WECC

Year 10 Extreme Cold Weather Event

November 2023

OVERVIEW

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Executive Summary

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

This study evaluates the potential impacts of an extreme cold weather event on the reliability of the system 10 years in the future. To do this, WECC extrapolated data from the extreme cold weather event that occurred between December 21 and December 26, 2022. That event brought very low temperatures, heavy snow, and high winds to much of the United States and parts of Canada. WECC applied the system conditions of the 2022 event to its 2032 Anchor Data Set (ADS), which is a stakeholder-vetted compilation of load, resource, and transmission information. Using that as a baseline, WECC then changed its input assumptions to model a similar storm in 2032, including:

- Mimicking the 2022 event load shape for 2032,
- Increasing the load by an additional 10% beyond the event load shape for 2032,
- Doubling the forced outage rates of thermal generation,
- Decreasing the output of wind and solar generation, and
- Limiting natural gas (NG) availability by 15%, 25%, and 35%.

No changes were made to the 2032 ADS resource mix or transmission topology other than the changes mentioned above.

Observations and Recommendations

Observation 1: Given the resource mix assumptions in the 2032 ADS, natural gas generation was necessary to continue serving load during the modeled extreme cold weather event. With all natural gas generators online, no load shedding occurred. However, natural gas derates led to load shedding, highlighting a dependence on natural gas generation during extreme weather events. Given that cold weather events can affect the natural gas system, this is a compound risk that bears further evaluation. Figure 1 shows the amount of unserved load in each of the modeled cases.

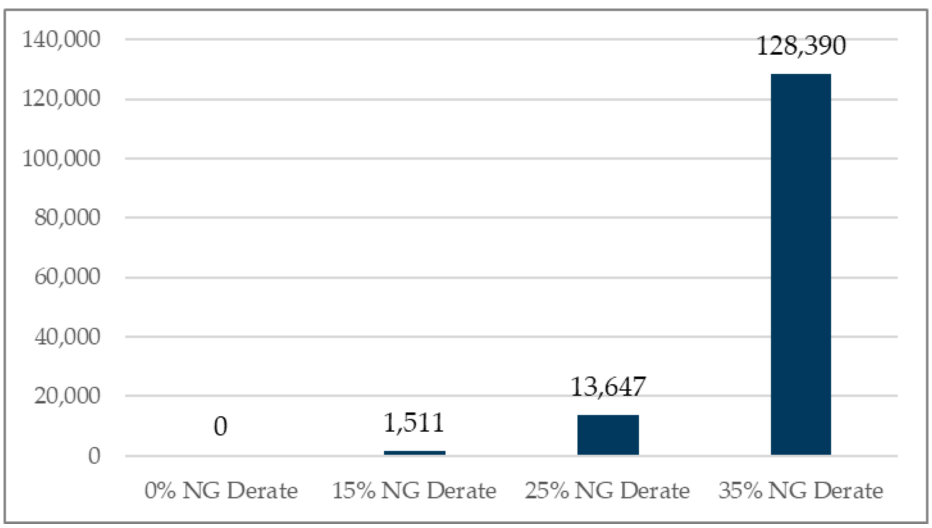


Figure 1: Unserved Load (MWh)

Recommendation 1: Industry should—

- Explore mitigation techniques for extreme weather conditions, such as high demand and low generation availability, and closely monitor natural gas availability under extreme cold conditions;
- Continually maintain datasets for studying extreme weather conditions and include potential impacts to the natural gas system; and
- Correlate detailed weather data with electric system data such as generation and load data, to facilitate weather event studies.

Observation 2: While unserved load was observed across multiple parts of the day because of the extreme weather conditions studied, the timing of the unserved load was heavily influenced by the battery charging schedule simulated in WECC's production cost model (PCM). The PCM schedules battery charging in the morning, which increases load at that time and shifts unserved load to the morning peak. Simulating battery charging at a different time may have shifted the unserved load to that time. It is important to note that not all unserved load occurred during times when batteries were charging. Figure 2 shows the correlation of unserved load with the behavior of the battery charging and discharging.

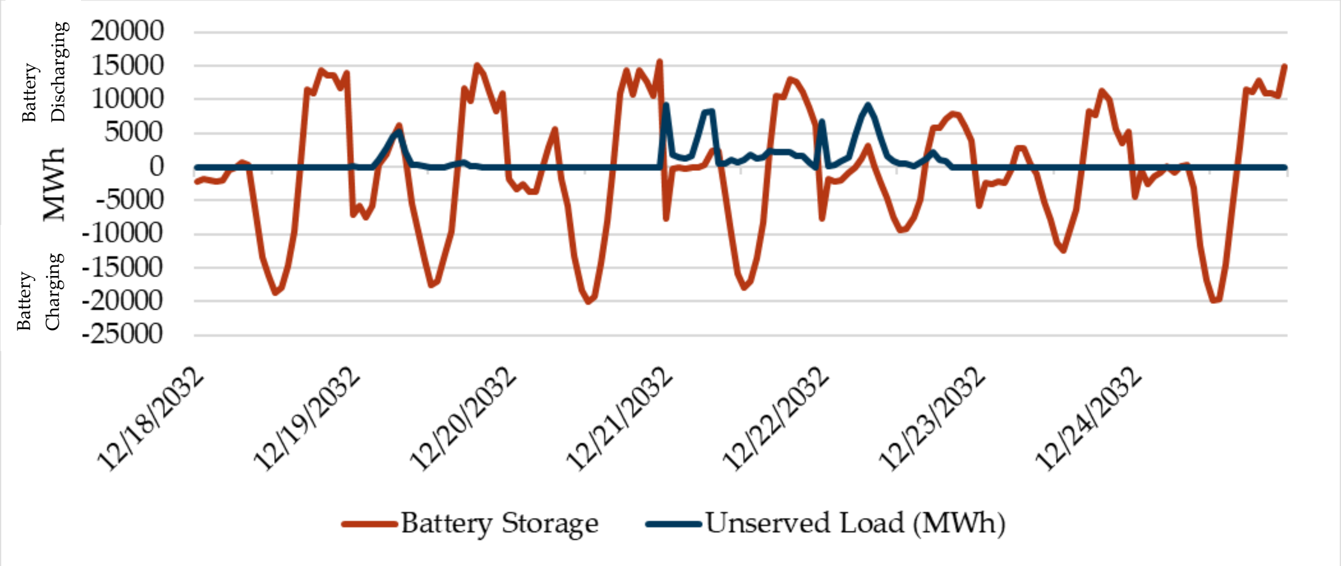


Figure 2: 35% Derate Case Unserved Load and Battery Storage (MWh)

Recommendation 2: WECC should implement software enhancements to enable multi-day storage cycling to more realistically analyze storage operation, dispatch, and commitment during extreme cold weather.

