WECC

Year 20 Extreme Cold Weather Event

April 2024

Executive Summary

Extreme weather is a growing risk to the reliability and security of the bulk power system in the Western Interconnection (WI). As such, it is one of WECC's Reliability Risk Priorities. As the power system changes and the frequency and severity of extreme weather events increase, it becomes more important to understand what potential reliability risks could arise on the system.

This study evaluates the potential impacts of an extreme cold weather event on the reliability of the system in the year 20 future. To do this, WECC extrapolated data from Winter Storm Elliott, which occurred between December 21 and December 26, 2022, and brought very low temperatures, heavy snow, and high winds to much of the United States and parts of Canada.

WECC used its Year 20 Foundational Case (Y20 FC) as the starting point for this assessment. The Y20 FC is built from the 2032 Anchor Data Set (2032 ADS), which is a stakeholder-vetted compilation of load, resource, and transmission information. The Y20 FC represents year 2042 and is intended to be a baseline case for this assessment; it represents one of many possible business-as-usual future scenarios. The Y20 FC does not represent the expected future, but rather a resource-balanced starting point for this year 20 study. It should be noted that the Y20 FC uses the same transmission topology as the 2032 ADS, no transmission was added, deleted, or changed to represent the year 20 future. The 2032 Anchor Data Set only contains transmission that is in-service in 2032 and does not include transmission that is being built, planned or necessary by 2042. To compensate for this fact, the new generation that was added in the Y20 FC that will be needed to serve load is judiciously represented near loads rather than in the resource locations where they will be located when they are built.

Using the Y20 FC as a baseline, WECC then changed its input assumptions to model impacts from extreme cold weather conditions in year 2042, which included the following assumptions:

- Mimicking the December 2022 event load shape for 2042,
- Increasing the load by 10% beyond the event load shape for 2042,
- Doubling the forced outage rates of thermal generators,
- Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022, and
- Limiting natural gas (NG) capacity by 5%, 10%, 15%, 25%, and 35%.

No changes, other than those mentioned above, were made to the Y20 FC resource mix or transmission topology.

Observations and Next Steps

Takeaways

WECC applied three types of extreme-cold-related elements: high loads, low wind/solar output, and doubled forced outage rates. In the year 20 simulation, when only one extreme-cold-related element was applied, the system performed as expected, and there was no unserved load. When cold weather elements were compounded, there was unserved load. The unserved load increased as more cold weather elements increased. Figure 1 shows a breakdown of unserved load for each case. See Tables 3 and 4 for a description of each case.

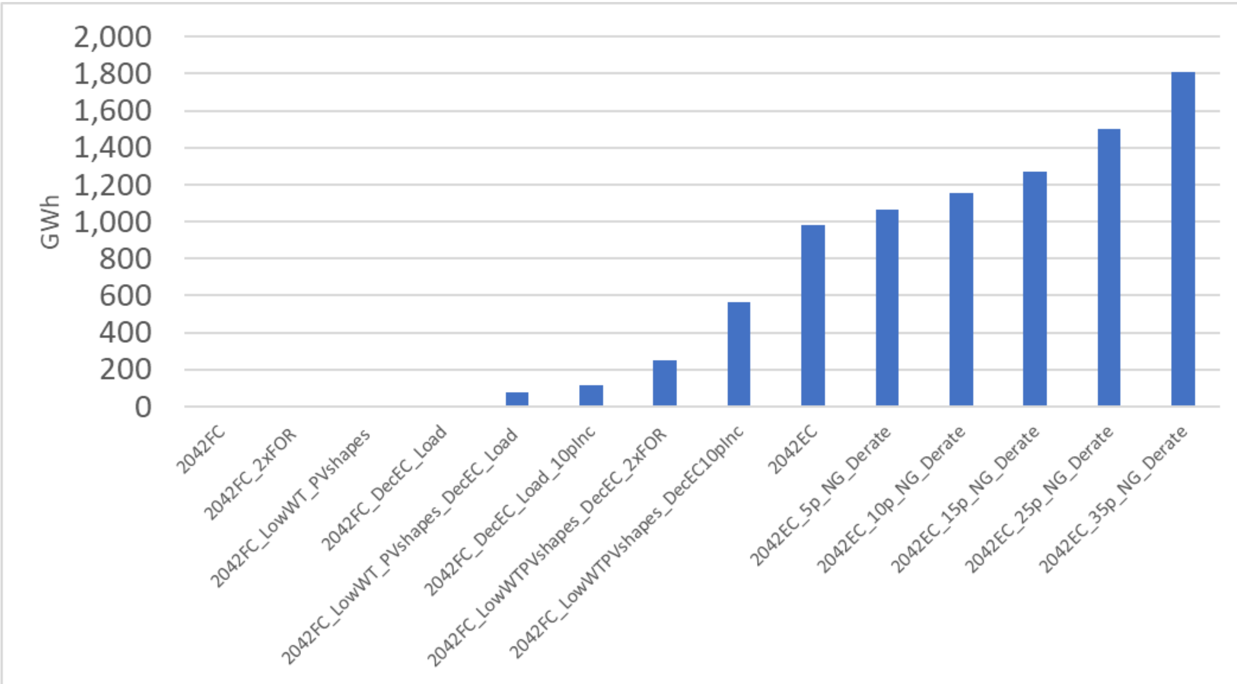

Figure 1: Unserved Load by Case (GWh)

The hours most susceptible to unserved load throughout the day leaned toward hour 1 (because of the influence of energy storage charging), and hours 7 and 8.

Transmission flows increase to the area of the system with the tightest operating margin until generation resources run out, which causes unserved load more broadly across the WI. Figure 3 shows the net subregional transfers, notice the increase in net flows going from the southern part of the WI to the north when comparing the Y20 FC case and the 2042EC_15% NG Derate case.

Observation 1: The system appears to be more sensitive to extreme cold weather events in the 20-year time frame than in the 10-year time frame. This is due to the characteristics of the new resource mix modeled in year 20, which includes an increase in wind and solar and a decrease in coal and natural gas. The results of this study are not absolute, but they indicate a risk in how the system may handle extreme cold weather events in 20 years.

Next Step: To better understand this risk, WECC and industry need to have more detailed information about 20-year predictions for loads and resources, including the effective load carrying capabilities of variable resources to more accurately model year 20 futures.

Observation 2: The study results show that hours 1, 7, and 8 were most susceptible to unserved load; however, this is due to the way the tool models energy storage, particularly for hour 1. The timing of the unserved load was heavily influenced by the energy storage charging schedule simulated in WECC's production cost model (PCM). At the time of this study, the PCM software was only able to cycle energy storage over a one day, rather than multi-day cycling. More accurate and realistic energy storage modeling will help WECC better simulate and understand the risks and the role of energy storage. If the software was able to cycle energy storage over multiple days, the energy storage may have behaved differently.

Next Step: WECC, in cooperation with the industry, should implement software enhancements to modeling capabilities to enable multi-day storage cycling to help analyze storage operation, dispatch, and commitment during extreme cold weather conditions in a more realistic manner.

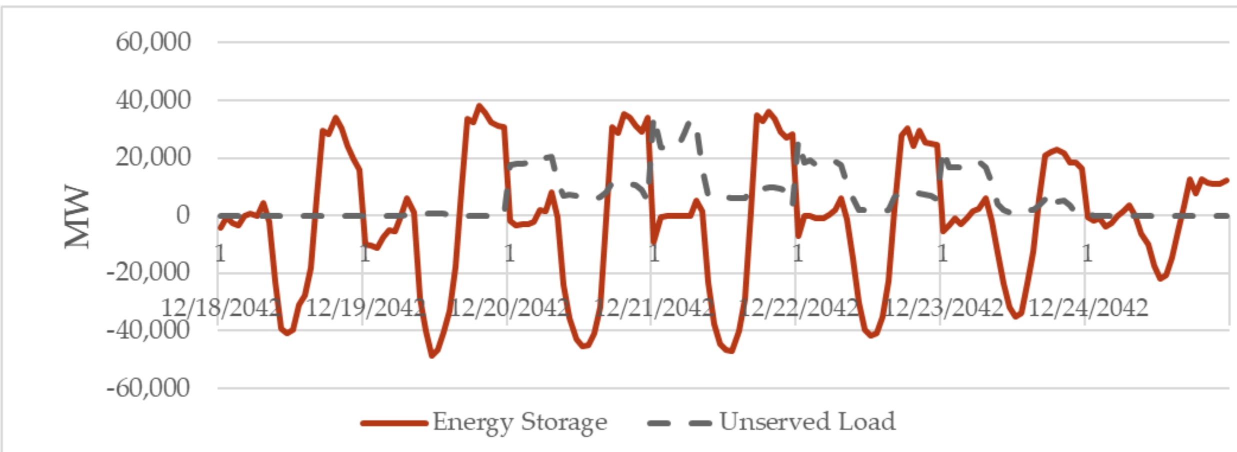

Figure 2: 2042EC_15% NG Derate Case Energy Storage and Unserved Load (MW)

Observation 3: In this study, the system relied heavily on natural gas generation to prevent or decrease unserved load. Given the effects that extreme cold weather events can have directly on the gas system, heavy reliance on gas generation during these events is a risk.

Next Step: WECC and the industry should understand how risks to the natural gas system can impact the electric sector reliability during extreme events.

Observation 4: One challenge in running this study was the lack of accurate data and robust predictions for weather and system conditions in the 20-year time frame. This emphasizes the need to continually maintain datasets for studying extreme weather events. Detailed weather data aligned with electric system data, such as generation and load data, will be needed to facilitate weather event studies. Understanding how cold weather affects natural gas unit operation and fuel supply is going to be crucial to help plan for future extreme weather events.

Next Step: The industry should:

- Assess and understand how extreme cold weather conditions affect the natural gas system and how risks to the natural gas system can affect the electric sector's reliability during extreme events.
- Correlate detailed weather data with electric system data, such as generation and load data, to facilitate weather event studies.

Observation 5: On many WECC paths, transmission flowed from south to north more during the extreme weather event cases to serve the load in the northern part of the WI, where the cold event was modeled to be most severe. This may signal a more substantial change in transmission use patterns, particularly during widespread extreme events.

Next Step: WECC and the industry should consider the following.

- Model new transmission projects that are under development—planned and needed—under various system conditions (scenarios) to evaluate the effect on transmission use and flows. WECC should plan to include large, planned transmission lines that are expected to come into service before 2033 and, if possible, additional transmission that will be needed before 2043.
- WECC should also explore and understand the reliability implications of reverse flows on major WECC paths.
- Assess the value of inter-subregional transmission to help mitigate impacts.

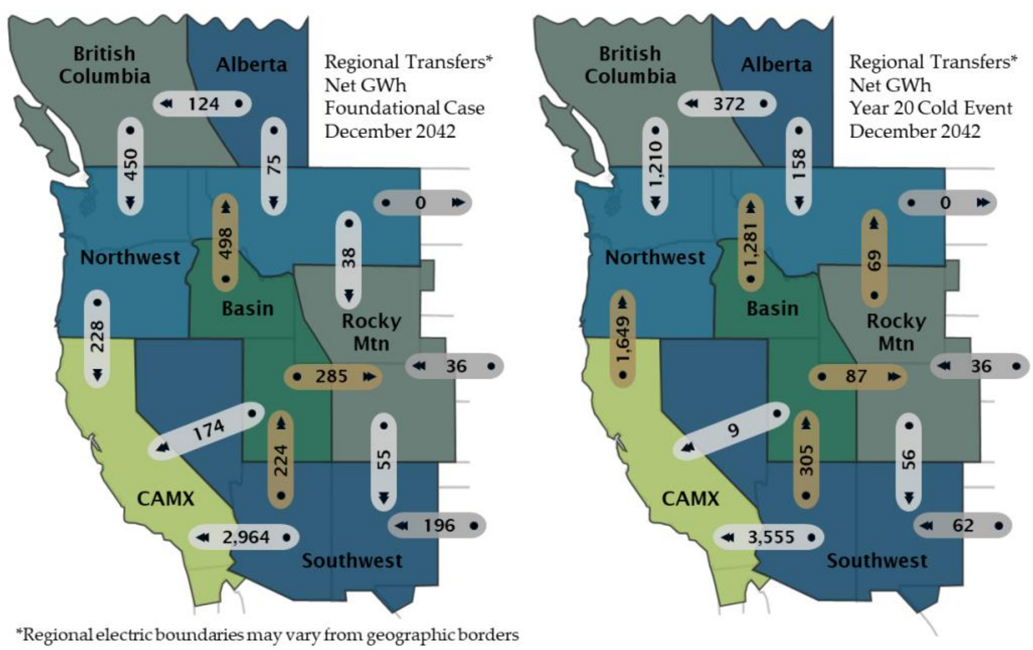

Figure 3: Subregional Net Transfers Y20 FC_December versus 2042EC_15% NG Derate Case

WECC conducts its study work in partnership with stakeholders. WECC would like to thank all the stakeholders who participated in this study.

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Background and Purpose

Extreme cold weather events stress the system by increasing loads while simultaneously decreasing wind and solar production, decreasing natural gas availability, and increasing forced outages of system generators. The frequency and intensity of extreme weather events is increasing and, in some cases, extreme events are widespread. The purpose of this study is to identify potential impacts of an extreme cold weather event on the reliability of the bulk power system (BPS) 20 years in the future.

Extreme weather can have different adverse effects on the power system. Those effects relate to weather intensity or temperature, duration of extreme temperature, geography or location, infrastructure, load pockets and populations, and resource portfolios. Extreme cold weather events in the Western Interconnection typically last between five and seven days.[1] The challenges associated with cold weather events include:

- Inconsistent temperatures across a cold weather event, with a ramp-up to the coldest day followed by a warmup.
- Increase in heating load in load pockets where electric heat is used.
- Frozen generation equipment, particularly when equipment is not winterized.
- Fuel supply impacts causing generation derates and outages.
- Changes in wind and solar patterns, affecting generation and sometimes leading to reduced solar output or "wind drought" for multiple days during an extreme cold event.

Compounding these challenges with the fact that every cold event is different makes modeling, planning for, and operating the system during a cold weather event very difficult. In this study, WECC chose a representative cold weather event to observe system performance under discrete sets of conditions. The results should be interpreted as indicative of general potential areas of concern rather than absolute risks.

Approach

WECC simulated several combinations of extreme cold weather assumptions set in December 2042 to see when the modeled system had difficulties serving load. See the Case Assumptions section for case details. To build the December 2042 case, WECC used load profiles from Winter Storm Elliott, which occurred from December 21 through December 26, 2022, and applied them to the Year 20 Foundational Case (Y20 FC). From there, WECC increased the load by an additional 10% to represent more extreme cold temperatures and used low wind and solar shapes to represent worst-case scenario for wind and

[1] See Pacific Northwest National Lab's (PNNL) Characterizing Heat Waves and Cold Snaps in the Western Interconnection

solar output. The forced outage rate for generation was doubled, and natural gas derates were included to mimic natural gas fuel disruptions.

Winter Storm Elliott resulted from an extratropical cyclone that created blizzard conditions, high snowfall, and record cold temperatures across most of the United States and parts of Canada. The coldest days of this extended event were December 22 and 23, when temperatures reached all-time lows across much of the West. See Table 1 and Figure 4. The storm caused over 100 deaths, delayed flights, and caused road closures and power outages. See the Appendix for more information.

WECC also looked at this event in the year 10 horizon in the Year 10 Extreme Cold Weather Event Study.

