Avoided Carbon Dioxide Production Rates in the Northwest Power System

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Contents

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 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

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

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, resources with low operating costs generate power before resources with higher costs. Typically, hydroelectric, nuclear, solar and wind generating units dispatch before coal-fired or natural gas-fired generating units. Sometimes scheduled units with more expensive operating costs operate primarily for the operating or contingency reserves they provide to the grid rather than the energy guaranteed by their minimum operation limits. However, in general, because of economic dispatch of units, resources that reduce the need for energy avoid the emissions from the more expensive resources, rather than an average of the emissions all units generating.

Additionally, at most times, the Pacific Northwest region is an exporter of power to other load centers in the WECC. This means net load reduction in the region may translate into the same energy production in the region, and higher exports out of the region. Thus a representation of the avoided CO_2 emissions rate of the unit that is marginal for the entire WECC is likely more reasonable than the emissions rate of the marginal unit in the Pacific Northwest. However, the determination of a WECC-wide marginal unit is a more complicated calculation including system constraints such as transmission limitations, line losses, and differing reserve requirements.

Despite the increased complexity in determining the exact marginal unit for the WECC, the general concept of remains the same. Finding the CO_2 emissions rate of the last resources brought to bear to meet system energy needs still seems to be the most reasonable proxy of the avoided emissions from 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.

For clarity and brevity in reporting[2], the following results are 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[3] and from the initial draft of this study. In this paper, we will examine two regional resource strategies, corresponding with the Existing Policy and Social Cost of Carbon scenarios from the Seventh Power Plan[4], in the following years: 2016, 2021, 2026, and 2031. The model is set up to test 80 hydro conditions[5] in both scenarios and in all of the test years.

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 WECC resource buildouts and retirements outside the region is consistent with the data from 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 to determine 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[6] over all hours of the year.
2. Calculate the WECC-wide change in emissions and change in power generated. Then,

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[2] Increased fidelity in results is available on request.
[3] See the "Marginal Carbon Dioxide Production Rates of the Northwest Power System" at https://www.nwcouncil.org/media/29611/2008_08.pdf.
[4] See the Seventh Power Plan.
[5] 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.
[6] 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. Additionally, the 100 MW and 250 MW reduction tests showed very similar results. One hundred MW reduction in load was determined to be a reasonable sized signal when considering the number of units in the WECC.

Equation 1: Equation for Avoided CO_2 Emissions Rate

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

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 generation in the WECC after 100 MW load reduction in the region, and $Output_0$ is power generation 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 less time intensive and required less data to calculate. Some stakeholders commented it might be useful to test this methodology for smaller and larger reductions to develop an avoided emissions rate curve[7].

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[8]. The avoided CO_2 emissions rate is 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 (mostly due to scheduled coal plant retirements) seems to be the main driver in the avoided emissions rate decrease.[9]

Existing Policy

Annual Comparison

The comparison in Table 1 examines the annual average avoided CO_2 emissions rate for 2016, 2021, 2026 and 2031. The calculation of annual average emissions rate for each test year is over all hours for all 80 hydro conditions.

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[7] This was determined to be out of scope for this initial study but will be considered for future studies.

[8] More work would be required to determine the exact load reduction threshold at which these rates no longer apply, but early indications are that these results would still hold for load reductions up to 250 MW over the 7th Power Plan conservation. However, larger reductions of 1000 MW to 4000 MW seem to cause an increased avoided carbon emissions rate. Large resource additions of any sort would likely require specific analysis and timing to better represent avoided emissions.

[9] 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.

Table 1: Annual Average Avoided CO_2 Emissions Rate

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

As coal plants retire, the CO_2 intensity of total WECC generation decreases over time. The expectation is that natural gas plants will replace some of these plants in other parts of the WECC.[10] There appears to 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, more WECC coal plants[11] are retired both within and external to the region. Most of those coal plants scheduled to be retired are not on the margin as often as natural gas combined cycle units and thus, while the average carbon intensity of the WECC may decrease, the avoided carbon emissions rate goes up slightly between 2021 and 2031.

Monthly Comparison

This comparison examines seasonal changes in emissions rate. Some variation in the avoided carbon emissions rate from -0.83 to 2.63 lbs. per kWh does exist, but there is not a significant, pervasive pattern associated with seasonality. The two periods that seem to have distinctive characteristics are as follows: 2016 summer and fall have higher avoided emissions rates and 2021 late spring and early summer shows a rare couple of months where emissions increase on average.

[10] 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.
[11] 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.