Observation 3: 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 is noteworthy, and may signal a more substantial change in transmission use patterns, particularly during widespread extreme events. Figure 3 shows the net transfer difference between the 2032 ADS and the 35% NG derate cases.

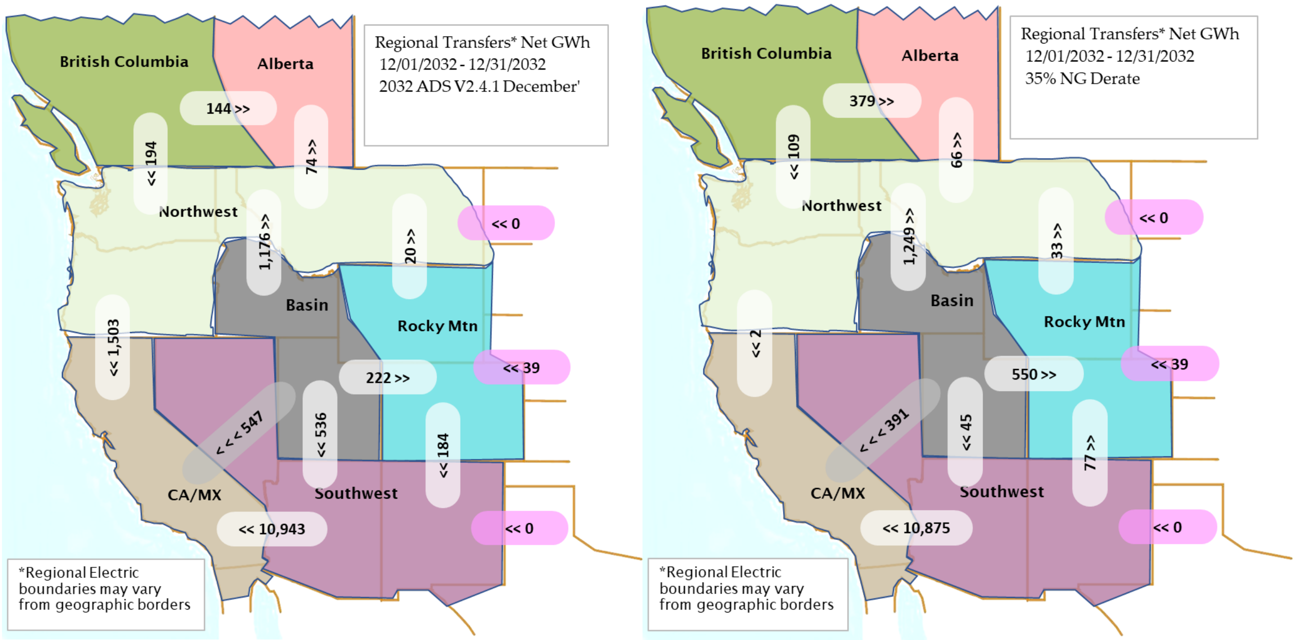


Figure 3: Regional Net Transfers 2032 ADS vs 35% NG Derate Case

Recommendation 3: WECC and industry should model new transmission projects under various system conditions (scenarios) to evaluate the effect on transmission use and flows. They should also explore and understand the reliability implications of reverse of flows on major WECC paths.

Table of Contents

Background and Purpose

Extreme cold weather events stress the system by increasing loads while simultaneously decreasing wind and solar production, natural gas (NG) availability, and increasing forced outages of system elements. The frequency and intensity of these events is increasing, and in some cases these extreme events are widespread. These factors merit study at the interconnection level. The purpose of this study is to identify potential reliability impacts of an extreme cold weather event on the reliability of the Western Interconnection (WI) bulk power system 10 years in the future.

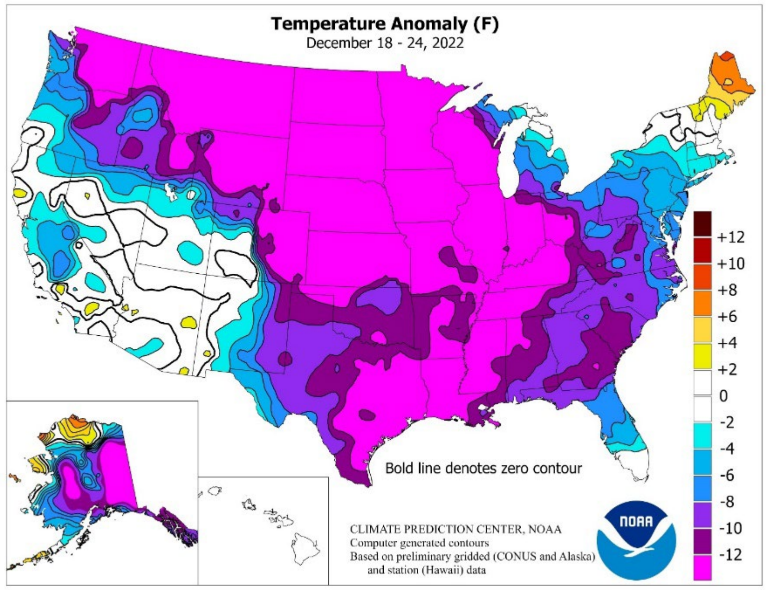


Figure 4: Temperature Anomaly, Dec. 2022 Cold Weather Event

To anchor its study, WECC used the cold weather event that occurred from December 21 through December 26, 2022. This event was the result of an extratropical cyclone that created blizzard conditions, high snowfall, and record cold temperatures across most of the country 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, flight delays, road closures, and power outages. (See Appendix A for more information.)