Table 1: Record Temperatures in Western States During Winter Storm Elliott

City	Temperature
Butte, Montana	-38° F
Casper, Wyoming	-42° F
Denver, Colorado	-18° F
Edmonton, Alberta	-40° F
Pullman, Washington	-20° F

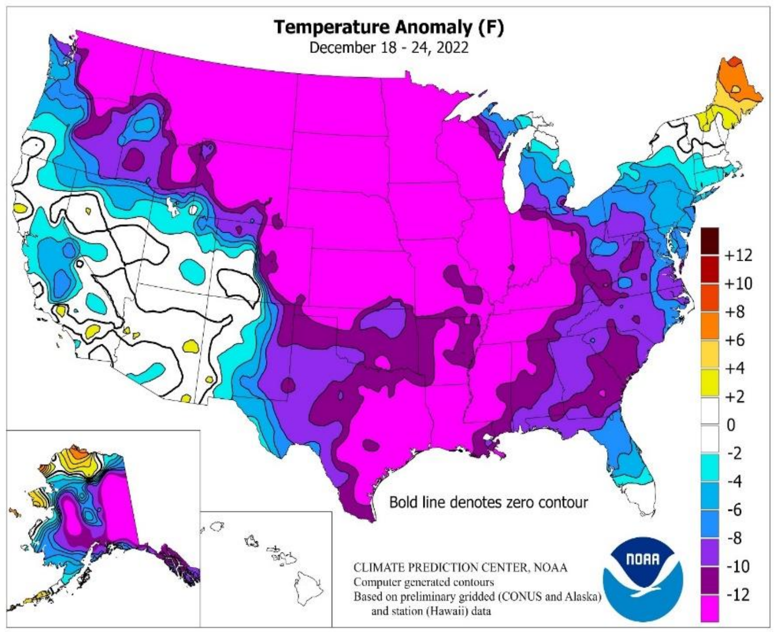


Figure 4: Temperatures Anomaly, Winter Storm Elliott, December 2022

Starting Case Assumptions

WECC used its Y20 FC as the starting point for this assessment. The Y20 FC represents year 2042. WECC uses the Y20 FC as a baseline case for its year 20 studies as it represents a possible business-as-usual future scenario.[2] The Y20 FC does not represent the expected future, but rather a resource-balanced starting point for studies of year 20, or 2042.

[2] For more information on WECC Year 20 Foundational Case (Y20 FC). The Y20 FC is the baseline for three year 20 studies: Extreme Heat Event, Extreme Cold Event, and Compound Load Impacts.

WECC built the Y20 FC on its 2032 Anchor Data Set Production Cost Model (2032 ADS) with a focus on updating the business-as-usual future loads and resources to reflect possible conditions in 2042. Some case elements—such as future technologies, transmission, and pricing—were not updated and remain the same as the 2032 ADS. The 2032 ADS only includes transmission that is in service in 2032 and does not include transmission that is under construction, planned, or necessary beyond 2032. To compensate for this in the Y20 FC, WECC placed new generation assets near load centers, so new transmission lines were not needed. See Figure 5: Year-20 Foundational Case Composition.

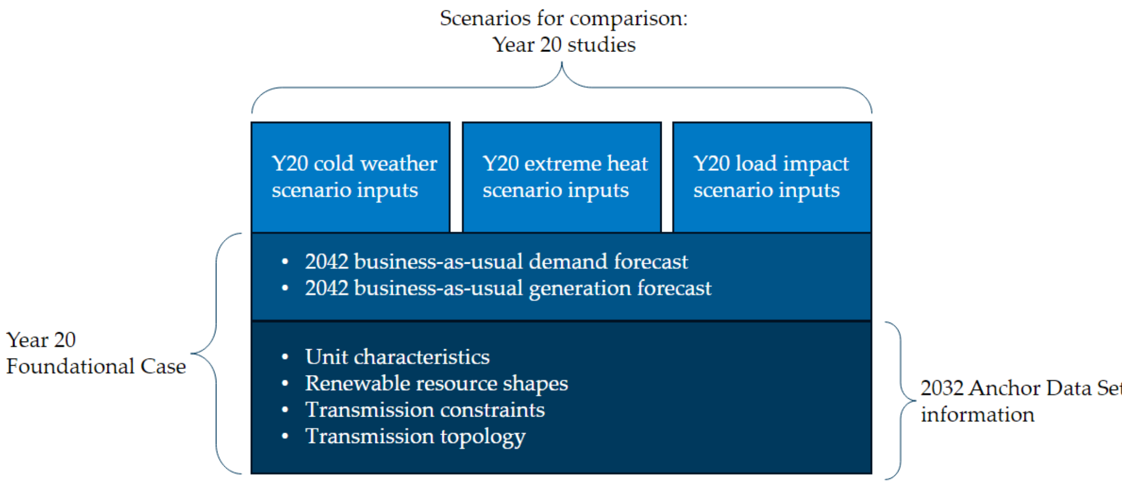


Figure 5: Year-20 Foundational Case Composition

Western Interconnection Subregions

WECC divided the interconnection into seven subregions. See Figure 6.

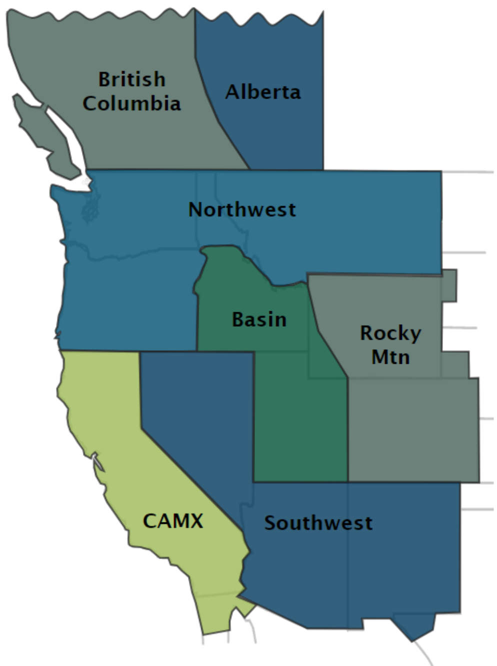


Figure 6: WECC subregions and Balancing Authorities

Study Assumptions

Load Assumptions

To create a cold weather load profile for 2042, WECC started with load shape data from Winter Storm Elliott and increased the magnitude for 2042. The resulting load profiles are referred to as Year 20 Cold Loads. From there, WECC increased the Year 2042 Cold Loads by 10% to reflect a more extreme cold event than the 2022 event. The load increase was ramped up 0.5% each hour on December 19 until it reached 10% above the base load profiles in the Y20 FC, then ramped down in the same way starting on December 23. See Figure 7.

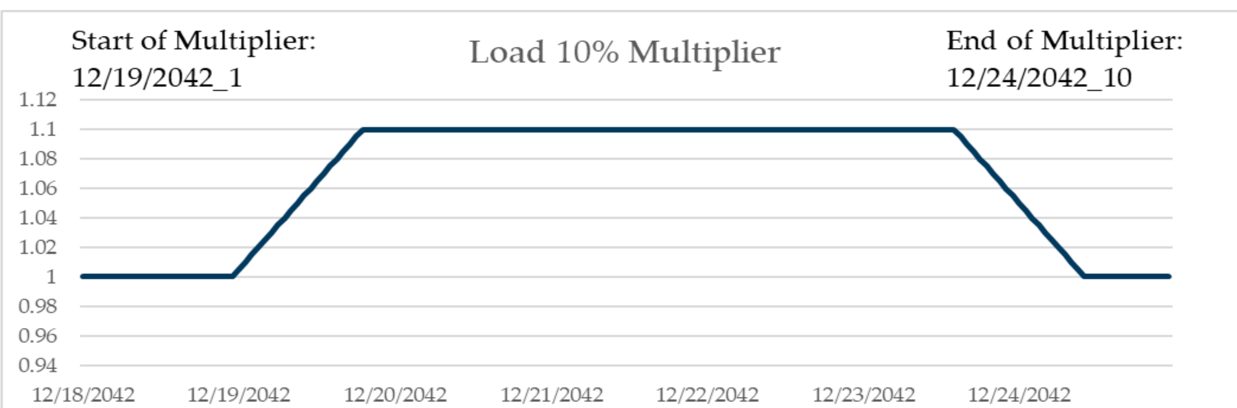


Figure 7: Western Interconnection load assumptions with 10% increase

A 10% increase on a load that is in the 50% load distribution (1-in-2), now becomes a load in the 92%–93% (1-in-12.5 [8%] to 1-in-14 [≈7%]) load distribution. This 10% load increase was applied to all areas system-wide during the event.

Generation Availability Assumptions

Forced Outage Rate Assumptions

WECC doubled the forced outage rates in the Y20 FC for thermal generators in the Alberta, British Columbia, Northwest, Rocky Mountain, and Basin subregions. For perspective, the highest forced outage rate in Texas during Winter Storm Uri in 2021 was three times greater than normal. However, since generation is typically winterized in the studied areas in the West, WECC used a lower—but still substantial—increase, assuming the forced outage rates would not be as significant.

Wind and Solar Assumptions

Wind and solar generators can have very different output patterns during extreme cold events, and sometimes have decreased output during parts of the cold event. To model solar and wind conditions, WECC evaluated historical generation data to identify the days of lowest combined production of wind and solar in the interconnection. WECC then overlayed these days of low wind and solar output on the days of the heaviest load due to extreme cold weather to represent an extreme scenario with high loads and low wind and solar output. “Wind droughts,” where wind is calm over a large area for multiple days, are common during extreme cold events; however, this study did not consider a specific wind drought during the cold weather event.

Natural Gas Derates

During cold weather events like Winter Storm Elliott and Winter Storm Uri, not only can natural gas generators be forced out of service due to freezing generator system elements, but natural gas derates and supply issues can also occur, compounding the risks posed by the event. To assess the potential impact of natural gas derates during an extreme cold weather event in the West, WECC studied five derate levels: 35% (peak derate experienced during Winter Storm Uri), 25%, 15%, 10% and 5%. See Table 2 for details about each scenario. Because WECC’s PCM does not model gas storage, the natural gas derates were modeled as capacity derates. For example, a 15% derate resulted in a 15% reduction in capacity for affected natural gas generators. WECC applied full natural gas derates to the Alberta, British Columbia, Northwest, Rocky Mountain, and Basin subregions. These subregions are more affected by the low temperatures during these events than subregions farther south. Northern California is generally warmer than the northern parts of the Western Interconnection; however, it is supplied by the same natural gas pipelines and infrastructure, so it may be affected, but to a lesser degree. To simulate this, WECC used a reduced derate of about half the full derate for Northern

California. The natural gas derates were modeled to start on December 19 on hour 5 and end on December 23 on hour 22. See Table 2 for a description of the natural gas derates.

Table 2: Assumptions for Extreme Cold Event Cases

Scenario:	Assumptions:
5% natural gas derate	• 5% natural gas derate in Alberta, British Columbia, Northwest, Rocky Mountain, and Basin subregions • 2.5% natural gas derate in Northern California
10% natural gas derate	• 10% natural gas derate in Alberta, British Columbia, Northwest, Rocky Mountain, and Basin subregions • 5% natural gas derate in Northern California
15% natural gas derate	• 15% natural gas derate in Alberta, British Columbia, Northwest, Rocky Mountain, and Basin subregions • 7.5% natural gas derate in Northern California
25% natural gas derate	• 25% natural gas derate in Alberta, British Columbia, Northwest, Rocky Mountain, and Basin subregions • 10% natural gas derate in Northern California
35% natural gas derate	• 35% natural gas derate in Alberta, British Columbia, Northwest, Rocky Mountain, and Basin subregions • 17.5% natural gas derate in Northern California

Case Assumptions

In addition to the foundational case, WECC modeled 13 cases in this analysis. WECC built all the study cases similarly, so each case includes the Y20 FC assumptions in addition to the listed assumptions. See Tables 3 and 4 for descriptions of each case.

Table 3: 2042 Foundational Case Description

Case Name:	Assumptions:	Notes:
Y20 FC/Y20 FC_December	The Y20 FC was run for the entire year of 2042 but, for this study, only December is being compared from the Y20 FC.	This is the 2042 Foundational Case (Y20 FC), the results of the extreme events are compared against these results.

Table 4: Study Case Descriptions

Case Name:	Assumptions (in addition to the 2042 Foundational Case):
Y20 FC_2xFOR	• Doubling the forced outage rates of thermal generators

Y20 FC_LowWT_PVshapes	• Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022
Y20 FC_DecEC_Load	• Mimicking the December 2022 event load shape for 2042
Y20 FC_Low_WT_PVshapes_DecEC_Load	• Mimicking the December 2022 event load shape for 2042 • Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022
Y20 FC_DecEC_Load_10pInc	• Mimicking the December 2022 event load shape for 2042 • Increasing the load by an additional 10 percent beyond the event load shape for 2042
Y20 FC_LowWTPVshapes_DecEC_2xFOR	• Mimicking the December 2022 event load shape for 2042 • Doubling the forced outage rates of thermal generators • Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022
Y20 FC_LowWTPVshapes_DecEC10pInc	• Mimicking the December 2022 event load shape for 2042 • Increasing the load by an additional 10 percent beyond the event load shape for 2042 • Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022
2042EC	• Mimicking the December 2022 event load shape for 2042 • Increasing the load by an additional 10 percent beyond the event load shape for 2042 • Doubling the forced outage rates of thermal generators • Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022
2042EC_5% NG Derate	• Mimicking the December 2022 event load shape for 2042 • Increasing the load by an additional 10 percent beyond the event load shape for 2042 • Doubling the forced outage rates of thermal generators • Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022 • Limiting natural gas capacity by 5%
2042EC_10% NG Derate	• Mimicking the December 2022 event load shape for 2042 • Increasing the load by an additional 10 percent beyond the event load shape for 2042 • Doubling the forced outage rates of thermal generators • Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022 • Limiting natural gas capacity by 10%
2042EC_15% NG Derate	• Mimicking the December 2022 event load shape for 2042 • Increasing the load by an additional 10 percent beyond the event load shape for 2042 • Doubling the forced outage rates of thermal generators

	• Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022 • Limiting natural gas capacity by 15%
2042EC_25% NG Derate	• Mimicking the December 2022 event load shape for 2042 • Increasing the load by an additional 10 percent beyond the event load shape for 2042 • Doubling the forced outage rates of thermal generators • Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022 • Limiting natural gas capacity by 25%
2042EC_35% NG Derate	• Mimicking the December 2022 event load shape for 2042 • Increasing the load by an additional 10 percent beyond the event load shape for 2042 • Doubling the forced outage rates of thermal generators • Decreasing the output of wind and solar generation to the lowest combined solar and wind output profiles from December 2022 • Limiting natural gas capacity by 35%

Models and Data

Models

WECC used a production cost modeling approach for this study using Hitachi Energy's GridView.[3] The following is a summary of the GridView settings WECC used for all cases in this study.

- Market Type Selection: Day-ahead Market
- Monte Carlo Simulation: Enabled
- MIP Options: MIP Relaxed Method
- General Options: Recalculate Base Flow, Recalculate GSF, Look Ahead Logic, Enable MIO, Generator Reserve Distribution, Generator Exempt, Ramp Rate Enforced in Unit Commitment, Quick Start Commitment, Enables Spillage, Bank Hydro
- Pumped Storage: 4-Daily Schedule on Price
- Emission: Calculated Emission Cost Model
- Hydro Dispatch Option: 2-Subregion Load-Wind-Solar
- Loss Options: No Loss Model (Required for the way the resource mix was modeled for this study)
- Load Shedding Penalty: Bus Level 2,000 $/MWh, Area Level 4,000 $/MWh

[3] GridView is an integrated electric power market and system simulation application. WECC used version 10.3.62.

Load Data

WECC evaluated loads for the last several years using the EIA Grid Monitor database[4] and the Loads and Resources (L&R) data collection from each Balancing Authority (BA) in the Western Interconnection. WECC's L&R data collection contains hourly BA load, wind, and solar energy generation from mid-2018 to present. During Winter Storm Elliott, the load began to increase rapidly on December 19th, peaked on 22, and then dropped gradually through 23 before returning to a significantly lower load on 24. WECC replicated this pattern in the assessment, then altered the load shapes as described above in Figure 7. Figures 8 through 10 show the load growth in the Western Interconnection and the Northwest and Rocky Mountain subregions.

