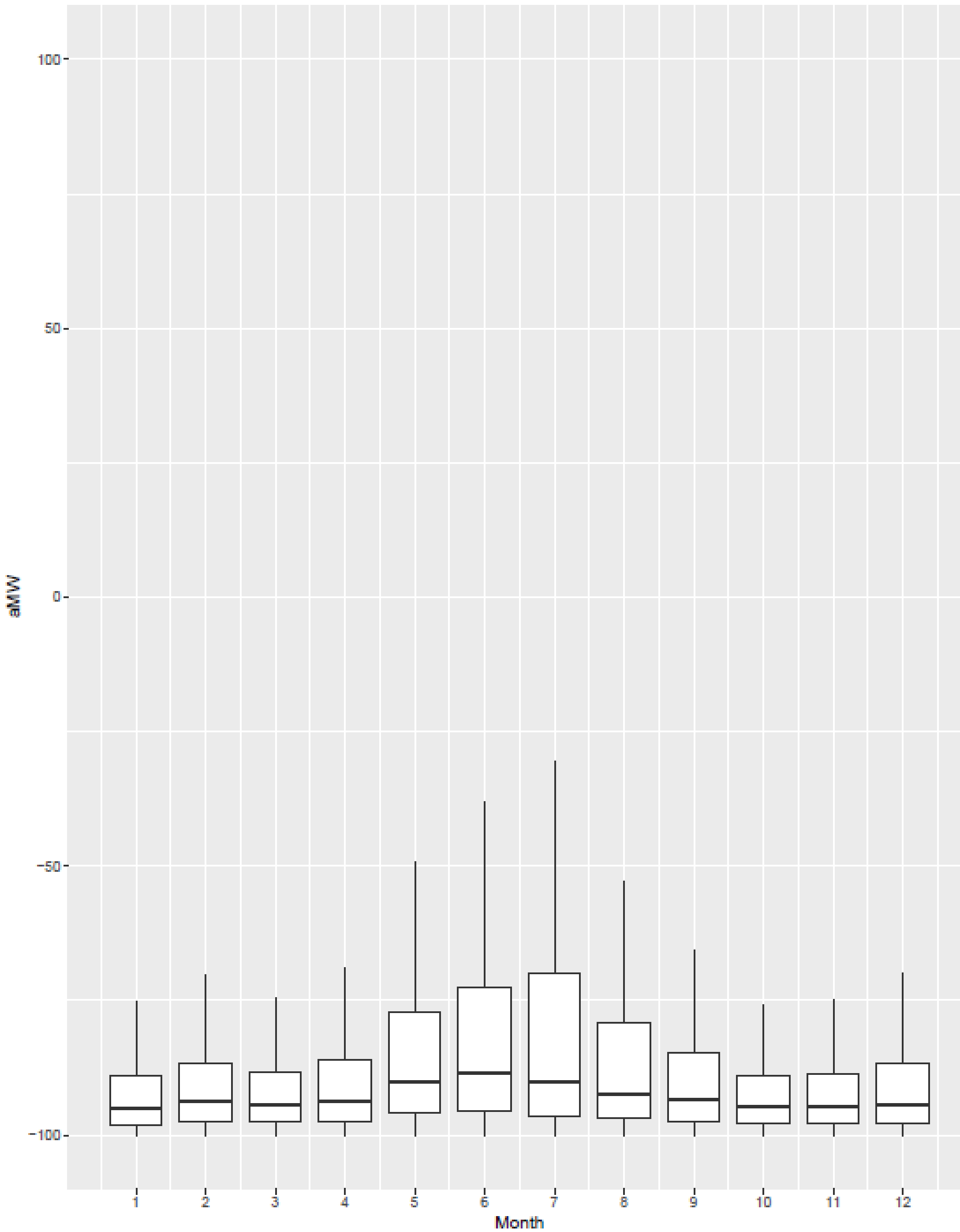

Figure 9: Avoided Generation by Month in the WECC in 2021 for 80 Hydro Conditions

Social Cost of Carbon

The Social Cost of Carbon (SCC), as used in the Seventh Power Plan, is the proxy for a carbon price in the WECC. The carbon pricing starts at 45 dollars per ton of CO_2 emitted in 2016 and peaks at just over 66 dollars per ton in 2031.

Annual Comparison

This comparison examines the annual average changes in the avoided CO_2 emissions rate for the Social Cost of Carbon set of scenarios.

Table 2: Annual Average Avoided CO_2 Emissions Rate

Scenario	Average Annual Avoided Emissions Rate (lbs. of CO2 per kWh)
2016 SCC	1.40
2021 Plan DR SCC	0.58
2026 SCC	0.70
2031 SCC	0.55

For the same reasons as the Existing Policy set of scenarios, as coal plants retire the CO_2 intensity of all generation sources decreases over time. In addition, the average annual avoided emissions rate is lower in general due to the price penalty on CO_2 emitting resources.