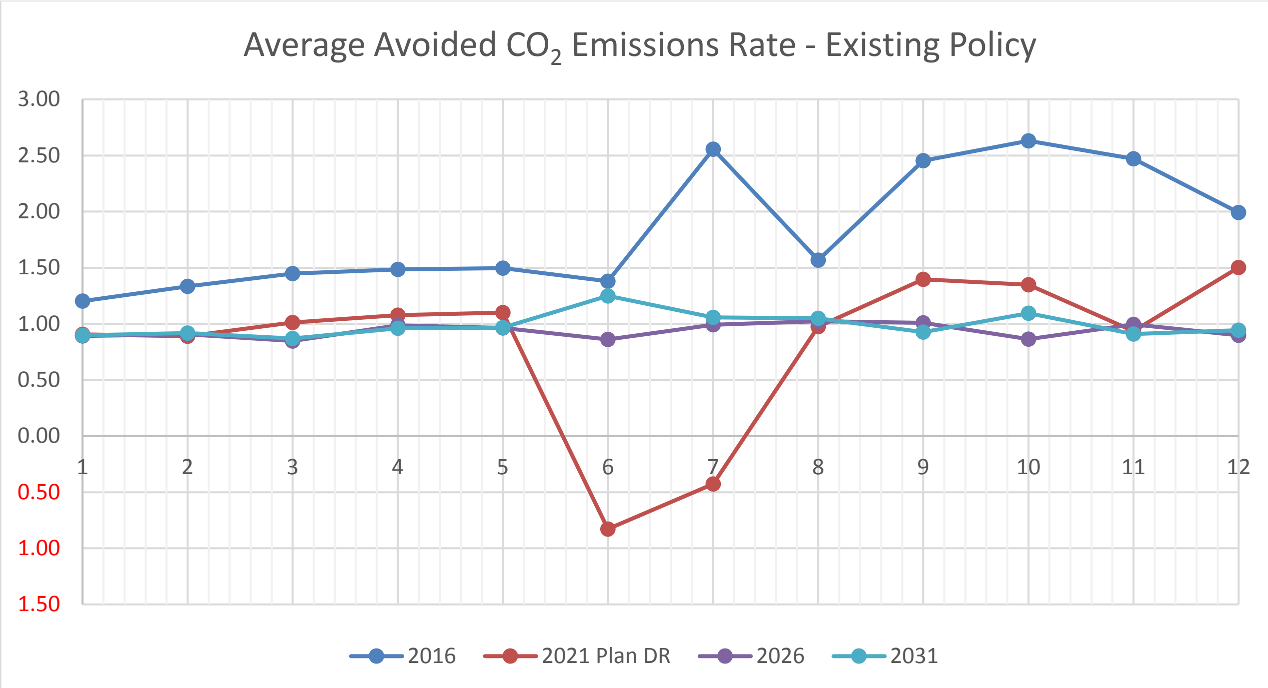

Figure 1: 2016, 2021, 2026 and 2031 monthly Avoided Emissions Rates for the Region

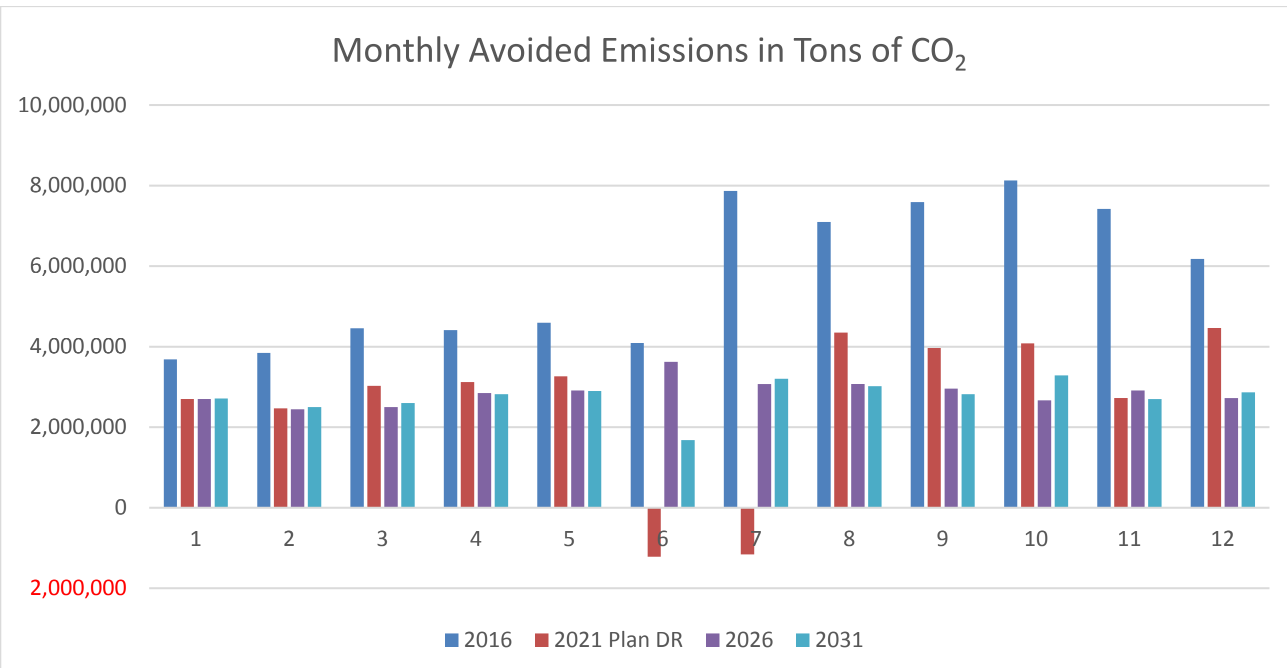

Figure 2: 2016, 2021, 2026 and 2031 Monthly Avoided Emissions (in tons of CO_2)