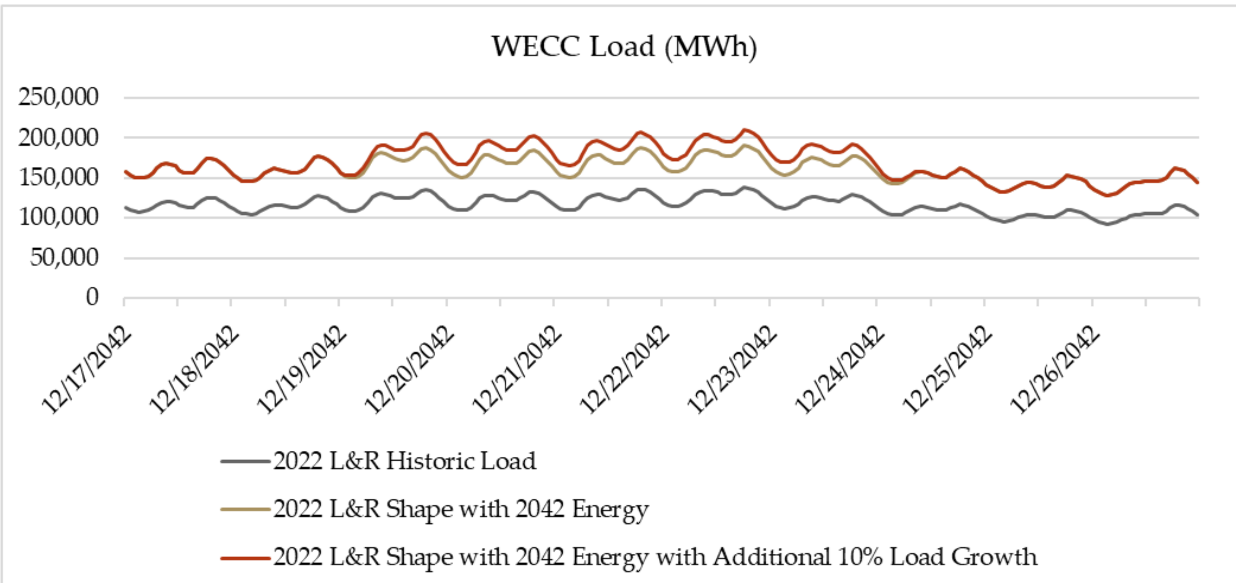


Figure 8: Simulated 2042 Load for the Western Interconnection

[4] https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48

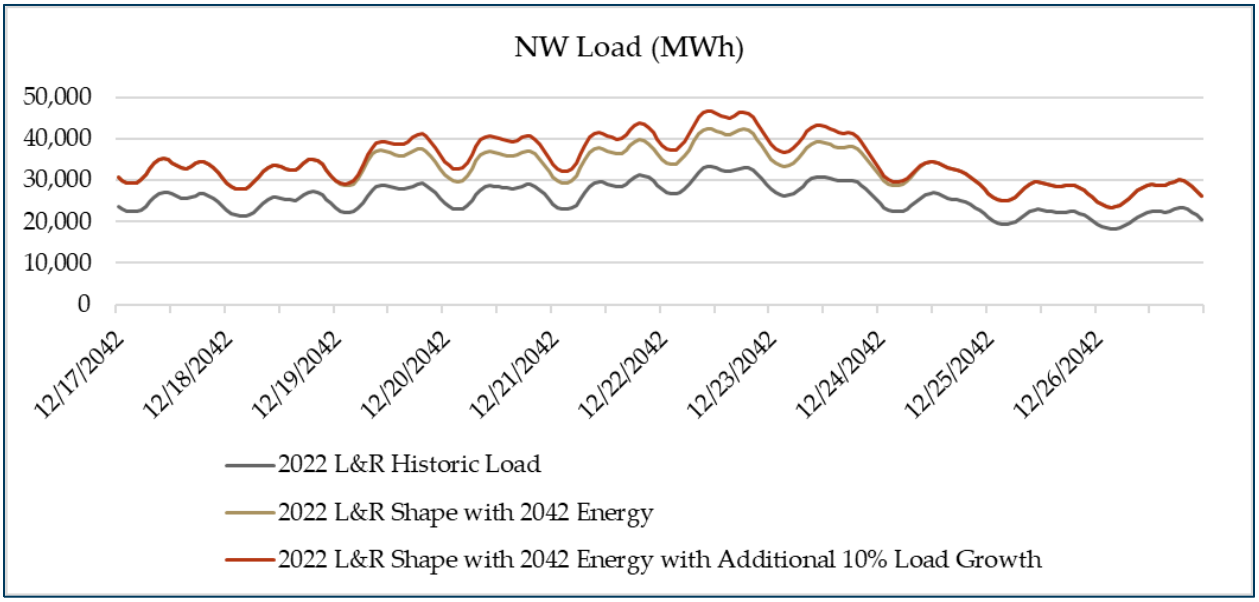


Figure 9: Simulated 2042 Load for the Northwest Subregion

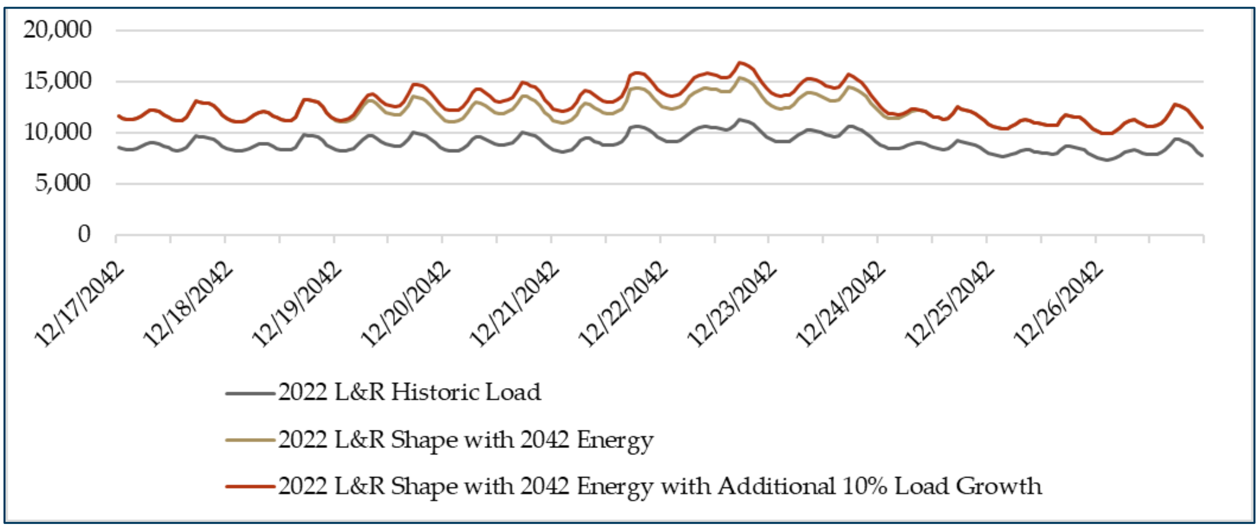


Figure 10: Simulated 2042 Load for the Rocky Mountain Subregion

Wind and Solar Generation

To model the potential impacts of reduced wind and solar generation, which often accompany cold weather events, WECC evaluated historical generation data to identify the date of lowest interconnection-wide combined production of wind and solar. This occurred on December 6, 2018. WECC used the wind and solar energy profiles from this date and paired them with load data from December 22, 2022. This represents an extreme scenario where the days of the highest load align with the days of the lowest wind and solar production, shown in Figure 11. However, this study did not consider a serious wind drought.

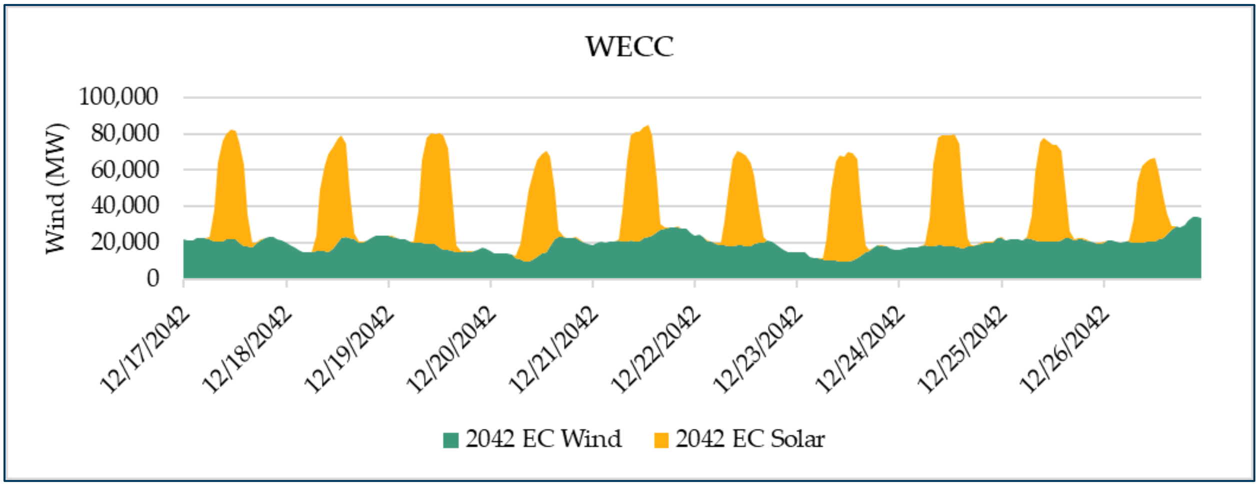


Figure 11: Simulated 2042 wind and solar shapes for the Western Interconnection.

Findings and Conclusions

Effect of Energy Storage

The energy storage charging schedule in WECC's model heavily influenced the timing of unserved load. The model optimizes energy storage on a 24-hour cycle, which means the energy storage charges and discharges in each 24-hour period. As the day starts, energy storage units are largely discharged from the night before and cannot contribute to cover morning load. As the sun ramps up in late morning and early afternoon, the energy storage begins to charge. The stored energy is discharged in the late afternoon and evening when load is highest as seen in Figure 12. This optimization pattern causes more unserved load in the morning, but the energy storage is able to contribute later, when loads are higher. This modeling limitation may not reflect actual operational practices, which charge and discharge energy storage units over several days. The limitation skews the results—the unserved load pattern would likely change with different energy storage operation and cycling. If the model had optimized energy storage over a span greater than one day, it may have pushed the energy storage discharge to another time or day, depending on how the model optimized load serving versus energy storage charging.

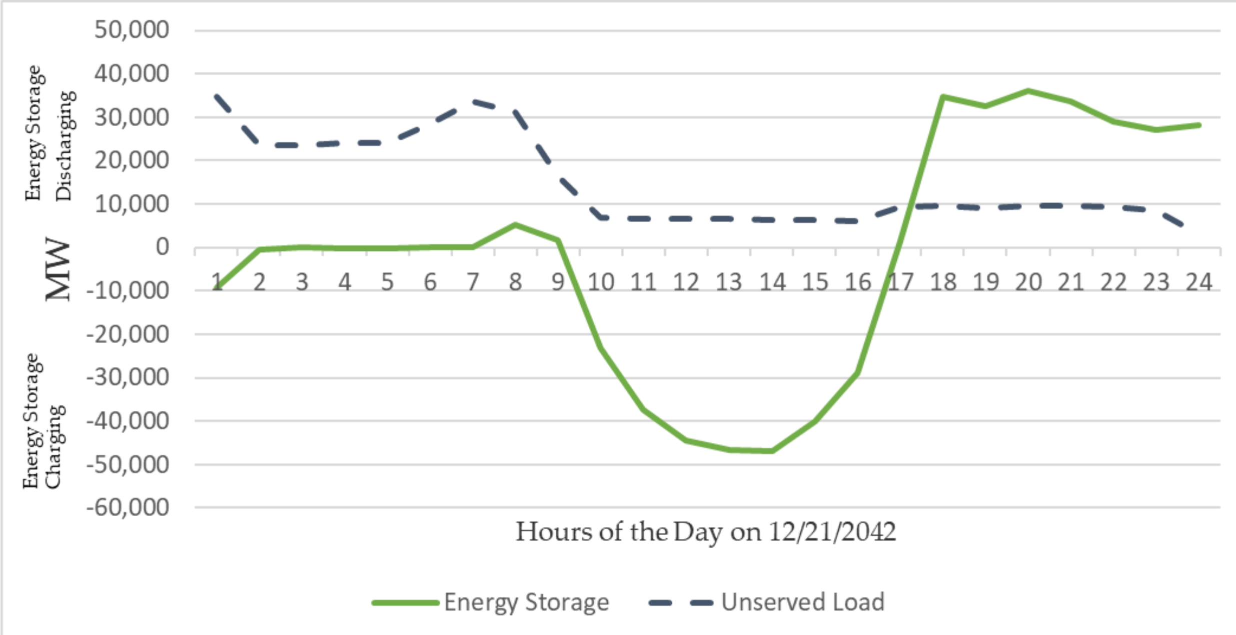


Figure 12: 2042EC_15% NG Derate Case Energy Storage and Unserved Load (MW)—Hour of the day

While energy storage mitigated much of the unserved load, unserved load was observed even during hours when energy storage was being discharged. This indicates that, regardless of the energy storage optimization, the system experienced energy shortages and was not able to serve load at times during the 2042EC_15% NG Derate case.

Figure 12 and Figure 13 show the relationship between energy storage charging and discharging and unserved load for the 2042EC_15% NG Derate case (negative MWh indicate energy storage charging) on a daily and weekly basis, respectively.

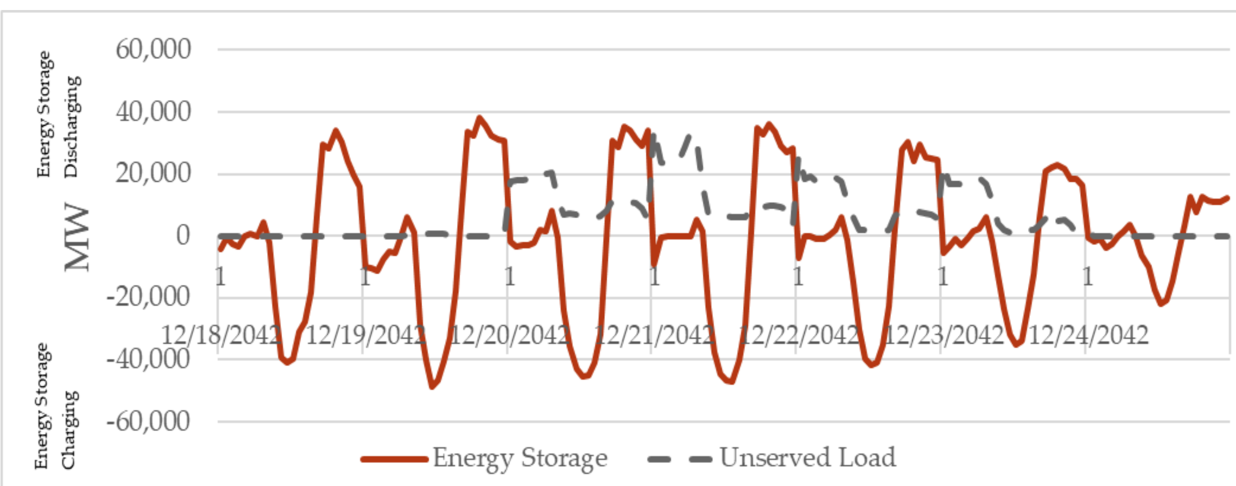


Figure 13: 2042EC_15% NG Derate Case Energy Storage and Unserved Load (MW)—Weekly

Unserved Load

Compared to WECC's [Year 10 Extreme Cold Event Study](), the year 20 results appear to show that the simulated system was more sensitive to cold weather impacts. Load loss occurred earlier in this year 20 study than in the year 10 study. For both studies, WECC applied individual cold weather impacts (high loads, low wind and solar, increased forced outages) one at a time, and then combined the impacts and added different levels of natural gas derates. In the year 10 study, unserved load did not occur until WECC applied all cold weather impacts and a 15% natural gas derate. In the year 20 case, the system did not experience load loss when a single cold weather impact was simulated. Load loss occurred once the cold weather impacts were combined, and unserved load increased as WECC added more cold weather impacts and natural gas derates as shown in Figure 14. WECC believes this is due to the characteristics of the new resource mix modeled in year 20, which includes large increases in wind and solar generation and decreases in resources such as coal and natural gas.