Monthly Comparison

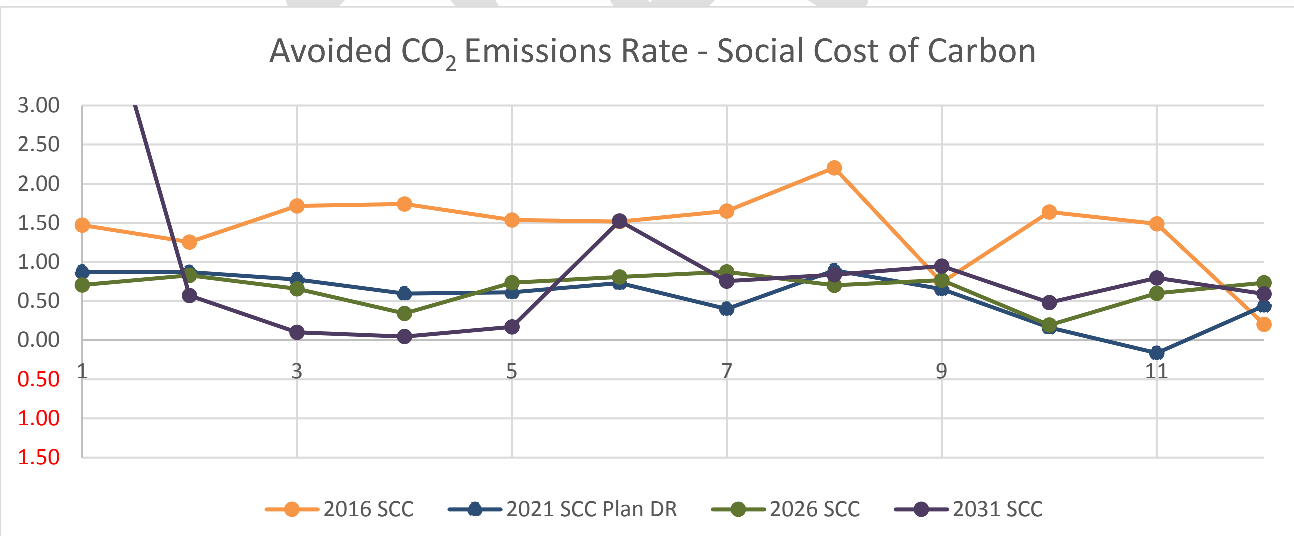

Figure 10: 2016, 2021, 2026 and 2031 monthly results for Social Cost of Carbon scenario

Similar to the seasonal results from the runs without carbon pricing there is some variation in the avoided emissions rate from 0.16 to 2.20 lbs. per kWh[10], but there does not seem to be a significant

[10] Note that January 2031 has an average Avoided Emissions Rate result over 5 lbs. per kWh, but this result is an outlier at the end of the study, and has little weight on the overall annual average.

pattern associated with seasonality. If anything, the avoided emissions rate is less in early spring and late fall. This effect is showing diminishing avoided emissions rate reductions when slightly higher emitting gas units are turned off for slightly lower emitting gas units. This result is consistent with what one might expect about the adverse effect of a carbon price on all coal plants in the WECC, and what might happen if those coal plants are retired as scheduled.

CONCLUSION

One of the main conclusions of this study in its current form is that the changing landscape of the Pacific Northwest region generation portfolio over time influences how many CO_2 emissions are avoided, but less so than the changing resource portfolio in the entire WECC. This makes sense, since the region is exporting significant power to California every year and in almost every hour, and the northwest has less high emitting resources than other places in the WECC. Therefore, the reduction in Pacific Northwest net demand primarily avoids carbon emissions by freeing up more regional export capability to California, and avoiding higher CO_2 emissions from would-be California suppliers in the desert southwest and mountain west. In addition, as coal plants are retired throughout the WECC and replaced with lower emitting resources, the avoided CO_2 emissions rate decreases. This effect is exacerbated at times by marginal generator commitment decisions and subsequent additional transmission losses reducing avoided output that might have been expected per the reduction in net demand.

This study shows an annual range for the marginal CO_2 emissions rate of 0.91 lbs. per kilowatt-hour to 1.83 lbs. per kilowatt-hour for the existing policy scenario. This is a slightly higher range of rates than reported in the 2008 Council Study. This likely has a fair amount to do with three major additions to the study: explicit accounting of between 1200 and 1800 megawatts of operating reserve,[11] using 80 different hydro conditions instead of average hydro[12] and consideration of emissions avoided elsewhere in the WECC. The first two factors put the system under more stressful situations and thus test more extreme operating conditions. The consideration of lower demand in the region avoiding emissions elsewhere in the WECC, is a major factor in the wider range, especially considering the regional coal fleet is small in comparison to the all the coal resources in rest of the WECC.

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[11] AURORAxmp can now explicitly solve considering the economics of reserves and energy. Note that the concept of marginal unit may change over time due to a more sophisticated understanding of reserves and the advent of potential reserve markets.
[12] Council's setup of AURORAxmp data is now more able test more scenarios simultaneously using parallel processing, and mine the significantly larger output datasets more easily using more advanced software tools.