Table 1: Record Temperatures in Western States During December 2022 Cold Weather Event

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

Study Assumptions

WECC used its 2032 Anchor Data Set (ADS) as the starting point for this assessment. The ADS contains a compilation of load, resource, and transmission information provided by Balancing Authorities based on their 10-year forecasts. This case represents an expected baseline from which WECC built the assumptions for this assessment. WECC made no changes to the resource mix or transmission topology in the 2032 ADS. The two variables WECC changed were load assumptions to reflect the extreme cold weather conditions being studied and generation availability to reflect different wind, solar, and natural gas conditions, and forced outages during the event.

Load Assumptions

The base assumptions for the load, wind, and solar hourly profiles are the same in all scenarios. To model the cold weather event, WECC created a new load profile. WECC started with actual load shapes from the December 2022 event, then projected load increases based on the forecasts in the 2032 ADS. From there, WECC added a 10% increase 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 reaching 10% above the base load profiles in the ADS, then ramped down in the same manner starting on December 23. This 10% increase represents the 92–93 percentile (1-in-12.5 to 1-in-14) load distribution. It was applied to all areas system-wide during the event.

Generation Availability Assumptions

Natural Gas Derates

During cold weather events like winter storms Elliot in 2022 and Uri in Texas in 2021, both natural gas generators may be forced out due to the extreme temperature, but also natural gas derates and supply issues can occur, compounding the risks posed by the weather event itself. To assess the potential impact of natural gas derates during an extreme cold weather event in the West, WECC studied three derate levels: 35% (peak derate experienced during Winter Storm Uri), 25%, and 15%. (See Table 2.) The natural gas derates were modeled as capacity derates, meaning, for example, a 15% derate resulted in a 15% reduction in natural gas capacity. WECC applied the derates to colder areas of the interconnection, which are more affected by the cold weather event. Northern California is generally warmer than the northwest WI; however, it uses the same natural gas pipelines and infrastructure, therefore it may be affected but to a lesser degree. The same goes for natural gas units being forced out. To demonstrate this, a reduced derate was applied to northern California.

Table 2: Assumptions for Extreme Cold Event Cases

Scenario	Assumptions
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

Forced Outage Rate Assumptions

WECC tracks the forced outage rates of generation facilities across the WI and uses this information in its assessments and the 2032 ADS. WECC doubled the forced outage rates in the 2032 ADS for thermal generators in the Alberta, British Columbia, Northwest, Rocky Mountain, and Basin regions. 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.

Approach and Input Data

Load Data

WECC evaluated loads for the last several years using the EIA Grid Monitor database[1] and the Loads and Resources (L&R) data. This L&R data contains hourly Balancing Authority (BA) load and BA wind and solar energy generation from mid-2018 to the present. During the December 2022 cold event, the load began to increase rapidly on December 19, peaked on 22, and then dropped gradually through 23 before returning to a significantly lower load on 24. WECC replicated this pattern in this assessment, then scaled the loads up to the energy level of the projected loads in the 2032 ADS. An additional 10%

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

load increment was then applied to represent more extreme conditions. Figures 5 through 7 show the load growth in the Northwest and Rocky Mountain regions, as well as the entire WI.