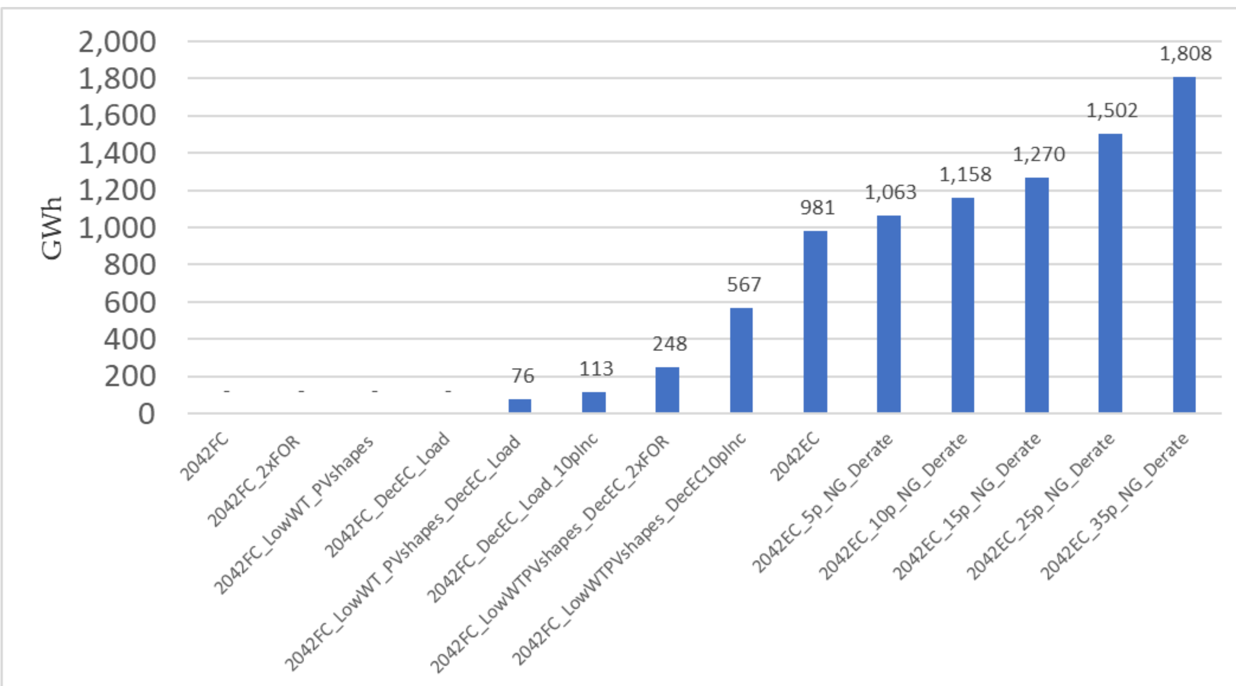
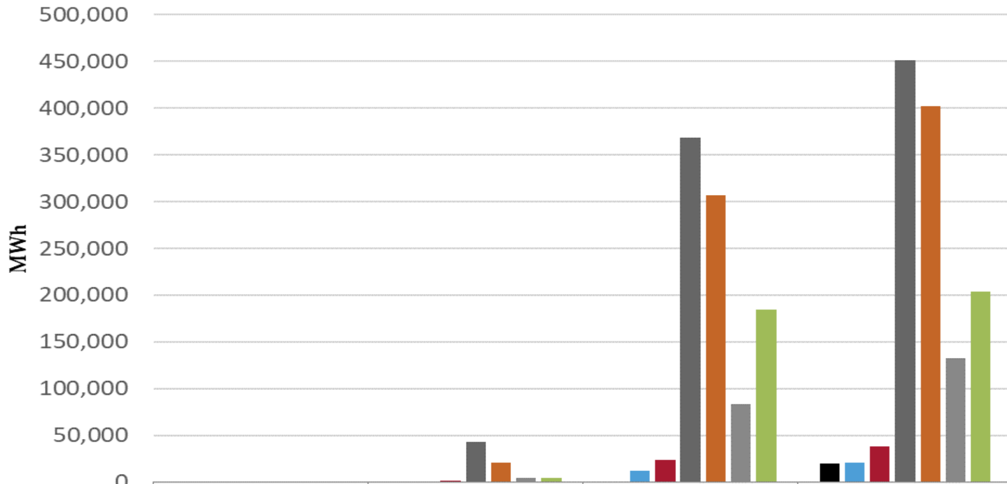


Figure 14: Year 20 Unserved Load by Case (GWh)

Figure 15 shows a breakdown of unserved load by subregion in four distinct cases for the month of December. The cases get more severe moving to the right. The two subregions with the most unserved load are California and the Northwest. Both are heavy load pockets affected by the high loads and the low wind and solar output assumptions. Even though other areas in the north are affected by high loads due to extreme cold temperatures, the areas with the heavier load pockets are shown to be most susceptible to unserved load in this study.



	2042FC	2042FC_LowWT_PVshapes_DecEC_Load	2042EC	2042EC_15p_NG_Derate
Alberta	-	-	-	19,943
British Columbia	-	1,112	12,079	20,649
Basin	-	1,459	24,165	38,302
California	-	43,314	368,345	451,382
Northwest	-	20,661	307,292	402,183
Rocky Mountain	-	4,945	84,055	133,095
Southwest	-	4,793	184,789	203,978

Figure 15: Unserved Load By Subregion (MWh)

Figure 16 shows the hourly unserved load by case for a week during the extreme cold event. As the cold assumptions get more severe from the Y20 FC to the 2042EC_15P_NG_Derate Case, the magnitude of the unserved load increases, but the pattern remains similar between each case. This identifies the more critical times of the day when generation is the shortest, which tend to be hours 1, 7, and 8.

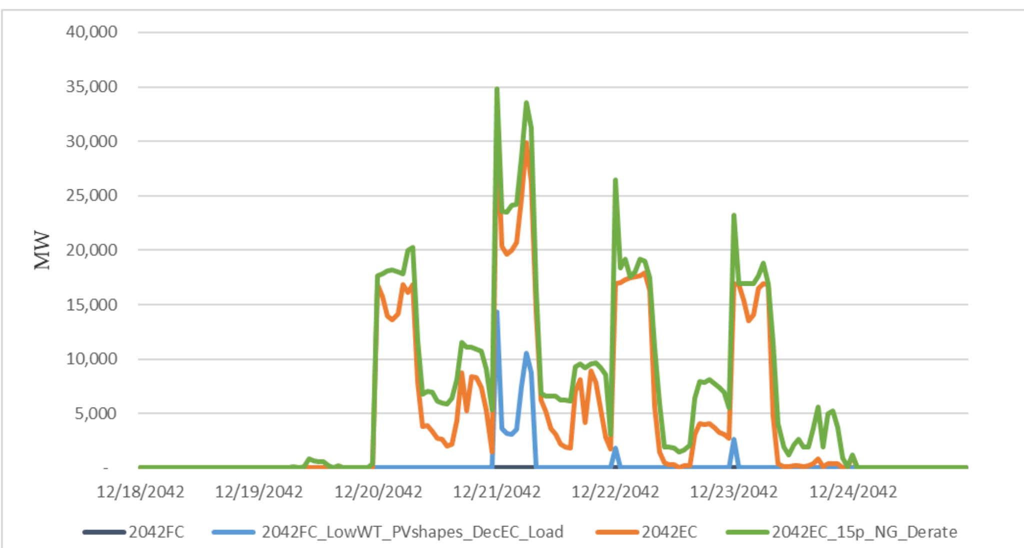


Figure 16: Interconnection Hourly Unserved Load Comparison (MW)

Figure 17 shows weekly snapshots of the generation makeup by subtype compared to load in the 2042EC_15% NG Derate case. The white space between the black line and the generation makeup is the unserved load; this shows when the generation makeup is insufficient to meet load. The most extreme part of the cold snap, with the extra 10% increase in load and the 15% NG derate, starts on December 19 and ends on December 24.

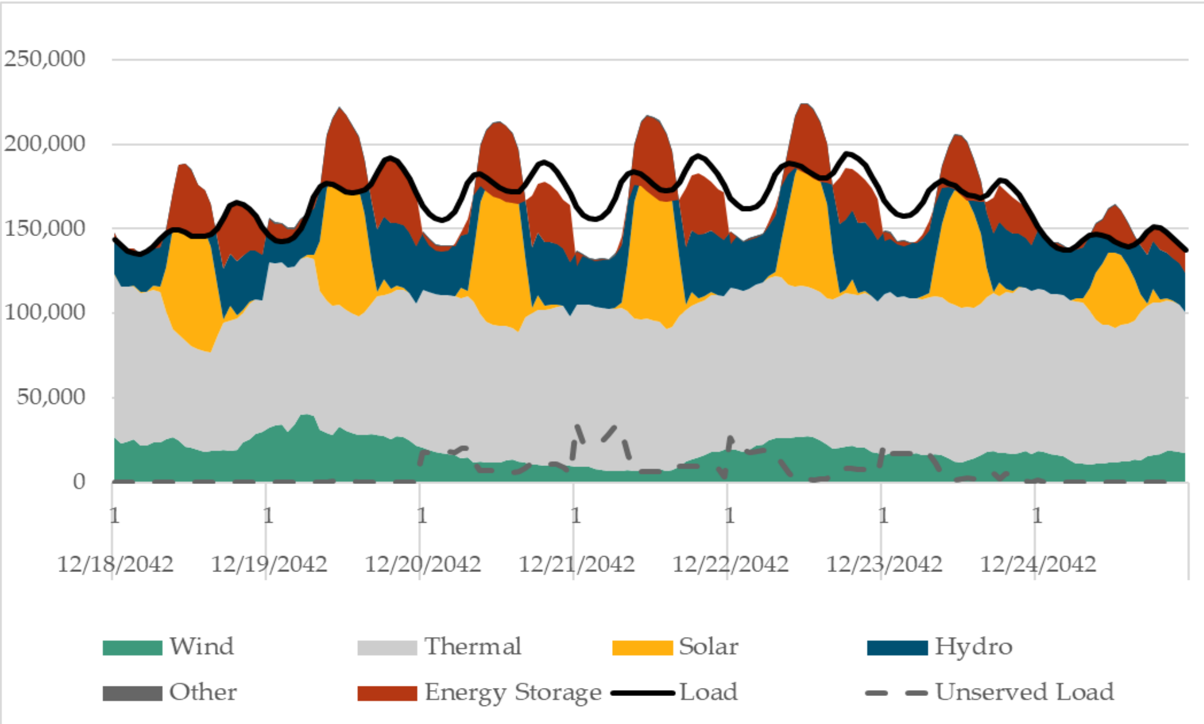


Figure 17: 2042EC_15% NG Derate Case Western Interconnection Subtype Hourly (MW)

Some hours of the day are more susceptible to unserved load than others. For the 2042EC_15% NG Derate case, the worst hour of unserved load was hour 1 on December 21, 2042. During this hour, approximately 21% of load was unserved. Hour 7 is very similar with 20% of the load unserved. (See Figure 18 for all hours of December 21, 2042). This load pattern, with the highest unserved load on hours 1 and 7, was similar across all the cases. As with the year 10 cold weather analysis, this is due to the modeling limitations for energy storage.

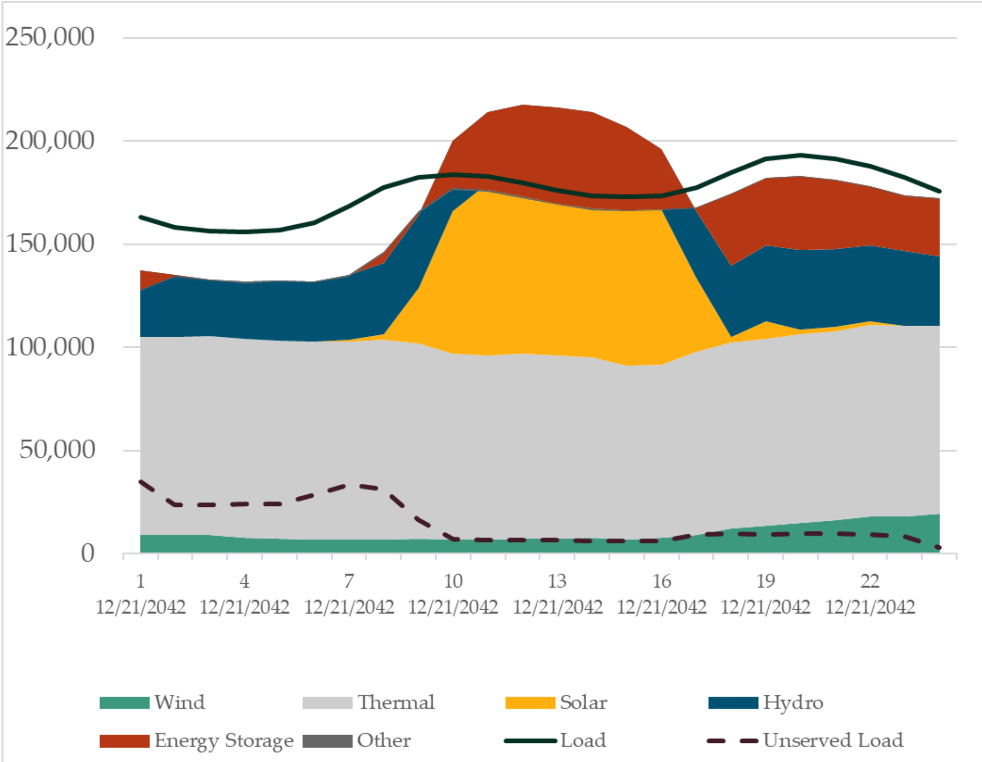


Figure 18: 2042EC_15% NG Derate Case Western Interconnection Subtype Hourly (MW)—Day 12/21/2042

Table 5 shows the hour when the most unserved load was experienced by subregion in the 2042EC_15% NG Derate case. Many subregions show hour 1 as the hour with the most unserved load. This is another result of the modeling limitations for energy storage. Figure 19 shows the number of hours when there was unserved load for each subregion, as well as for the whole interconnection. Some subregions had unserved load during the same hours of the day; as a result, the interconnection total is not a sum of the subregion totals.