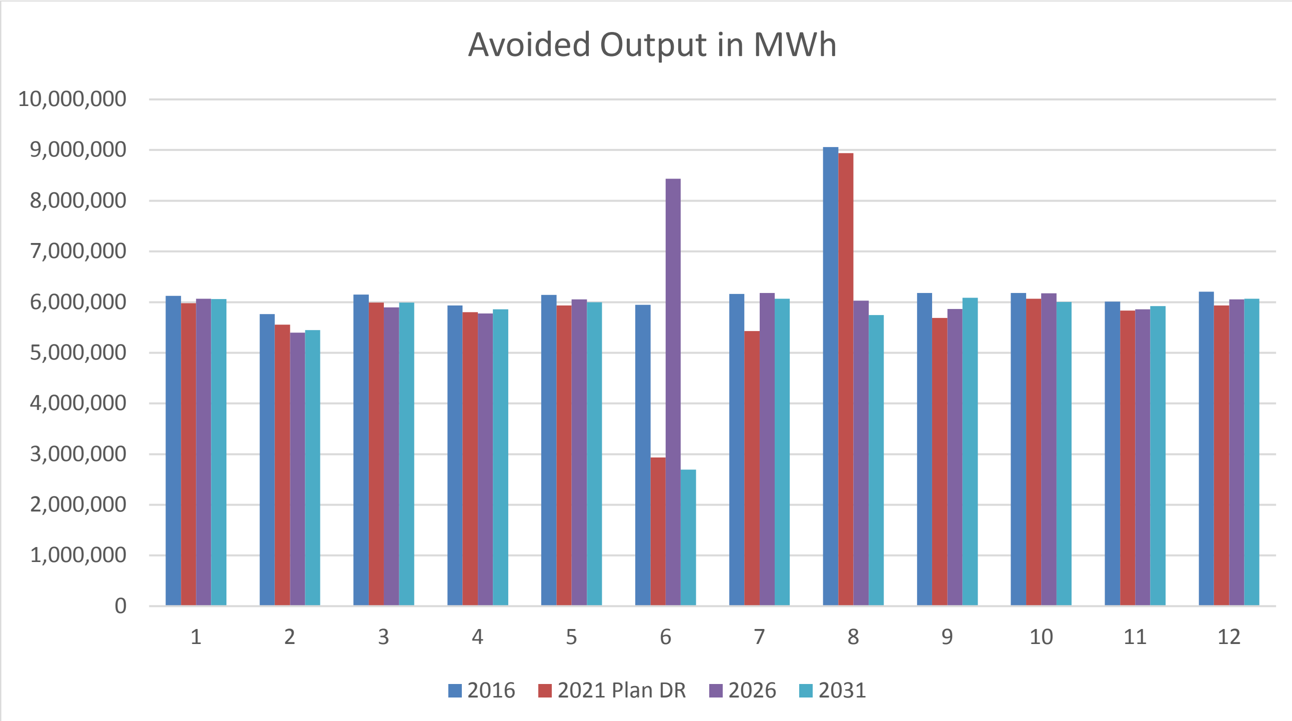

Figure 3: 2016, 2021, 2026 and 2031 Monthly Avoided Output (in MWh) Observations

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.[12] 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 monthly average avoided emissions in 2021 drop below zero (indicating an 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 on other days emissions increase due to the load decrease in the region. This daily and hourly variation is not uncommon within the results, but on a monthly average level, the amount of emissions avoided are generally enough to overwhelm the occurrences when emissions go up.

A common reason these sort of counter intuitive scenarios can occur is generally associated with fluctuating exports out of the region and the impact WECC-wide of fluctuating exports. Why might changing exports produce counterintuitive avoided emissions results? Consider the following scenario.

[12] Although in August the output does also goes up.