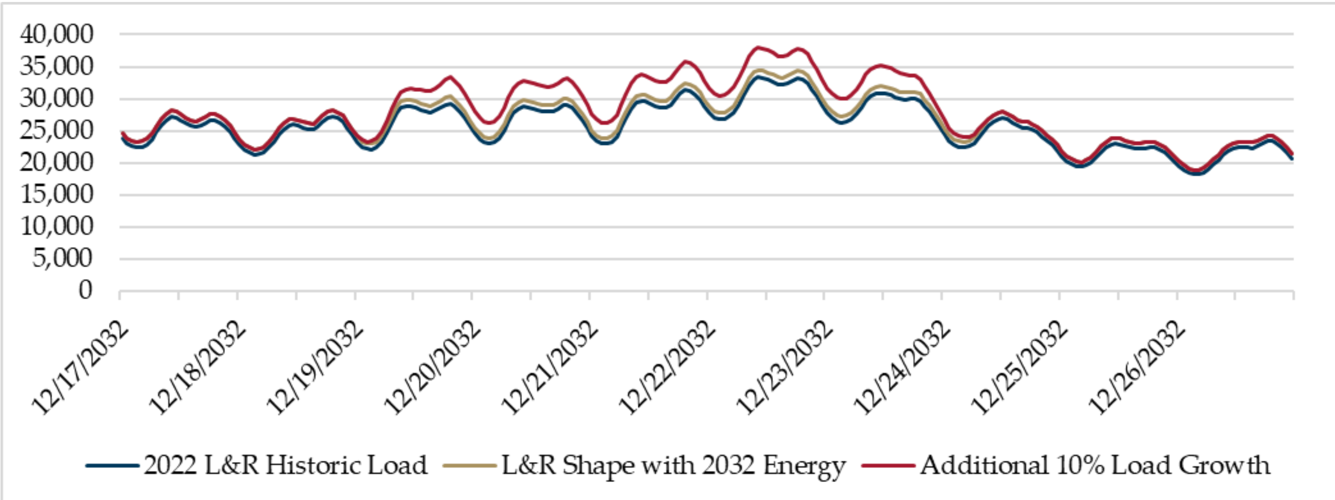


Figure 5: Northwest Load Growth

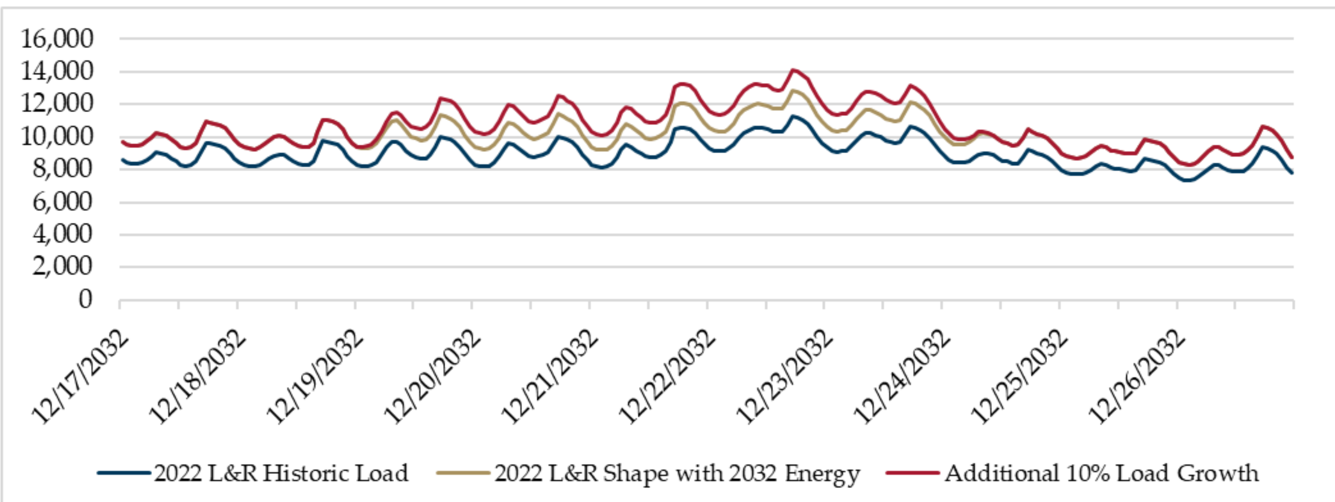


Figure 6: Rocky Mountain Load Growth

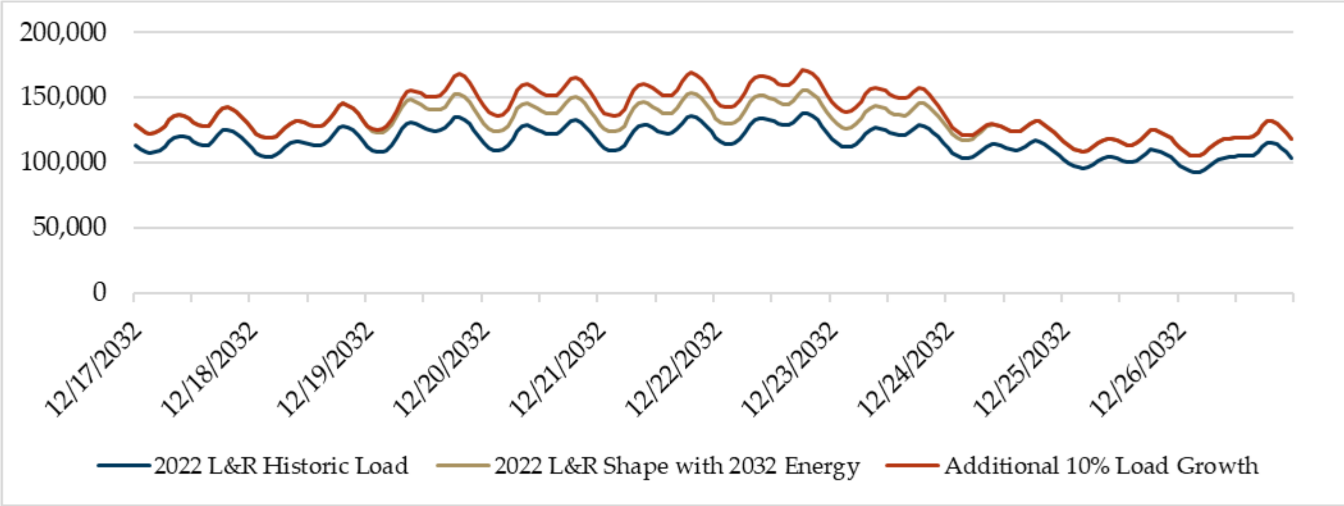


Figure 7: Western Interconnection Load

Wind and Solar Generation

To model the potential impacts of reduced wind and solar generation, which often accompany winter cold events, WECC evaluated historical generation data to identify the time 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, to run the scenarios with the highest load and lowest wind and solar production. (See Figure 8.) From here, WECC prepared wind and solar energy shapes for each load area and applied them to all units in those areas. This study did not consider a serious "wind drought," where wind can be very low for many days.