Table 5: 2042EC_15% NG Derate Case—Peak Unserved Load

Subregion	Max (MW)	Date	Hour of Day with Max Unserved Load
Alberta	1,427	Dec 20	18
British Columbia	1,547	Dec 14	1
Basin	1,377	Dec 21	9
California	16,929	Dec 21	1
Northwest	8,738	Dec 21	1
Rocky Mountain	4,799	Dec 22	1
Southwest	5,768	Dec 20	1
Interconnection	**34,804**	**Dec 21**	**1**

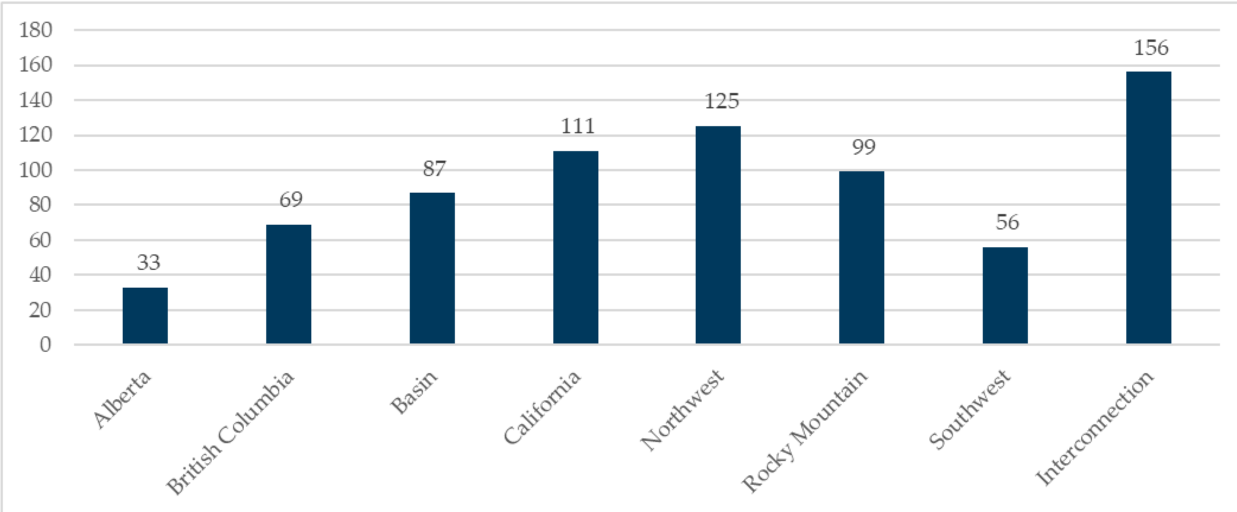


Figure 19: 2042EC_15% NG Derate Case—Number of Hours When Unserved Load Occurred in December

Reliance on Natural Gas During Extreme Cold Events

Sufficient availability of natural gas generation was critical to serve load in the extreme cold event modeled in this assessment. As the simulated extreme cold event reduced solar and wind output and increased load, the Western Interconnection relied heavily on natural gas generation. Natural gas units ran at maximum capacity but were unable to keep up with load, leading to unserved load. Figure 20 compares annual generation by subtype between the cases. Since the extreme cold cases had much less wind and solar generation, gas was primarily used to make up the deficit until the gas generation ran out. This finding is particularly important because cold weather events can cause gas supply interruptions or derates of gas generation capacity, making it risky to rely heavily on natural gas resources during these events.

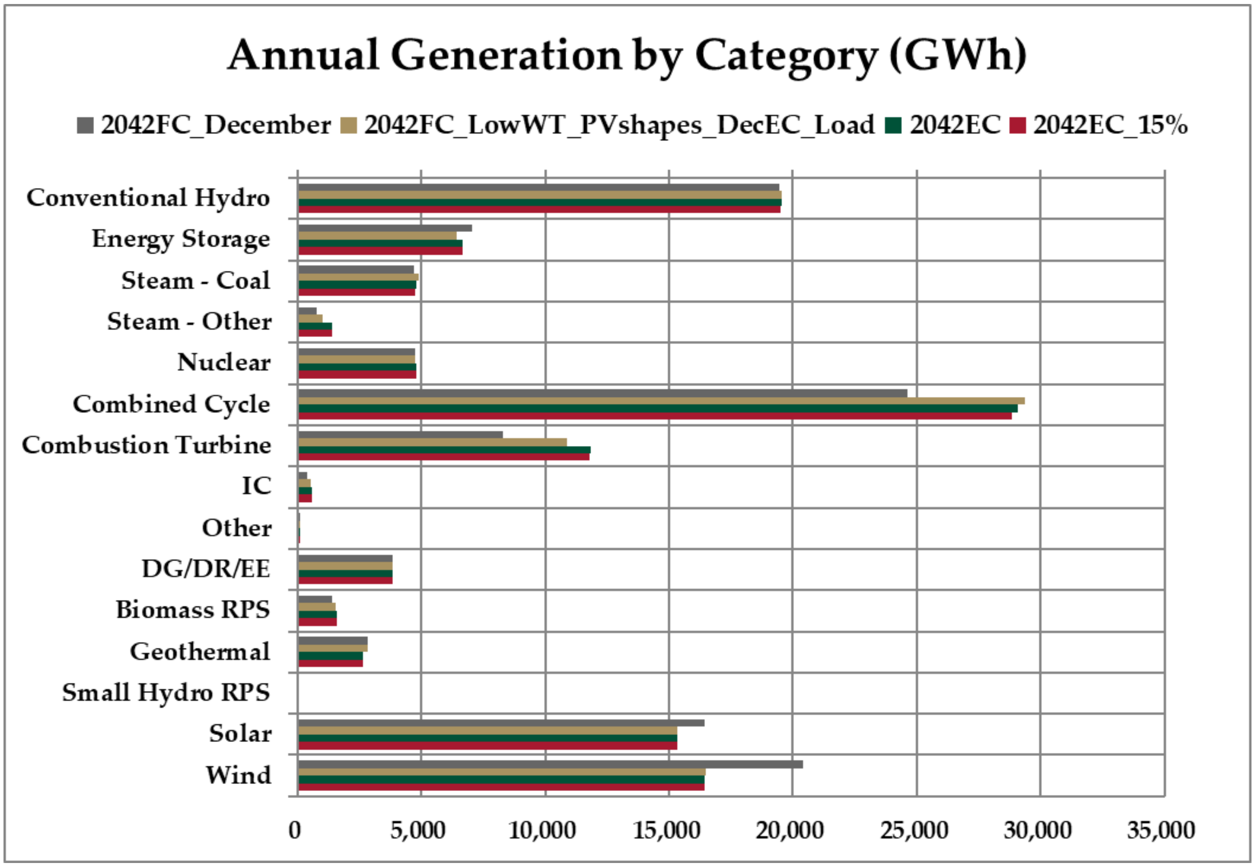


Figure 20: Annual Generation Comparison by Category or Subtype

Transmission Flows

During the modeled extreme cold event, WECC observed an increase in transmission flows going to the northern part of the Western Interconnection on several major WECC paths. Figure 21 compares the net inter-subregional transfers between the Y20 FC and the 2042EC_15% NG Derate case. Figure 22 shows the increase in net annual flows south-to-north on major WECC paths.

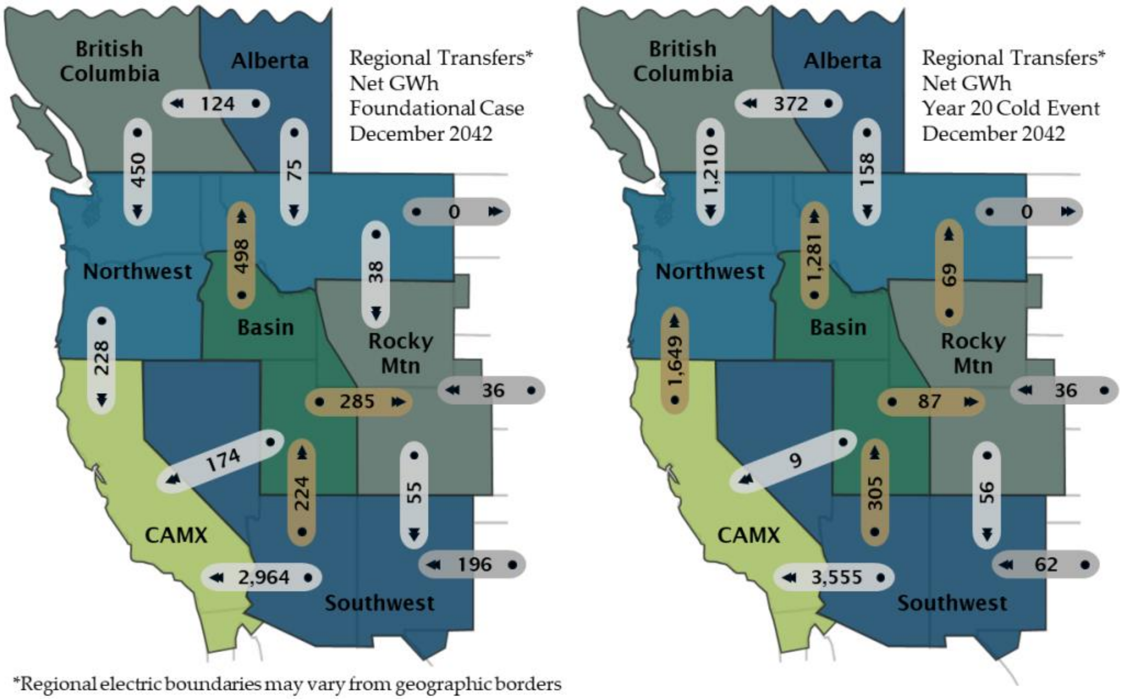


Figure 21: Subregional Net Transfers Y20 FC versus 2042EC_15% NG Derate Case

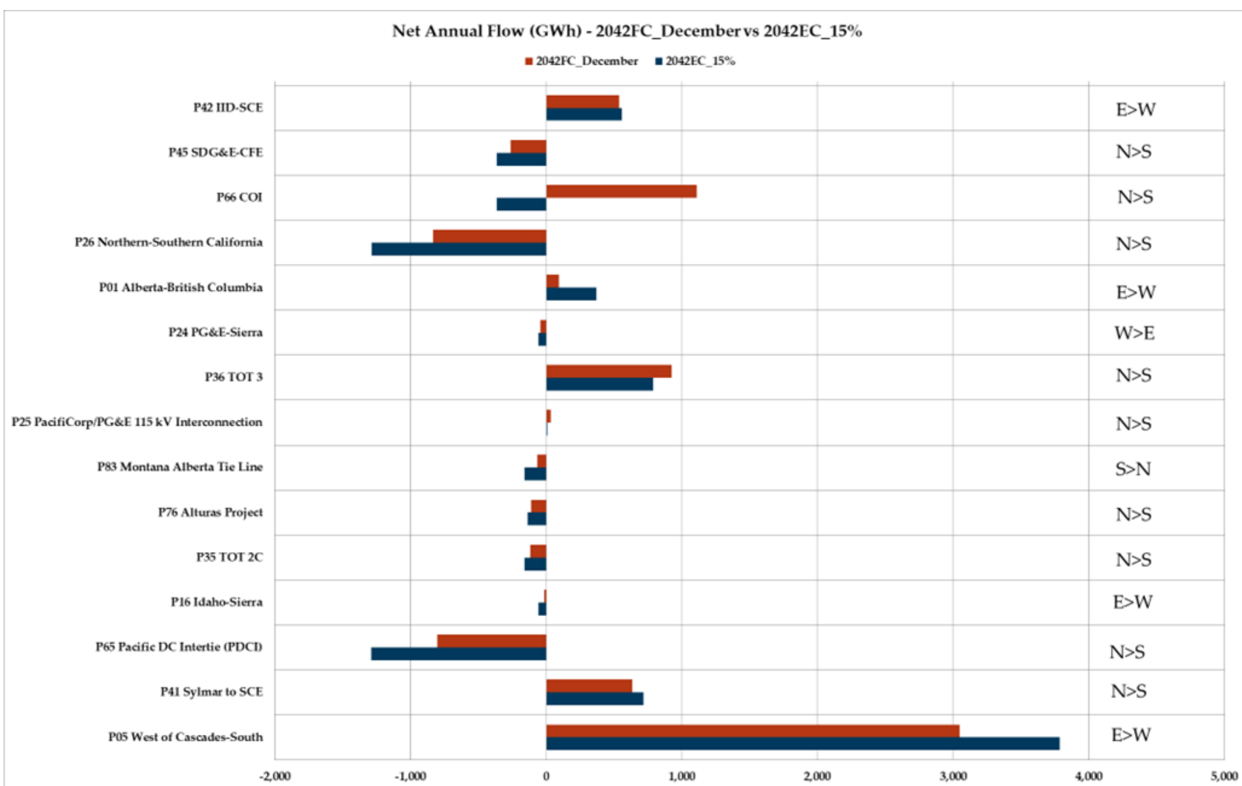


Figure 22: Net Annual Flow 2042FC versus 2042EC_15% NG Derate Case

Figures 23 through 27 show chronological hourly flow on major WECC paths. The increased flows to the north, while a result of the cold weather event, may signal a more substantial change in transmission use patterns, particularly during widespread extreme events. In most cases, the northward flow only increased, but in the case of the Path 66, the California Oregon Intertie, the predominant direction of flow was reversed. This did not cause major congestion issues in this study; however, it could have implications in real-time operations. If the ratings differ significantly in opposite directions and one direction is more restricted, the reversal of flows could lead to congestion or overloading of the path.[5]

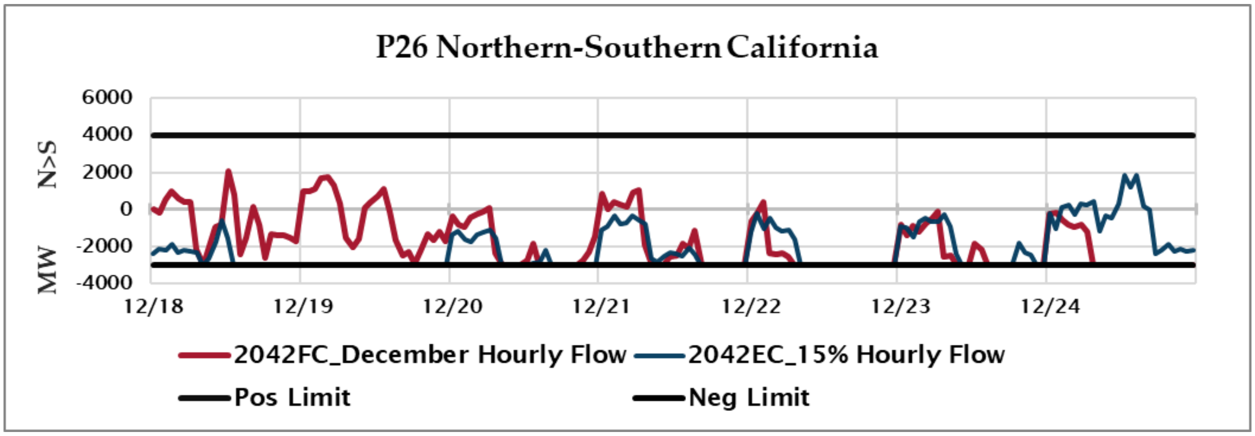


Figure 23: P26 Northern-Southern California Chronological Hourly Flows 2042EC_15% NG Derate Case

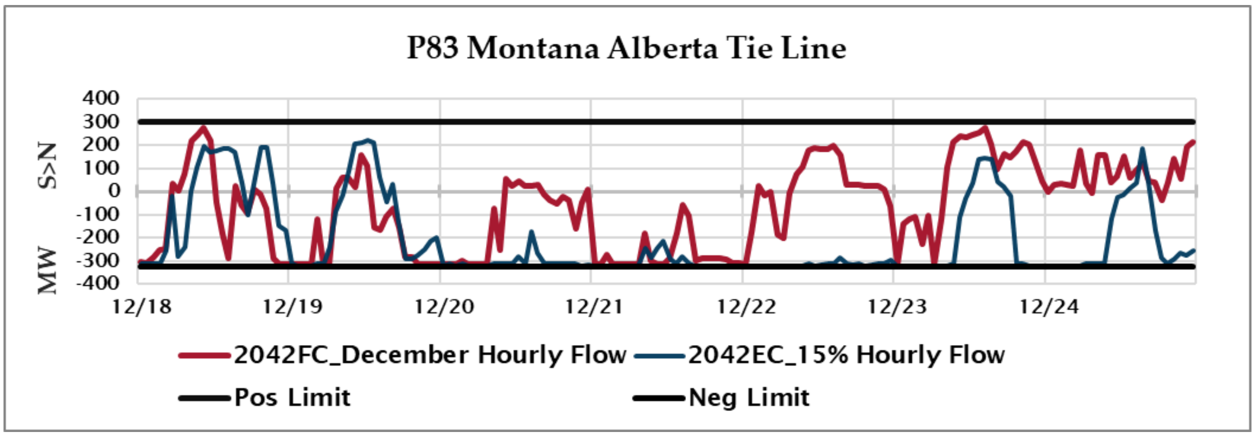


Figure 24: P83 Montana Alberta Tie Line Chronological Hourly Flows 2042EC_15% NG Derate Case

[5] WECC did not include transmission that is under construction, planned for construction, or necessary over the next 20 years in the model. WECC located new generation resources near load centers rather than in energy-rich wind and solar resource areas where they will likely be added. The resulting energy flows on existing paths in the model are only illustrative.