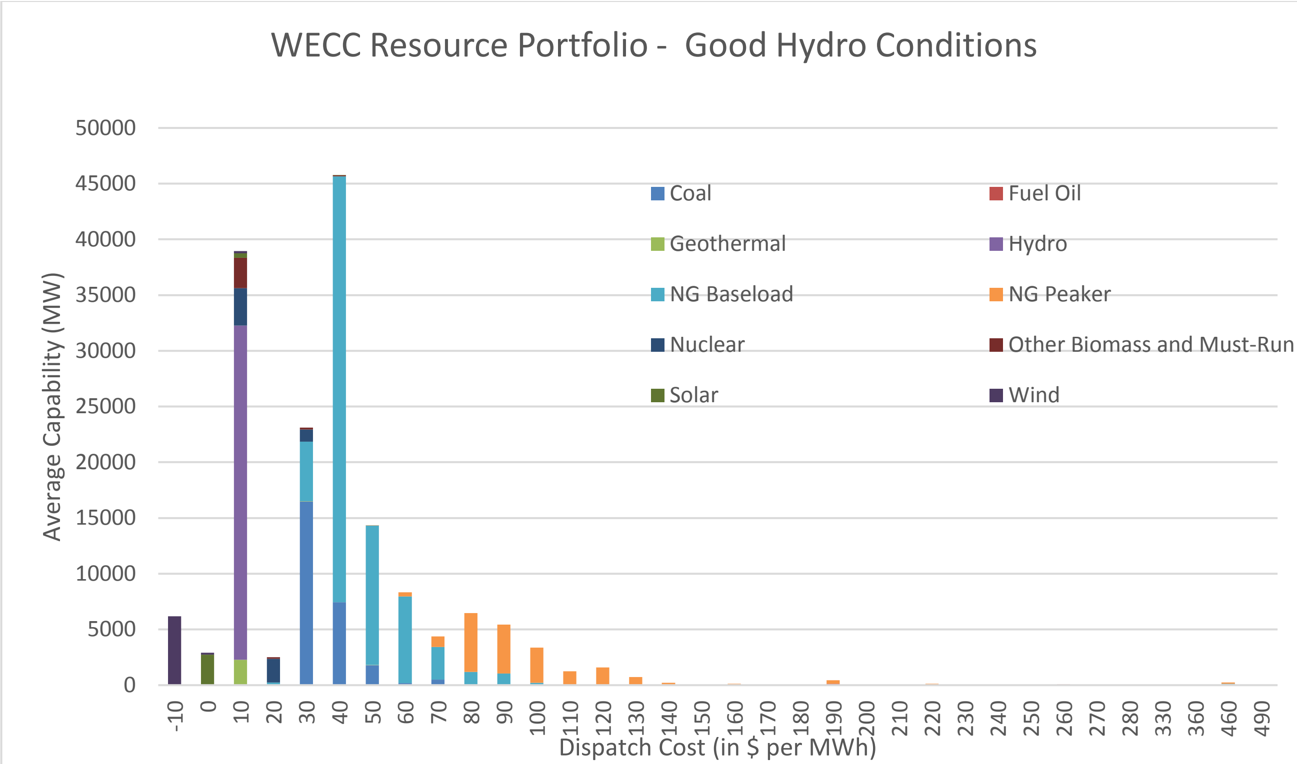

Figure 4: WECC Resource Portfolio in 2021 under 1996 Hydro Conditions

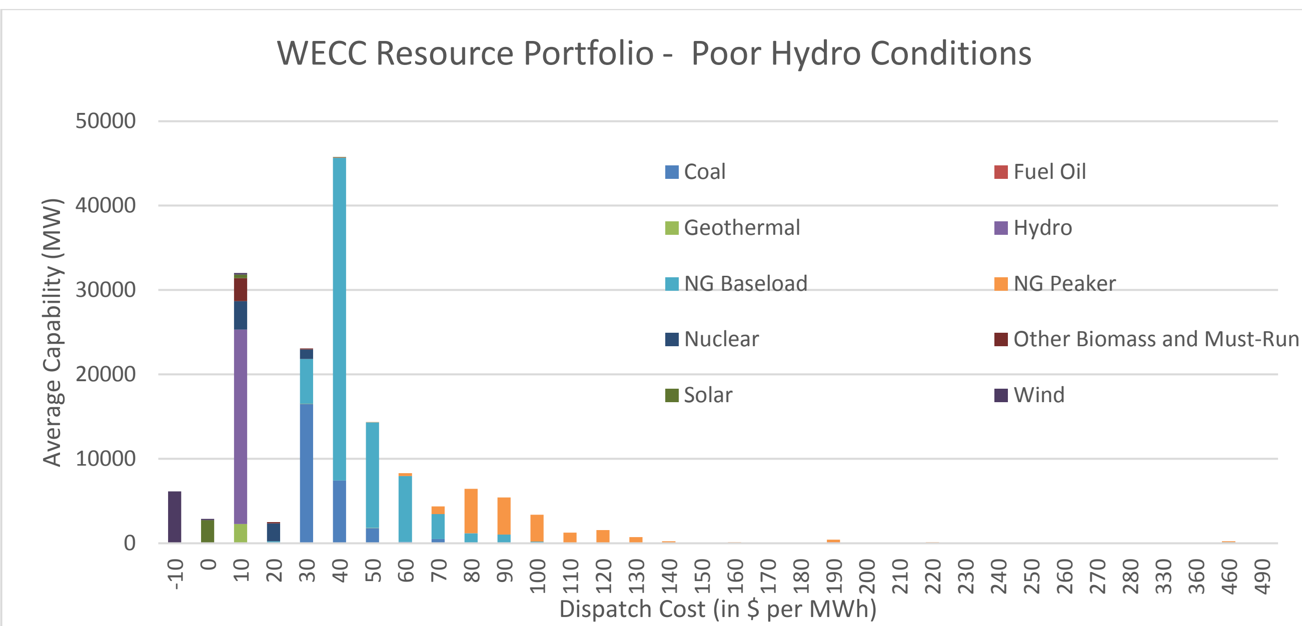

Figure 5: WECC Resource Portfolio in 2021 under 1937 Hydro Conditions

A relatively low emitting combined cycle unit in the Northwest is close to the margin during some period until a persistent 100 megawatts regional load reduction happens. Since there is less local regional demand to meet and with transmission losses and charges, the combined cycle unit is not necessarily economic for just exporting power out of the region. Therefore, the unit does not dispatch under the reduced load scenario. Since these sort of combined cycle units are generally 300 to 400 megawatts in size, there is now at least a few hundred more megawatts of demand that would have been served that now needs to be served by some other units during some hours of the day. Higher emitting simple cycle gas units might serve some of the residual local demand, but it is more likely the region just exports less power to California. Since California relies heavily on northwest and southwest imports, when the northwest exports less to California, the southwest often makes up the difference. That difference tends to filled in 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 situation discussed here, where emissions go up during certain days, it is usually a larger response from the desert southwest and mountain west coal fleet to decreased northwest exports to California that causes emissions to go up in the WECC.

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 variability of hydro conditions in the Pacific Northwest. Over time, as more marginal coal plants leave the fleet due to scheduled retirements, this seasonal effect of emissions going slightly up for a whole month disappears. However, on an hourly basis the phenomena, where WECC wide emissions increase 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 variability in 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.