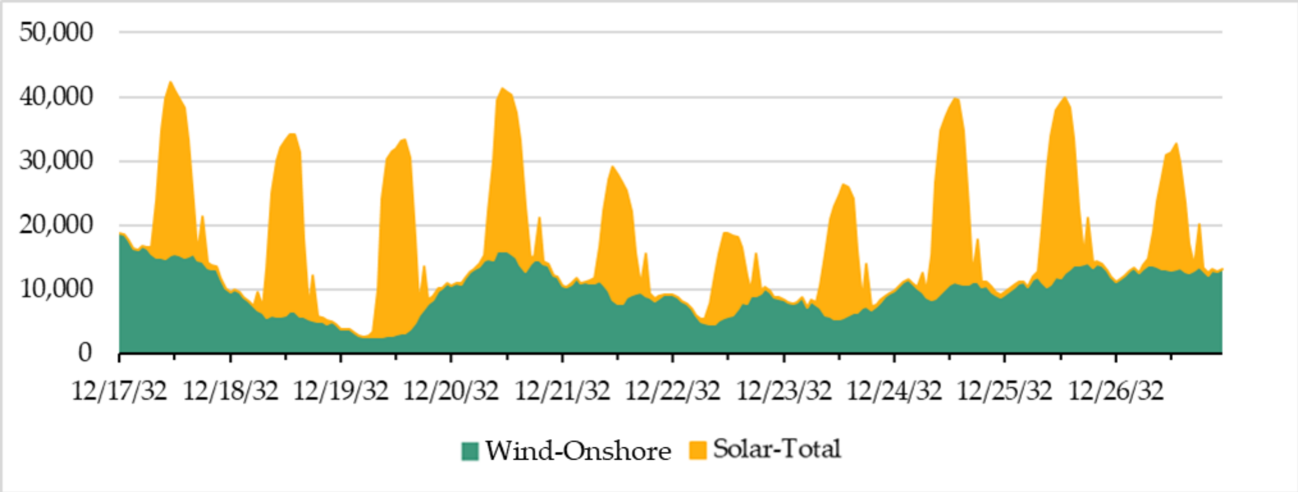


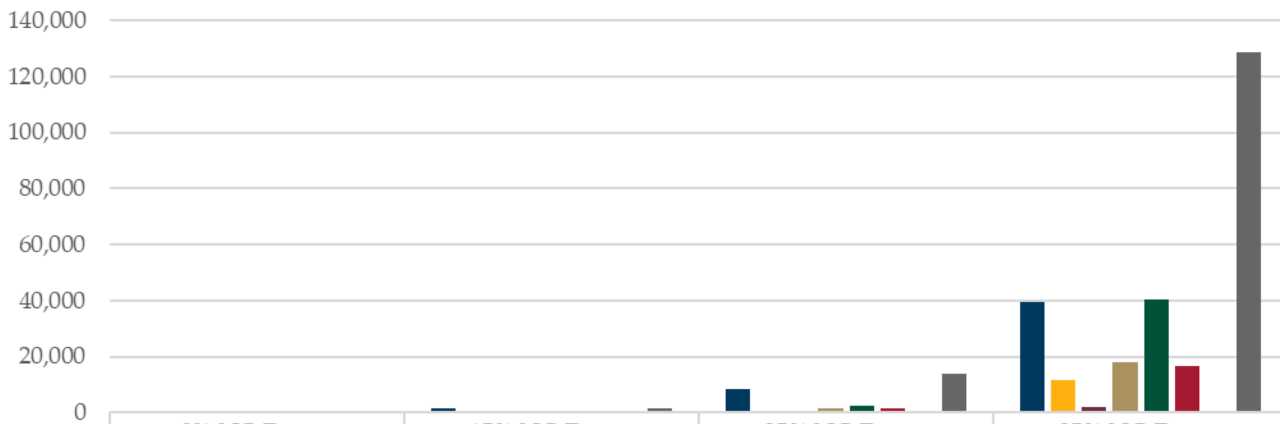
Figure 8: Western Interconnection Wind and Solar Shapes

Findings and Conclusions

The results of the study fall into three areas: 1) reliance on natural gas; 2) effect of battery storage; and 3) changes in transmission flow.

Reliance on Natural Gas

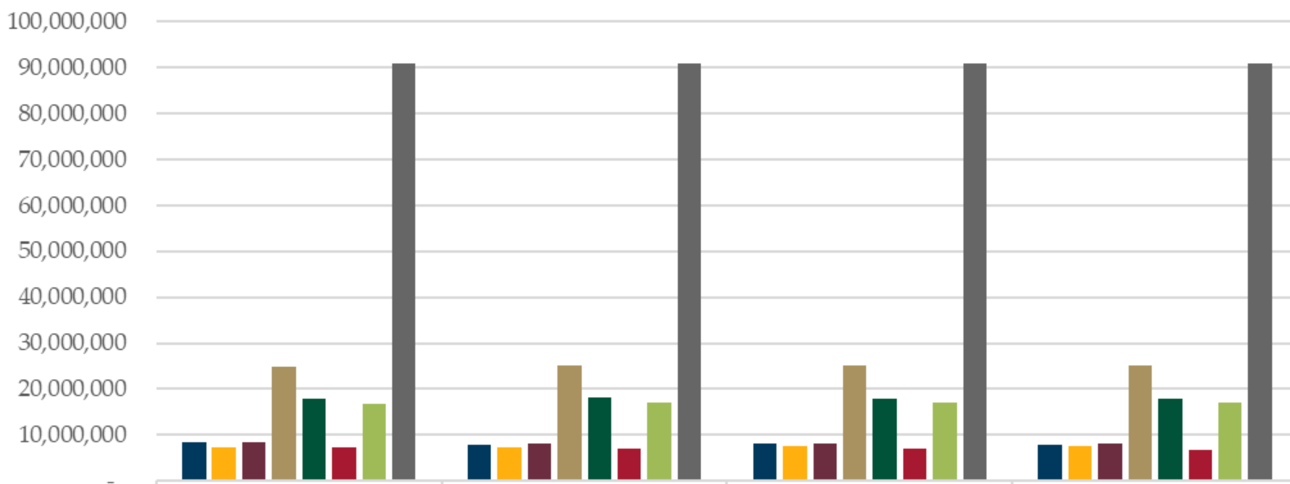
Sufficient availability of natural gas generation was critical to serve load in the extreme cold event modeled in this assessment. As the resource mix transitions to renewable generation and energy storage, the WI will continue to rely on available natural gas generation during extreme weather events. This finding deserves attention because cold weather events can cause interruptions of gas supply or derates of gas generation capacity, making reliance on this resource risky. There was no unserved load observed in the base scenario (without natural gas derates); however, all three derate scenarios resulted in unserved load. (See Figures 9 and 10.)



	0% NG Derate	15% NG Derate	25% NG Derate	35% NG Derate
AB	0	1,511	8,309	39,414
BC	0	0	0	11,433
BS	0	0	0	2,148
CA	0	0	1,476	17,794
NW	0	0	2,464	40,228
RM	0	0	1,375	16,619
SW	0	0	22	754
Total	0	1,511	13,647	128,390

AB BC BS CA NW RM SW Total

Figure 9: Total Unserved Load by Region (MWh), December 19–22



	0% NG Derate	15% NG Derate	25% NG Derate	35% NG Derate
AB	8,354,778	7,993,559	8,046,034	8,011,568
BC	7,335,307	7,467,321	7,474,692	7,487,371
BS	8,378,643	8,169,148	8,152,395	8,138,261
CA	24,797,368	25,225,519	25,265,768	25,192,032
NW	18,011,024	18,091,071	18,044,861	18,012,918
RM	7,336,036	6,990,347	6,946,368	6,874,262
SW	16,709,076	16,972,865	16,970,054	17,071,881
Total	90,922,232	90,909,829	90,900,171	90,788,293

AB BC BS CA NW RM SW Total

Figure 10: Total Generation by Region (MWh), December

15% Natural Gas Derate

At a 15% natural gas capacity derate, there were 1,511 MWh of unserved load in Alberta, from hour 17 to hour 20 on December 21. Alberta has a large natural gas fleet; so, when the availability of gas generation is reduced, Alberta is significantly affected. No other regions experienced unserved load in this scenario.