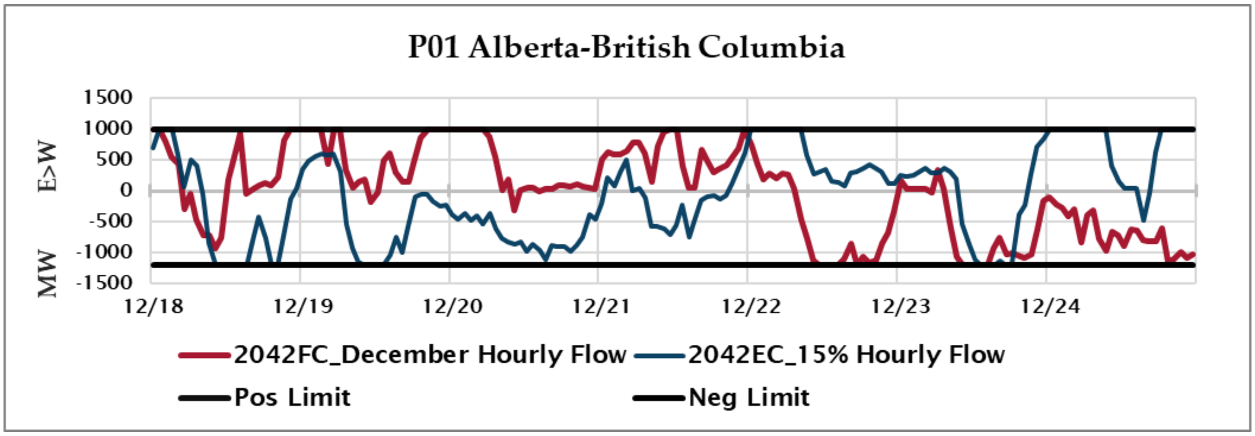


Figure 25: P01 Alberta-British Columbia Chronological Hourly Flows 2042EC_15% NG Derate Case

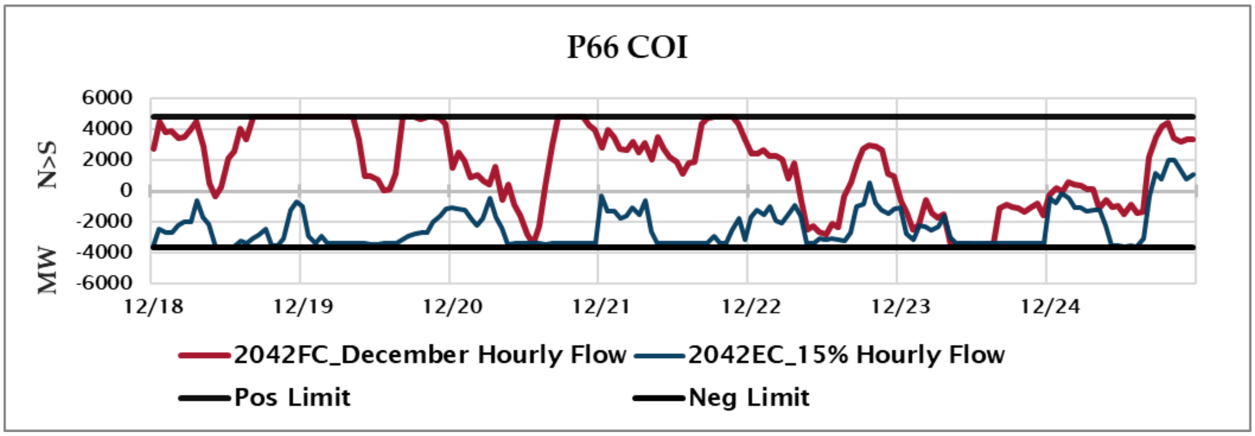


Figure 26: P66 California Oregon Intertie (COI) Chronological Hourly Flows 2042EC_15% NG Derate Case

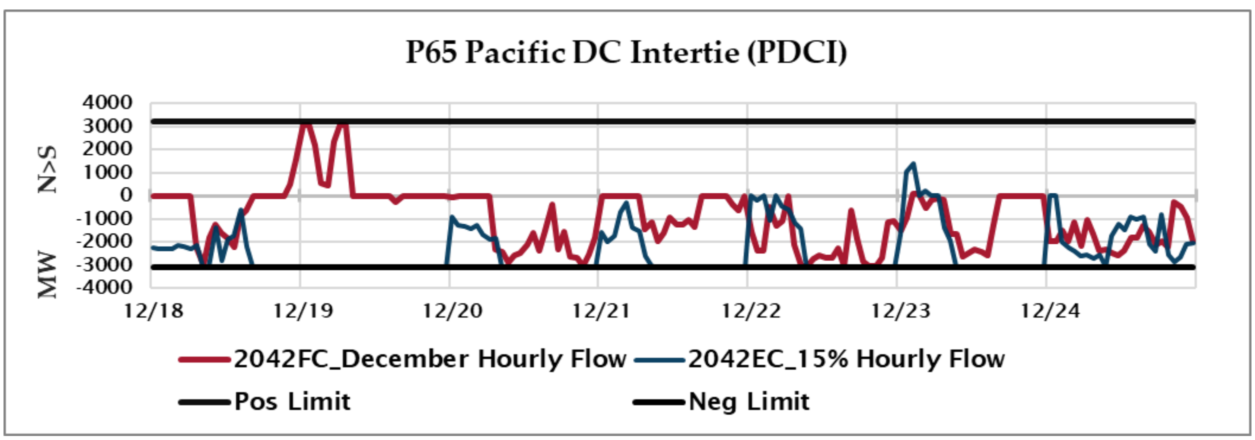


Figure 27: P65 Pacific DC Intertie Chronological Hourly Flows 2042EC_15% NG Derate Case

Observations and Next Steps

Observation 1: The system appears to be more sensitive to extreme cold weather events in the 20-year time frame than in the 10-year time frame. This is due to the characteristics of the new resource mix modeled in year 20, which includes an increase in wind and solar and a decrease in coal and natural gas. The results of this study are not absolute, but they indicate a risk in how the system may handle extreme cold weather events in 20 years.

Next Step: To better understand this risk, WECC and the industry need to have more detailed information about 20-year predictions for loads and resources, including the effective load carrying capabilities of variable resources to more accurately model year 20 futures.

Observation 2: The study results show that hours 1, 7, and 8 were most susceptible to unserved load; however, this is due to the way the tool models energy storage, particularly for hour 1. The timing of the unserved load was heavily influenced by the energy storage charging schedule simulated in WECC's production cost model (PCM). At the time of this study, the PCM software was only able to cycle energy storage over a one-day period, rather than multi-day cycling. More accurate and realistic modeling of energy storage will help WECC better simulate and understand the risks and the role of energy storage. If the software was able to cycle energy storage over multiple days, energy storage may have behaved differently.

Next Step: WECC, in cooperation with the industry, should implement software enhancements to modeling capabilities to enable multi-day storage cycling to help analyze storage operation, dispatch, and commitment during extreme cold weather conditions more realistically.

Observation 3: In this study, the system relied heavily on natural gas generation to prevent or decrease unserved load. Given the direct effects that extreme cold weather events can have on the gas system, heavy reliance on gas generation during these events is a risk.

Next Step: WECC and the industry should understand how risks to the natural gas system can affect the reliability of the electric sector during extreme events.

Observation 4: One challenge in running this study was the lack of accurate data and robust predictions for weather and system conditions in the 20-year time frame. This emphasizes the need to continually maintain datasets for studying extreme weather events. Detailed weather data aligned with electric system data, such as generation and load data, will be needed to facilitate weather event studies. Understanding how cold weather affects natural gas unit operation and fuel supply is going to be crucial to help plan for future extreme weather events.

Next Step: The industry should:

- Assess and understand how extreme cold weather conditions affect the natural gas system and how risks to the natural gas system can affect electric sector reliability during extreme events.
- Correlate detailed weather data with electric system data, such as generation and load data, to facilitate weather event studies.

Observation 5: On many WECC paths, transmission flowed from south to north more in the extreme weather event cases to serve the load in the northern part of the WI, which is where the cold event was modeled to be most severe. This may signal a more substantial change in transmission use patterns, particularly during widespread extreme events.

Next Step: WECC and the industry should consider the following.

- Modeling new transmission projects that are under development, planned and needed, under various system conditions (scenarios) to evaluate the effect on transmission use and flows. WECC should plan to include large, planned transmission lines that are expected to come into service before 2033 and, if possible, additional transmission that will be needed before 2043.
- WECC should also explore and understand the reliability implications of reverse flows on major WECC paths.
- Assessing the value of inter-subregional transmission to help mitigate impacts.

Contributors

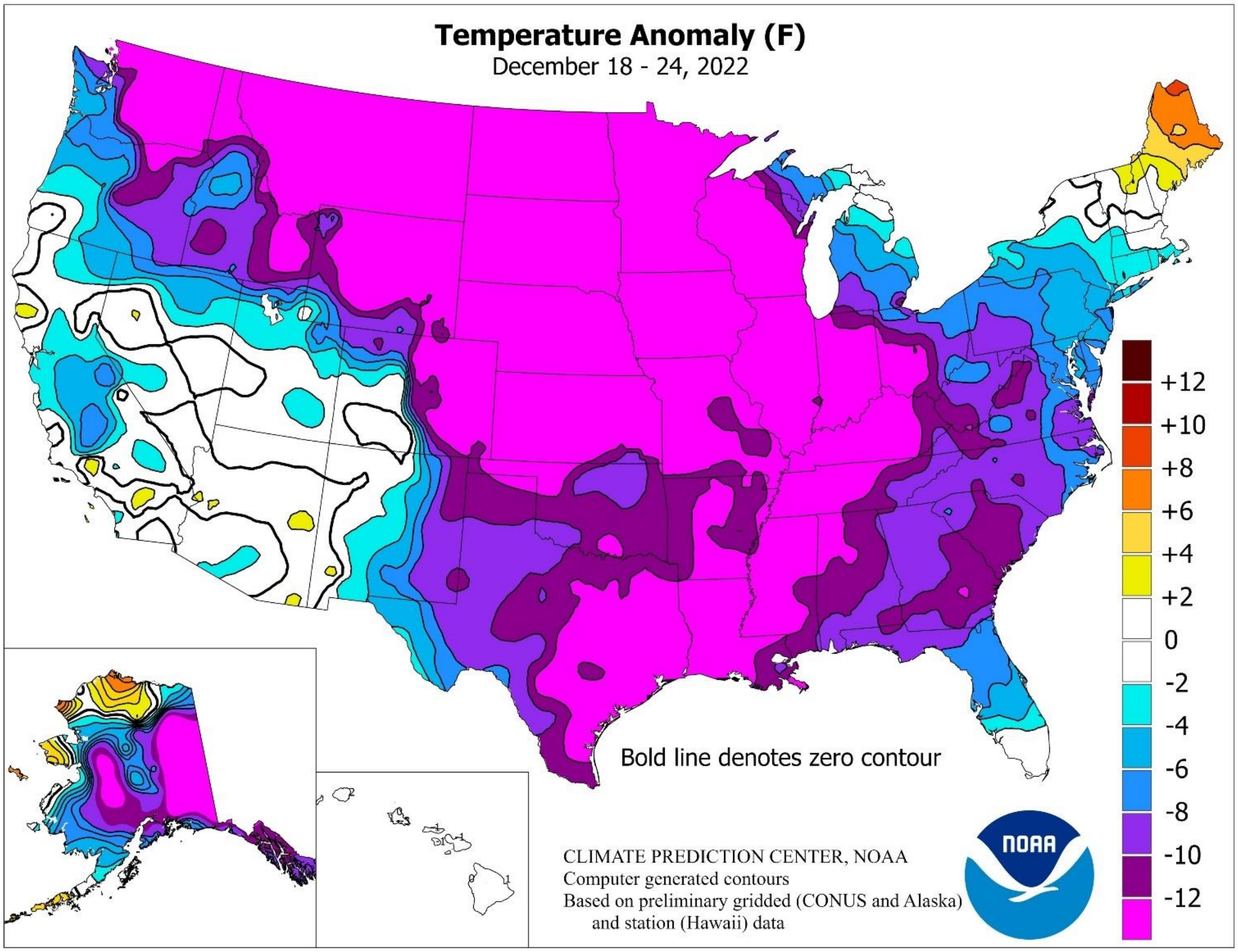
WECC wants to thank the following people and organizations for the hard work and time they invested in this project:

Jack Moore, E3; Saamrat Kasina, E3; Rawley Loken, E3

Year 20 Extreme Cold Weather Event Advisory Group

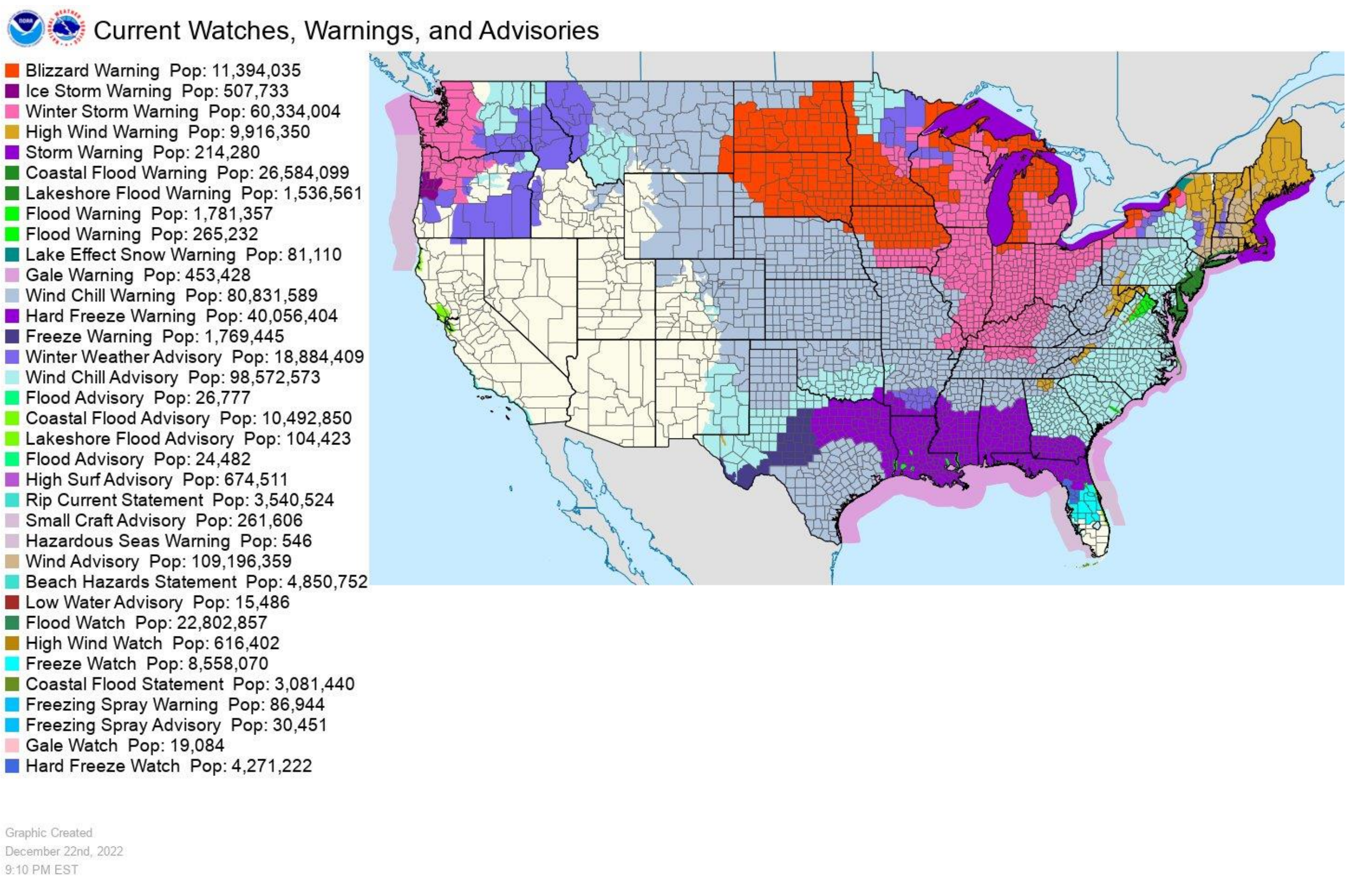
Appendix

Maps



December_18–24_Temperature_Anomaly_in_the_United_States.jpg (4096×3165) (wikimedia.org)