To give a little context for the scale of Figure 6 and Figure 7, based on the previous example, if that 400 megawatt of combined cycle generation replaced by 400 megawatts of typical coal power generation for one hour. Recall that an efficient combined cycle will have an emissions rate of 0.8 lbs. of CO_2 emitted per kilowatt-hour generated and a traditional coal plant will emit 2.1 lbs. of CO_2 per kilowatt-hour. The emissions change resulting from switching between efficient gas and coal generation can be calculated as follows:

$$Avoided\ Emissions\ (tons) = \left(2.1\ \frac{lbs}{kWh} - 0.8\ \frac{lbs}{kWh}\right)\left(\frac{1\ ton}{2000\ lbs}\right)\left(\frac{1000\ kWh}{1\ MWh}\right)(400MWh) = 260\ tons$$

Similarly, the emissions change resulting from efficient gas plant shutting off can be calculated as follows:

$$Avoided\ Emissions\ (tons) = \left(0.8\ \frac{lbs}{kWh}\right)\left(\frac{1\ ton}{2000\ lbs}\right)\left(\frac{1000\ kWh}{1\ MWh}\right)(400MWh) = 320\ tons$$

Notice that in all parts of the WECC most of distribution of hourly and monthly avoided emissions in Figure 6 and Figure 7 respectively, lies between 250 tons of CO_2 emissions avoided and 250 tons of CO_2 emissions increase. This variation is indicative of the tradeoff between gas and coal plant emissions, or the tradeoff between gas plant emissions in different parts of the WECC. Regardless, when the emissions go up in one area, usually they go down in another and in general net to an emissions reduction because less load needs to be served.

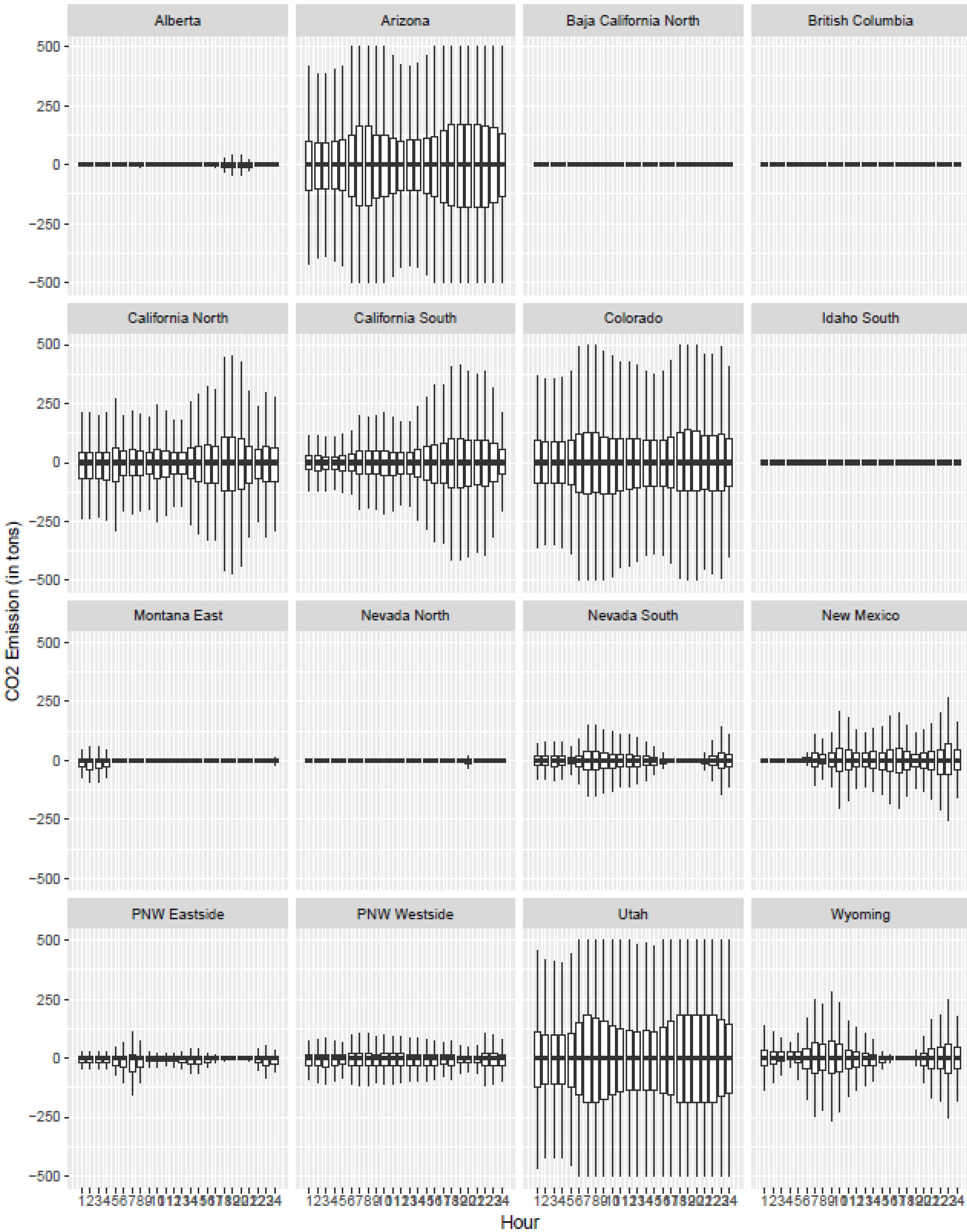

Figure 6: Distributions of Avoided Emissions by Hour in Different Parts of the WECC in 2021 over all 80 Hydro Conditions