25% Natural Gas Derate

A 25% natural gas derate resulted in unserved load across much of the interconnection; however, most of the unserved load was in Alberta. The British Columbia and Basin regions showed no unserved load in this scenario.

35% Natural Gas Derate

The 35% natural gas derate resulted in a significant increase in unserved load, especially in the Northwest and Alberta regions, there was no unserved load observed on December 23, despite continued high loads in the northern portion of the interconnection. By December 23, loads had decreased enough across the interconnection to prevent unserved load in this derate scenario. (See Figure 11.)

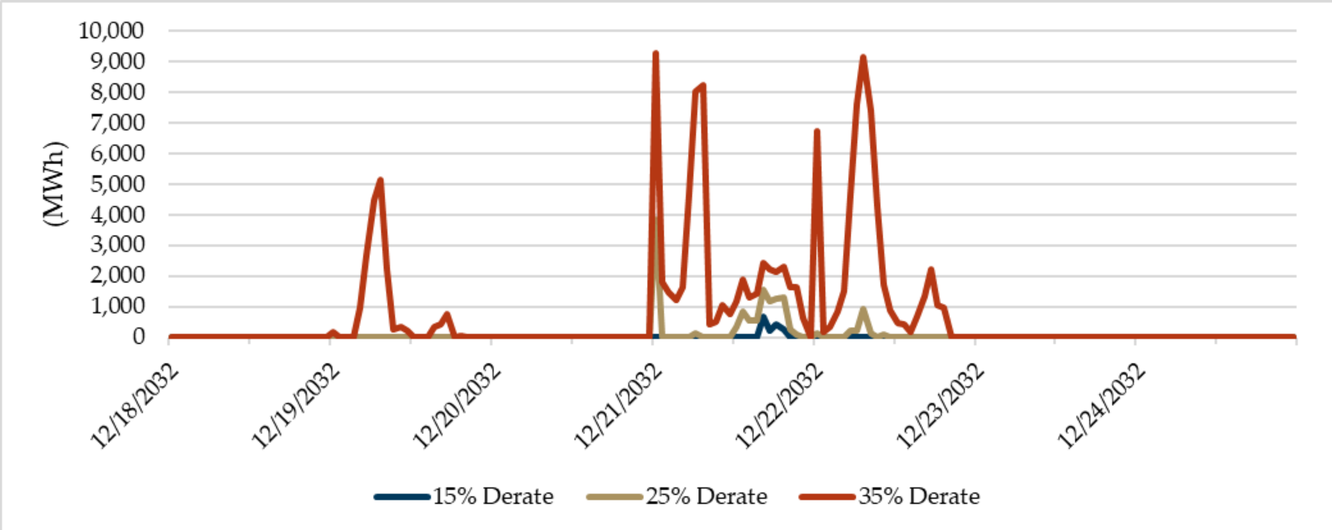


Figure 11: Interconnection Unserved Load Comparison (MWh)

The peak hours of unserved load varied across the regions. (See Table 3.) Most of the hours of unserved load occurred in the Alberta region. Figure 12 shows the number of hours in which there was unserved load for each region, as well as the whole interconnection. Some regions had unserved load occur during the same hours of the day; that is why the interconnection total is not a sum of the region totals.

Table 3: 35% Derate Case Peak Unserved Load

Region	Max (MW)	Date	Hour of Day with Max Unserved Load
Alberta	2,440	Dec 21	17
British Columbia	1,450	Dec 19	8
Basin	512	Dec 22	10
California	3,606	Dec 21	1
Northwest	4,446	Dec 22	8
Rocky Mountain	1,522	Dec 22	8
Southwest	509	Dec 21	1
Interconnection	**9,286**	**Dec 21**	**1**