Figure 28: December 2022 Cold Event Temperature Anomaly



[December 22, 2022 Warnings and Watches—December 2022 North American winter storm—Wikipedia]

Figure 29: December 2022 Cold Event Watches, Warnings, and Advisories

Additional Charts

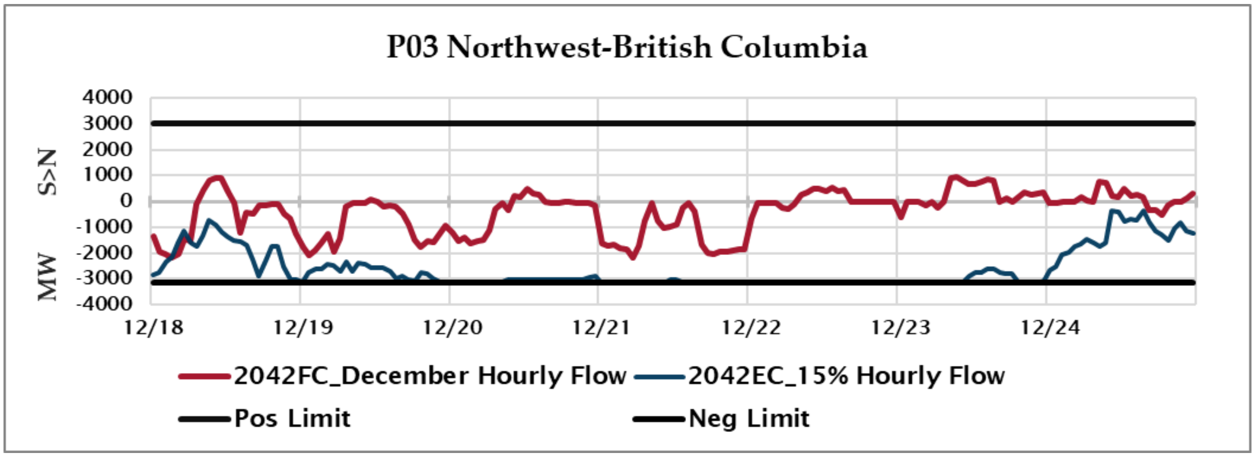


Figure 30: P03 Northwest-British Columbia Chronological Hourly Flows 2042EC_15% NG Derate Case

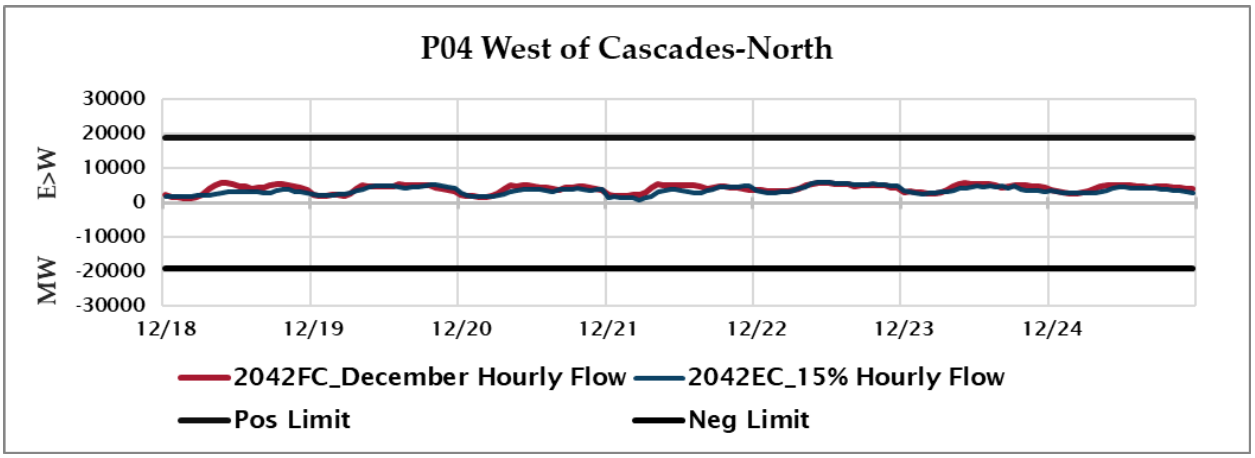


Figure 31: P04 West of Cascades-North Chronological Hourly Flows 2042EC_15% NG Derate Case

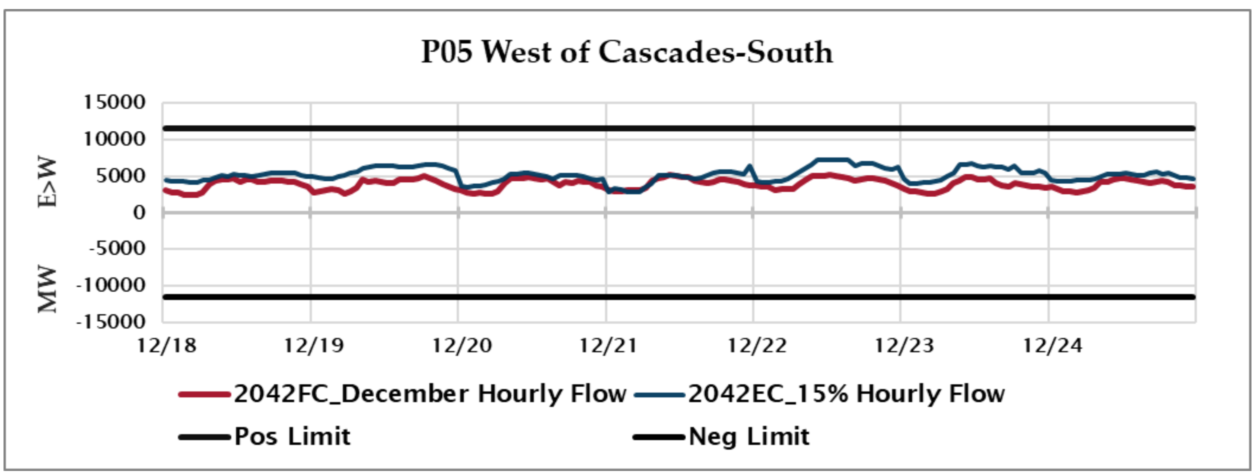


Figure 32: P05 West of Cascades-South Chronological Hourly Flows 2042EC_15% NG Derate Case

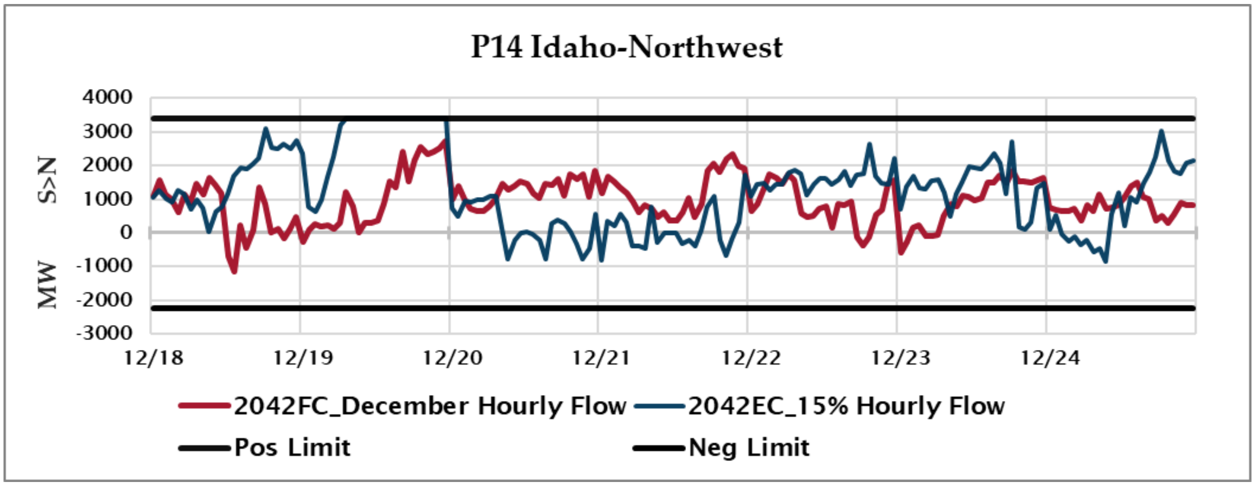


Figure 33: P14 Idaho-Northwest Chronological Hourly Flows 2042EC_15% NG Derate Case

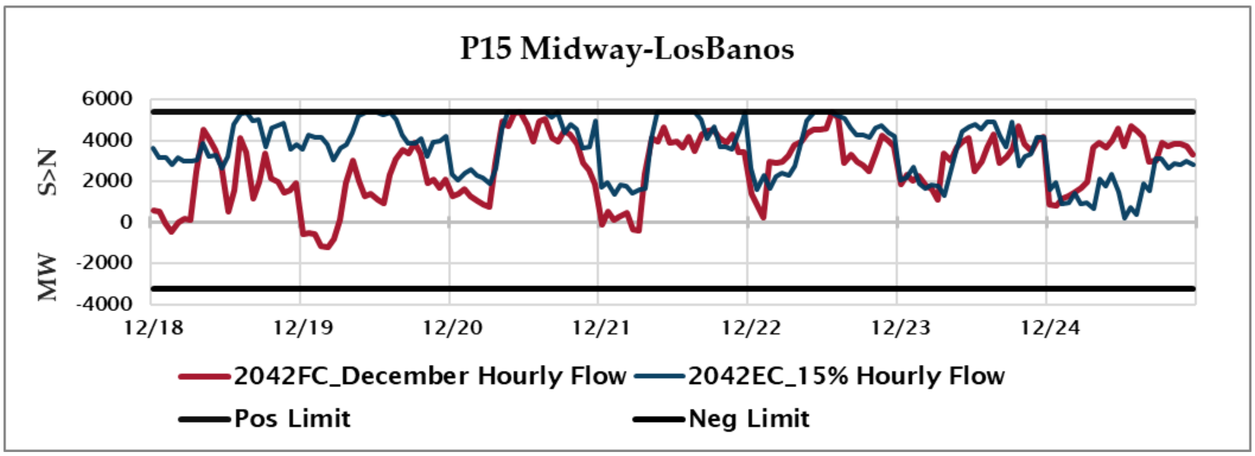


Figure 34: P15 Midway-Los Banos Chronological Hourly Flows 2042EC_15% NG Derate Case

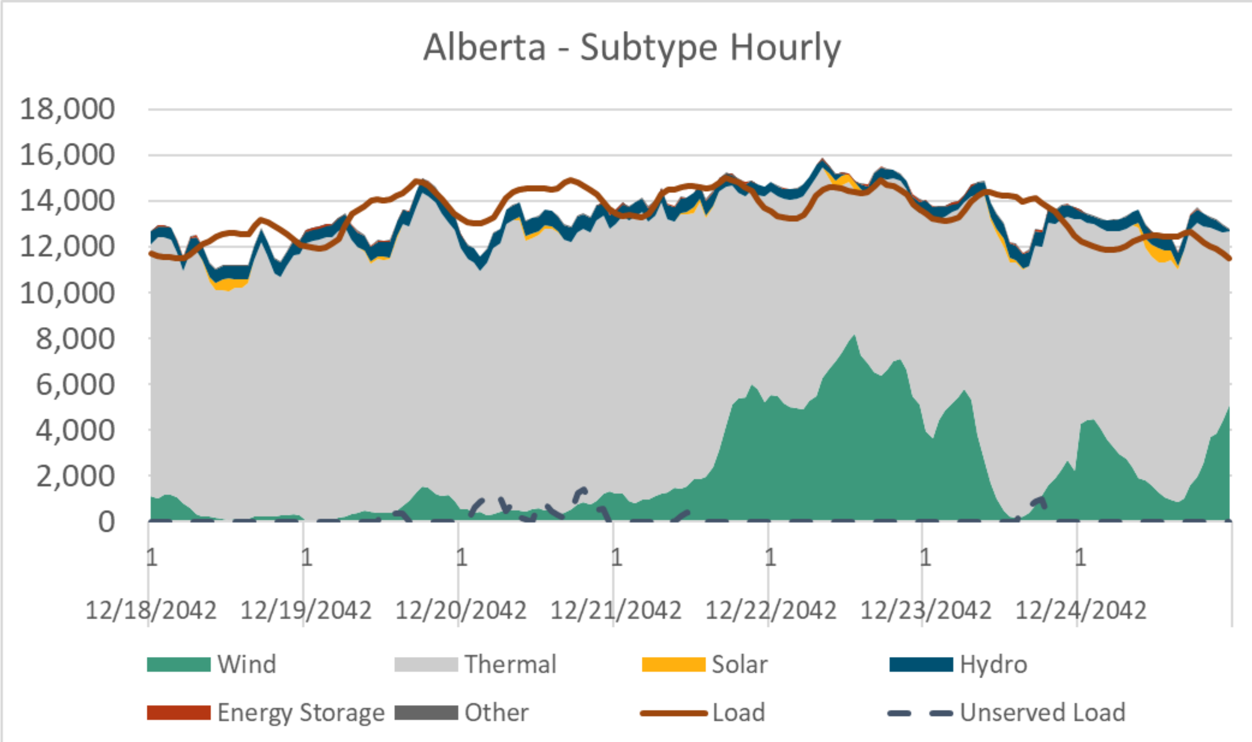


Figure 35: 2042EC_15% NG Derate Case Alberta Subtype Hourly (MW)