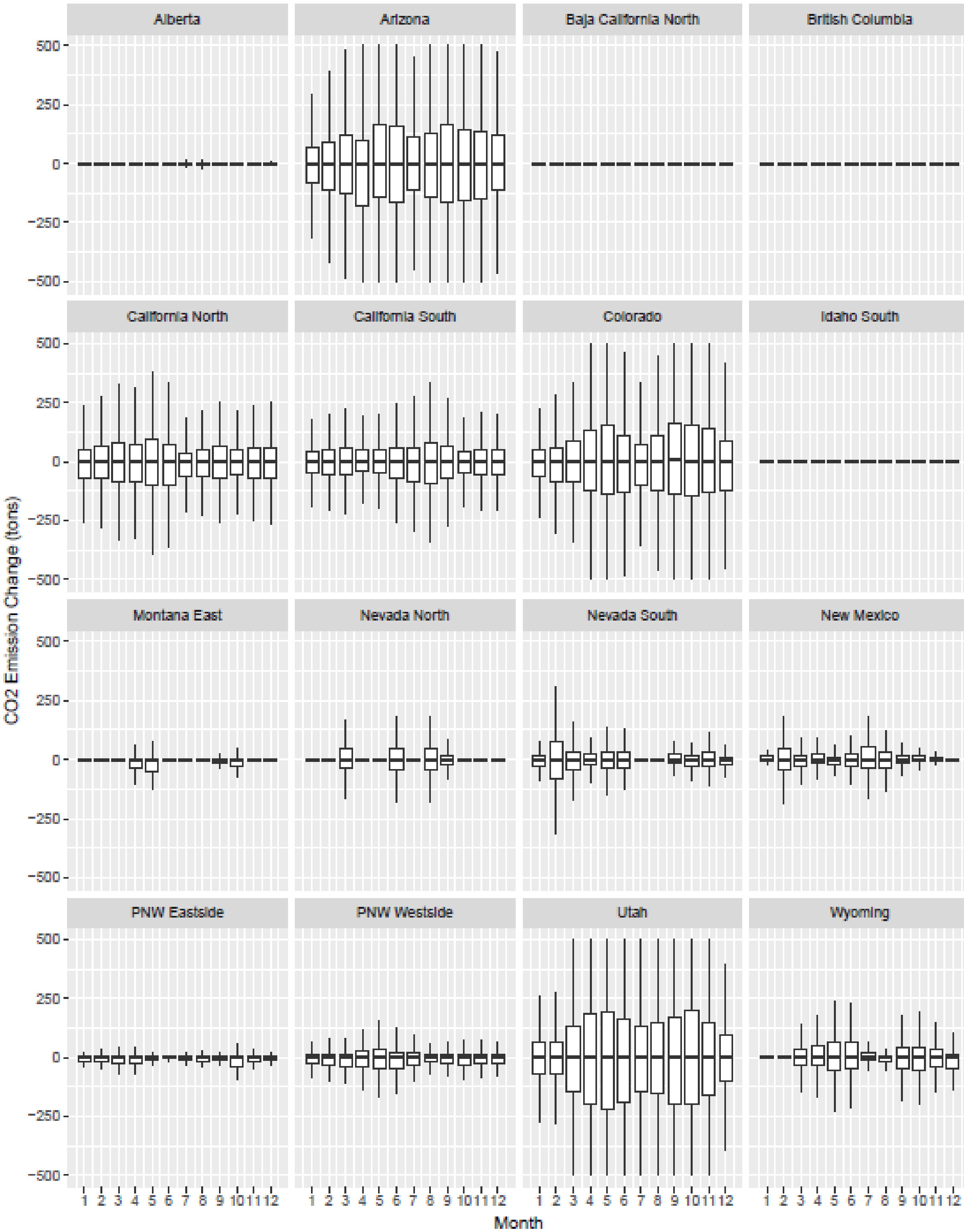

Figure 7: Distributions of Avoided Emissions by Month in Different Parts of the WECC in 2021 over all 80 Hydro Conditions

Observe that a regional demand drop of 100 megawatt in every hour does not necessarily correspond to exactly 100 megawatt less generation from either the region, or elsewhere in the WECC. This phenomenon seems varies by hydro availability in the region, per Figure 8, and has some seasonality, per Figure 9. Some counterintuitive avoided emissions rate results are due in part to this phenomenon[13].