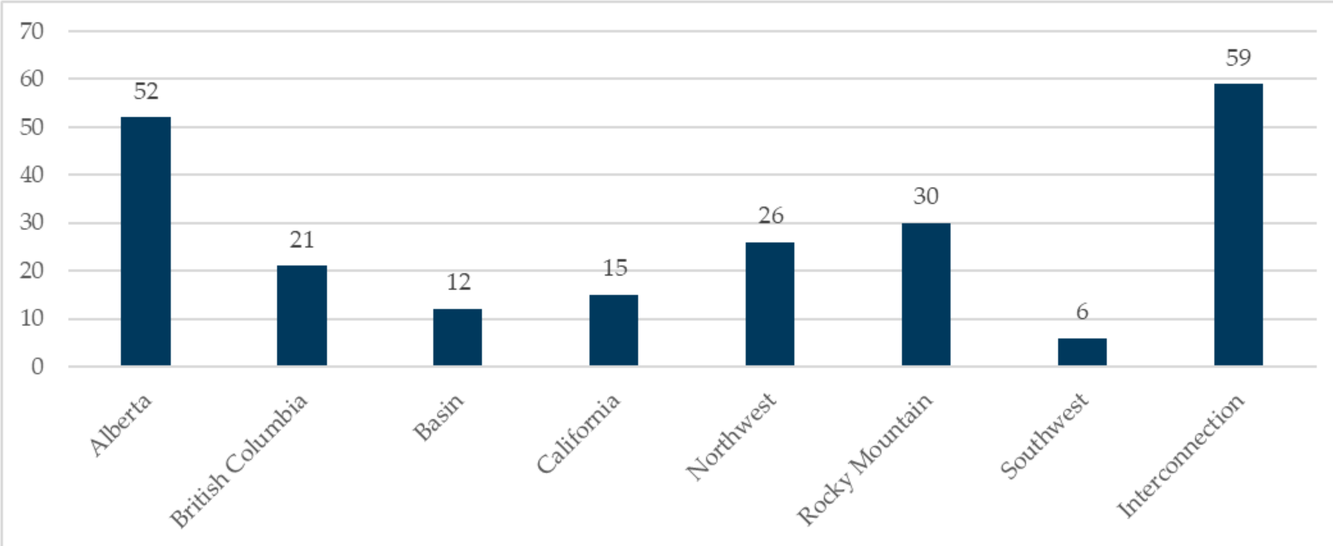


Figure 12: Number of Hours in Which Unserved Load Occurred

Effect of Battery Storage

The battery charging schedule in the model heavily influenced the timing of unserved load. There are some areas and some days when the model is trying to charge batteries on Hour 1 to have energy storage for later in the day, which is causing unserved load on Hour 1. (See red traces in Figure 13.) WECC's energy storage model optimizes on a 24-hour cycle, which requires the batteries to charge and discharge each day. In addition to Hour 1, the model also charges the batteries in the morning and mid-day during high solar output and discharges them in the afternoon and into the evening when load is typically higher. This modeling limitation may not reflect actual operational practices of charging and discharging batteries over multiple days, and it may skew the results by shifting unserved load to the morning peak.

In addition to battery charging, the battery discharging schedule in the model affected unserved load. Battery storage mitigated much of the unserved load in the afternoon when the batteries are discharged. If the model had optimized batteries over a span greater than one day, the batteries may not have been able to fully cover the unserved load every afternoon. The model may have pushed the battery discharge to another time or day, depending on how the model optimizes load serving versus battery charging.

While batteries were able to mitigate much of the unserved load, there were hours when unserved load was observed even while batteries were being discharged. This indicates that regardless of the battery optimization, there were times during the 35% derate simulation where the system experienced energy shortages and was not able to serve load and would have experienced unserved load.

Figure 13 shows the relationship between battery charging and discharging and unserved load for the 35% derate case. (Negative x-axis indicates battery charging.)

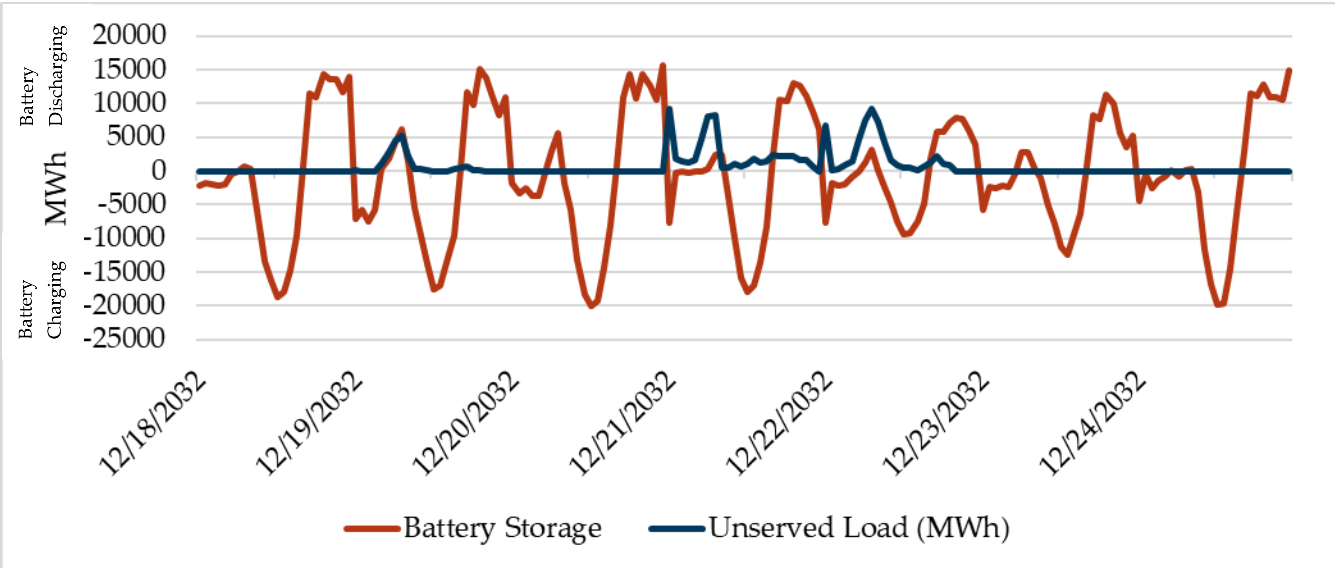


Figure 13: 35% Derate Case Unserved Load and Battery Storage (MWh)

Transmission Flows

During the extreme cold event, WECC saw an increase in transmission flows going to the northern part on several major WECC Paths across the interconnection, which is where we modeled this cold event to be the most severe. Figure 14 shows the net regional transfers. Notice the increase net flows going from the southern part of the WI to the north. Figure 15 shows the net annual flow compared to the net path flows of the 2032 ADS case versus the 35% derate case. Figures 16 through 19 show chronological hourly flow; the yearly net direction of flow can be seen on these paths, contributing to the net annual flow difference in Figure 15. While there was an increase in flows to the north, it is a noteworthy observation that may signal a more substantial change in transmission use patterns, particularly during widespread extreme events. The differing transmission patterns seen in this study were more reversals of flows in some paths (Path 66 COI). While this did not cause any issues in this study, there may be cause for concern if ratings differ drastically one direction to another and happen to be more restricted in a certain direction.