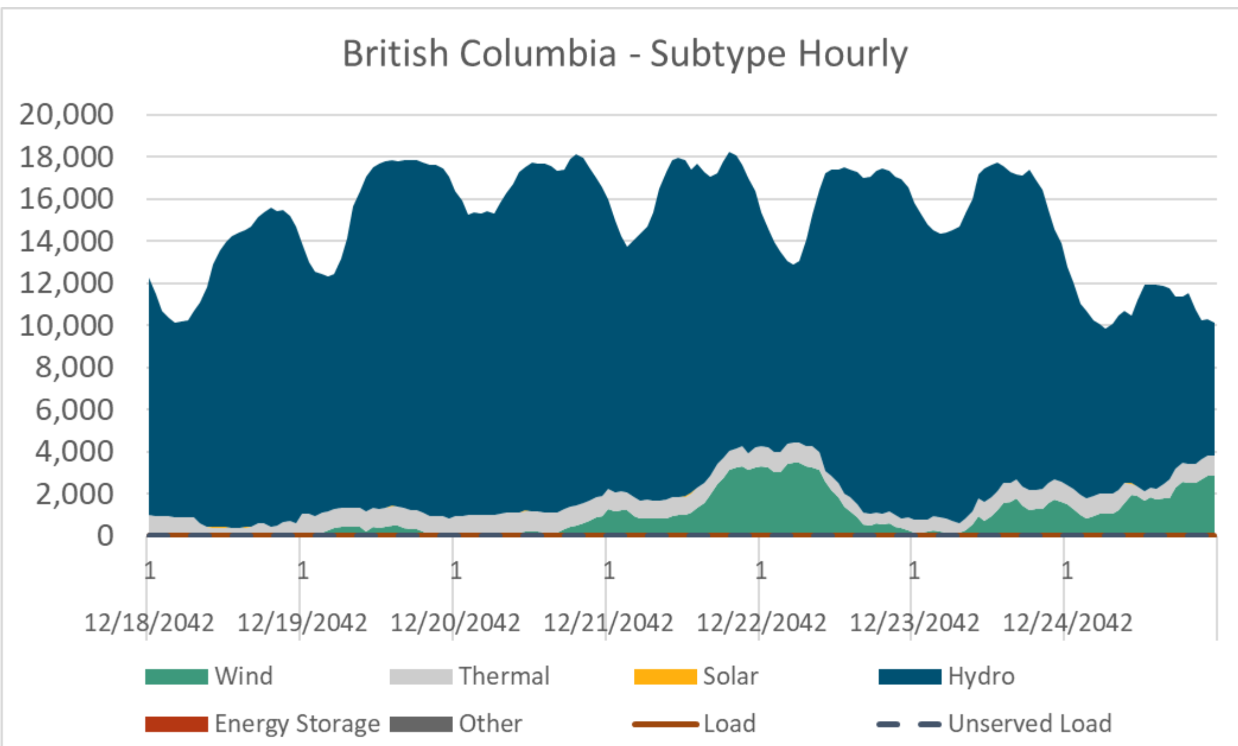


Figure 36: 2042EC_15% NG Derate Case British Columbia Subtype Hourly (MW)

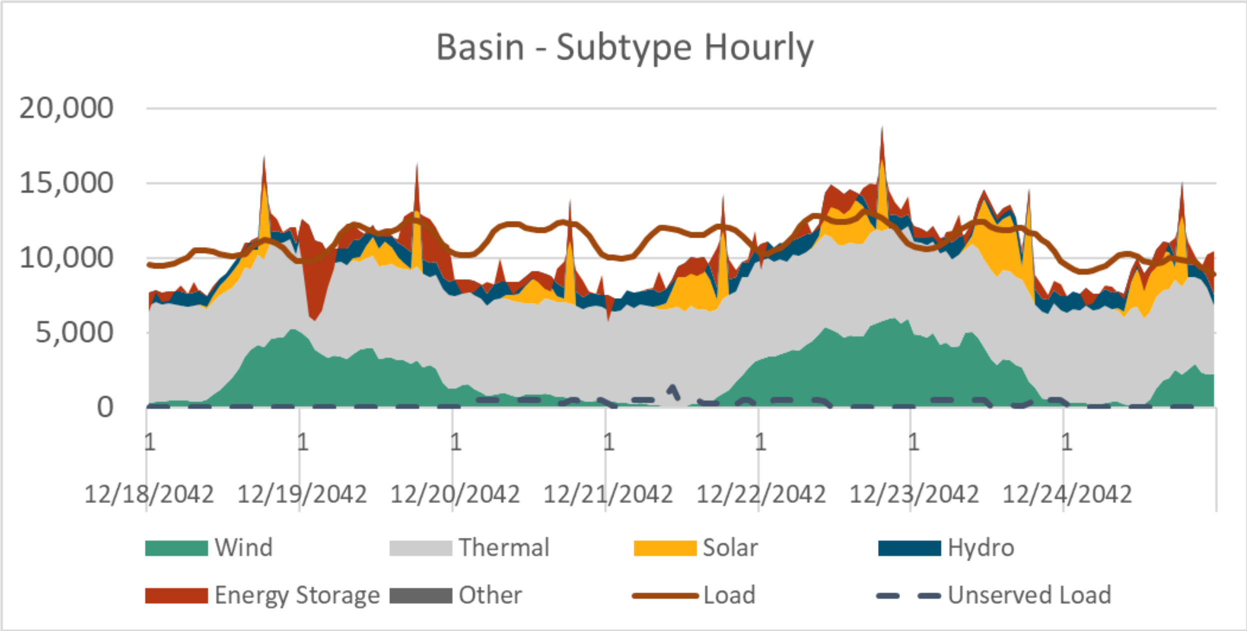


Figure 37: 2042EC_15% NG Derate Case Basin Subtype Hourly (MW)

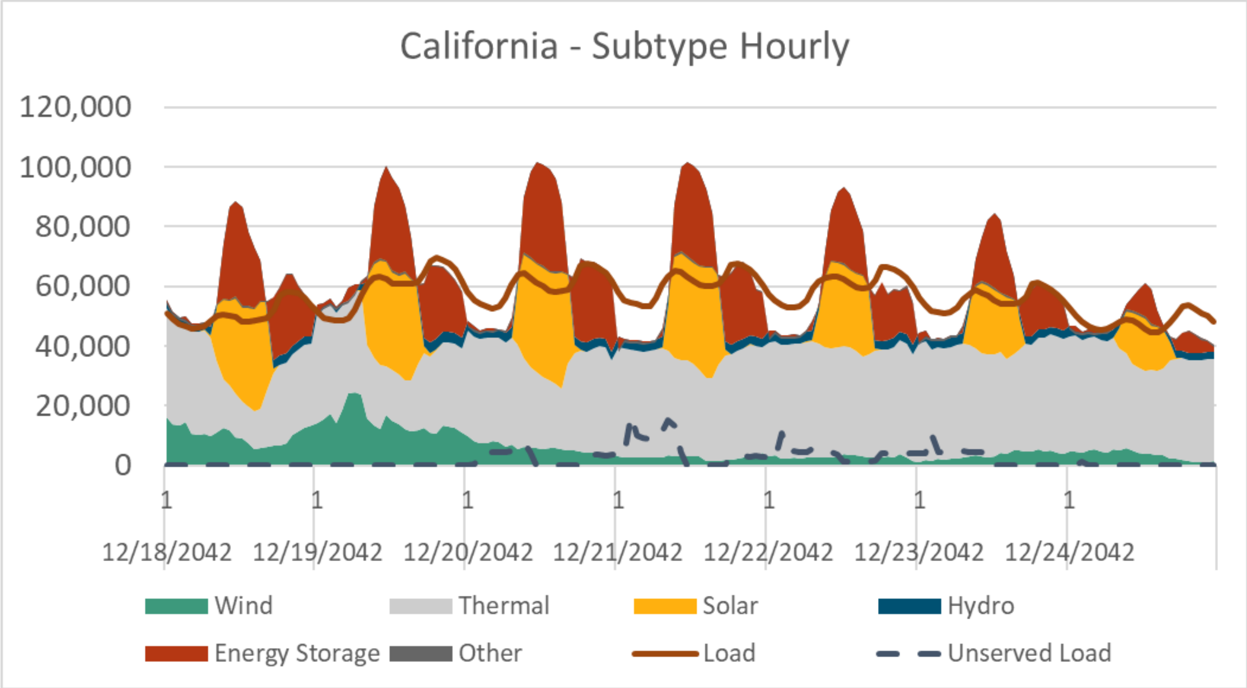


Figure 38: 2042EC_15% NG Derate Case California Subtype Hourly (MW)

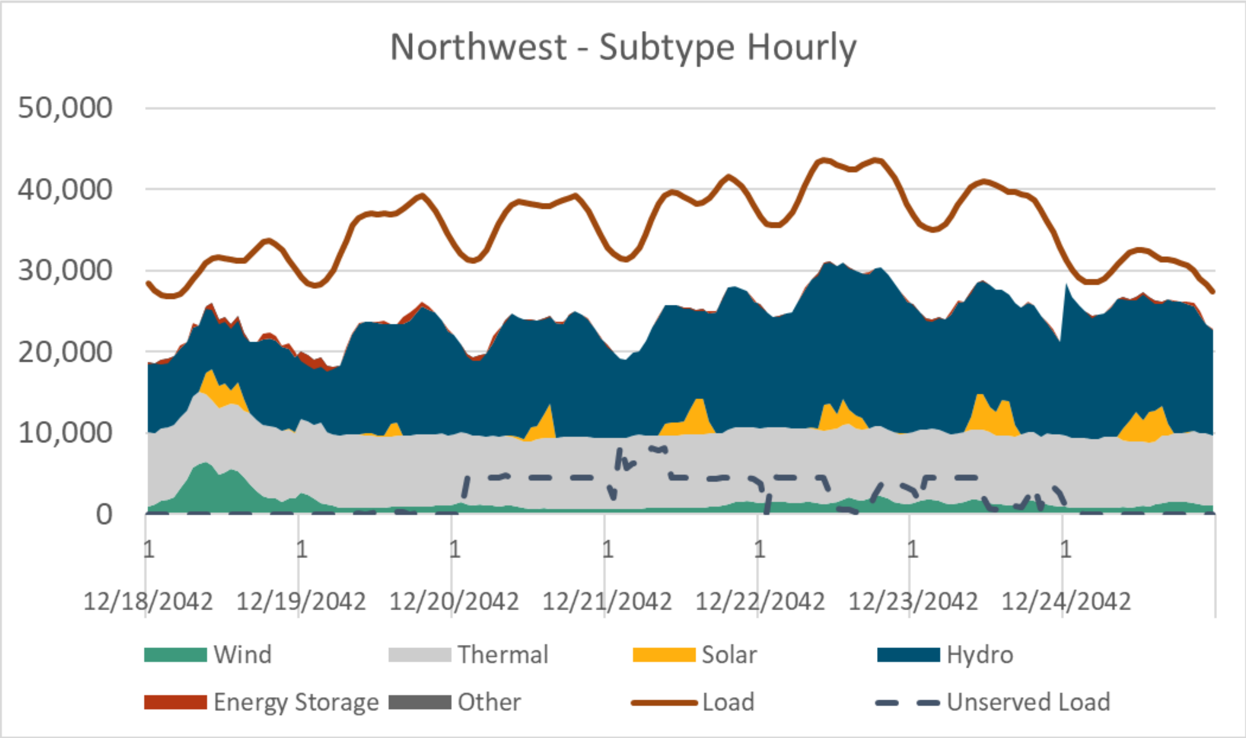


Figure 39: 2042EC_15% NG Derate Case Northwest Subtype Hourly (MW)

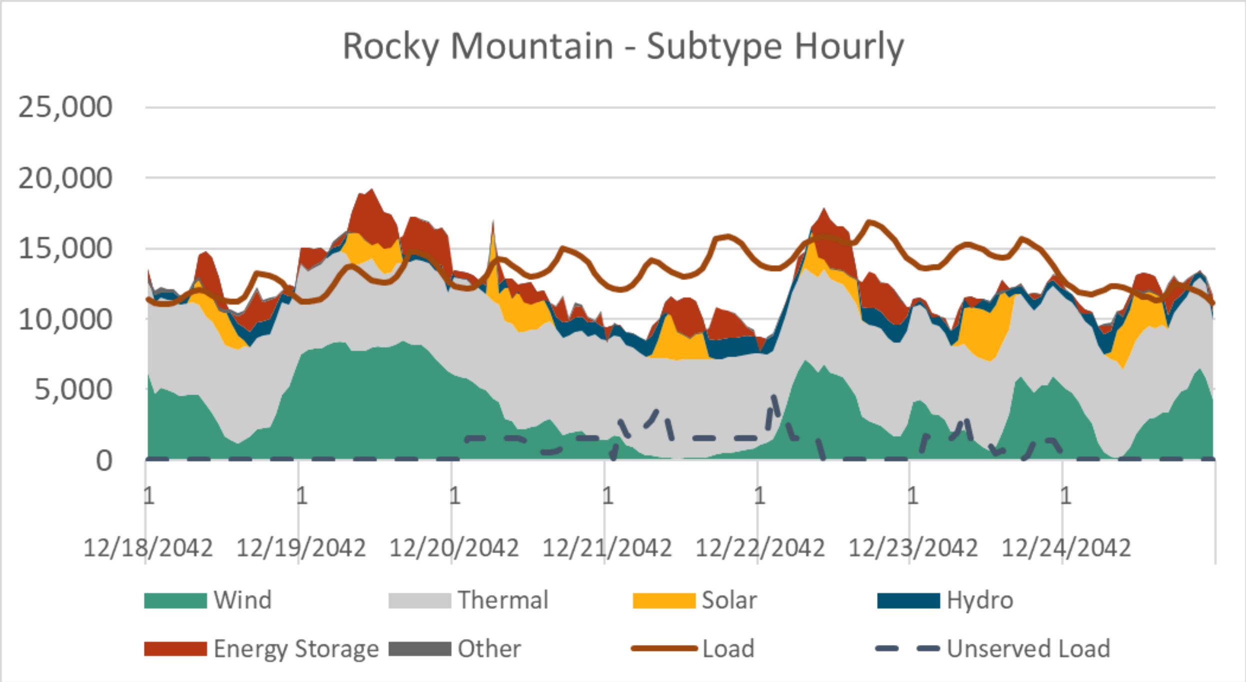


Figure 40: 2042EC_15% NG Derate Case Rocky Mountain Subtype Hourly (MW)

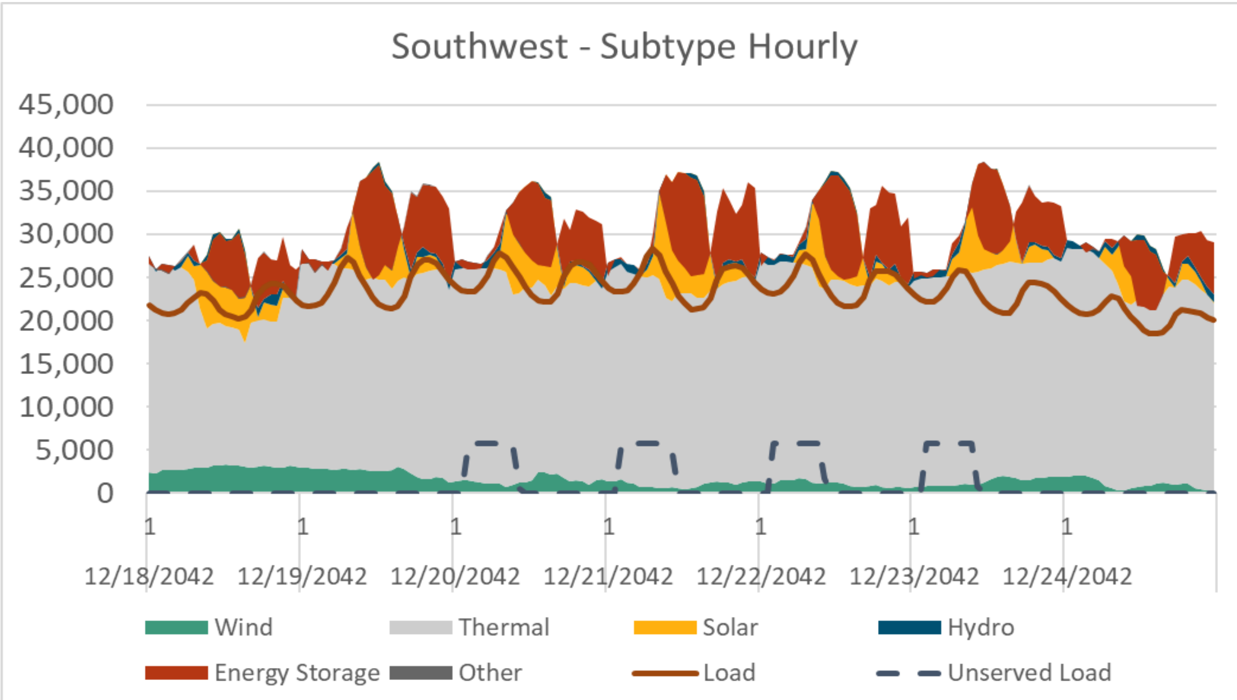


Figure 41: 2042EC_15% NG Derate Case Southwest Subtype Hourly (MW)

Other References

Cold snap: Denver's temperature drops 37 degrees in one hour (mercurynews.com)