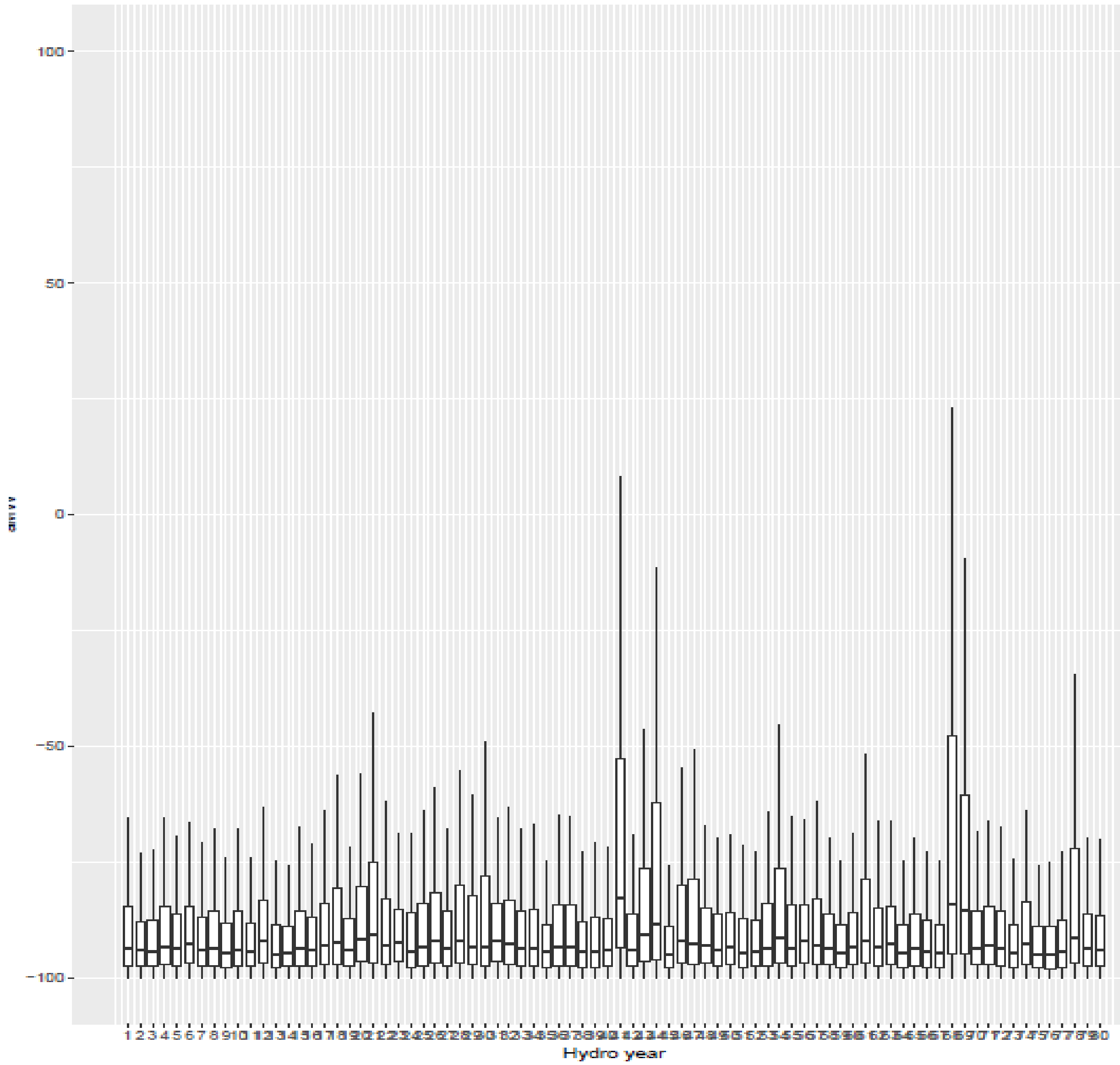

Figure 8: Avoided Generation by Hydro Condition in the WECC in 2021 for all Hours

[13] Some stakeholders suggested, because of this phenomenon, it might be better to divide emissions reduction by the flat 100 megawatt reduction in load. This methodology was tested and yielded more extreme results that seemed to be a less appropriate proxy, per the SAAC judgement, than the rate defined by emissions change over the corresponding generation change.

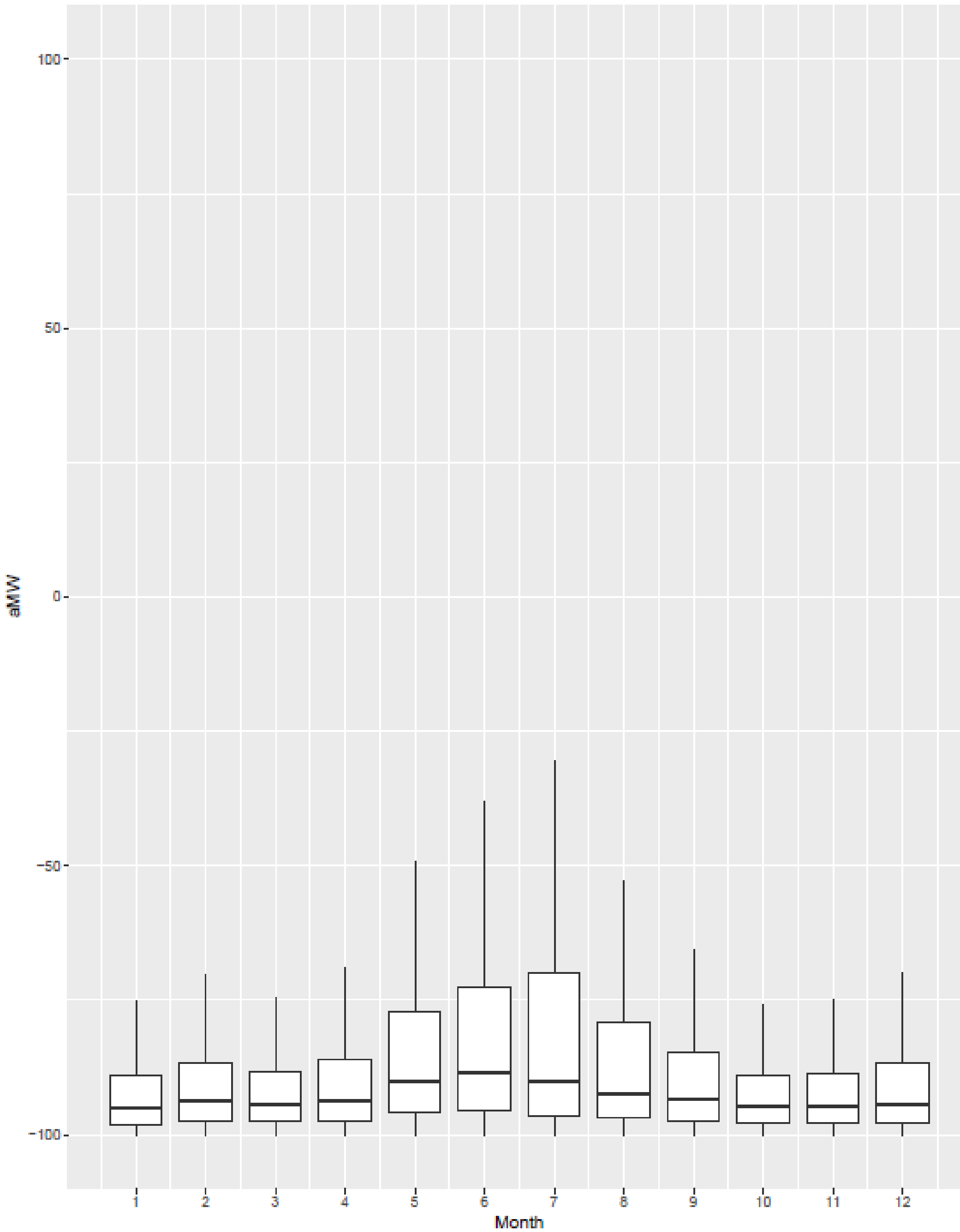

Figure 9: Avoided Generation by Month in the WECC in 2021 for 80 Hydro Conditions

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

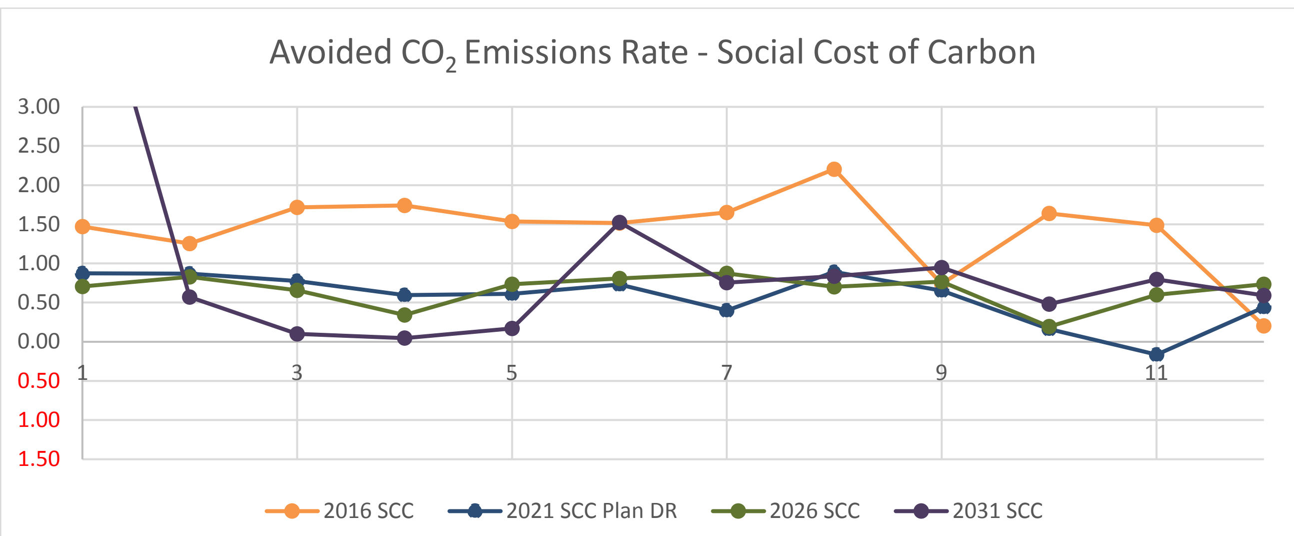

Figure 10: 2016, 2021, 2026 and 2031 monthly results for Social Cost of Carbon scenario

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[14], but again there does not seem to be a

[14] 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.

significant pattern associated with seasonality. If anything, the avoided emissions rate is slightly 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 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 should make some 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. As coal plants are retired throughout the WECC and replaced with lower emitting resources, the avoided CO_2 emissions rate decreases. Marginal generator commitment decisions and subsequent additional transmission losses reducing avoided generation per the reduction in net demand exacerbate this effect at times.

This study shows an annual range for the marginal emissions rate of 0.91 pounds of CO_2 per kilowatt-hour to 1.83 pounds of CO_2 per kilowatt-hour for the existing policy scenario. This is a slightly larger range of rates than reported in the 2008 Council Study. The cause of this increased range 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,[15] using 80 different hydro conditions instead of average hydro[16] and consideration of emissions avoided elsewhere in the WECC rather than just the region. 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 also a contributor in the wider range, which is not too surprising considering the regional coal fleet is small in comparison to the all the coal resources in rest of the WECC.

[15] 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.
[16] 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.