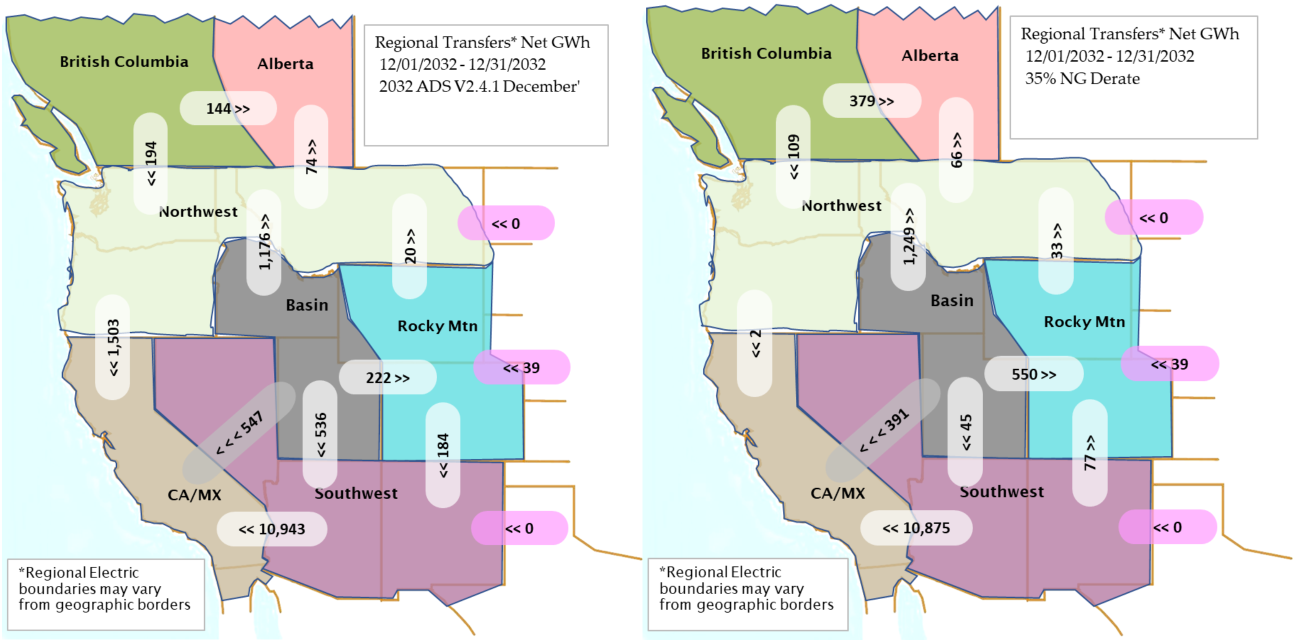


Figure 14: Regional Net Transfers 2032 ADS vs 35% NG Derate Case

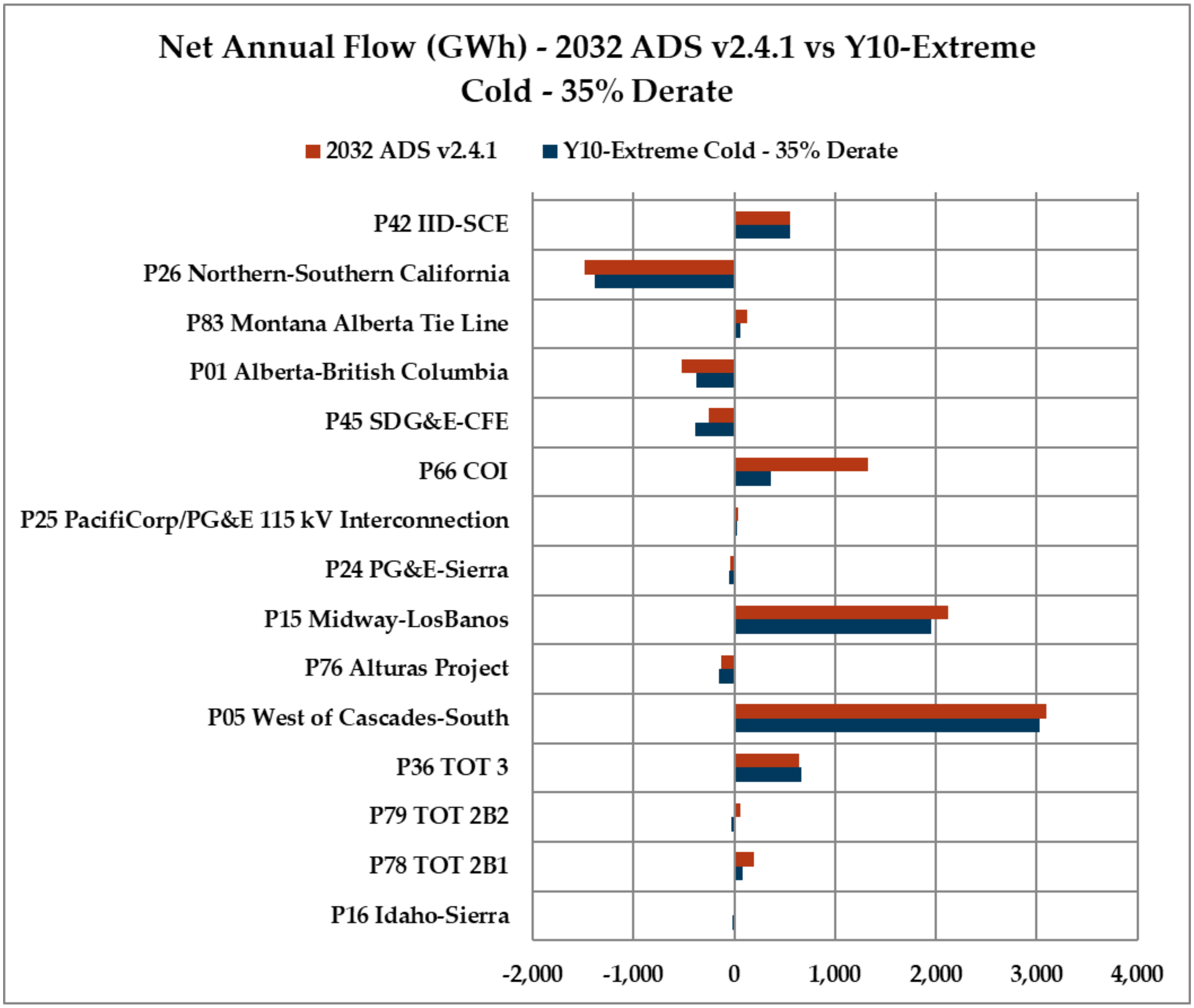


Figure 15: Net Annual Flow

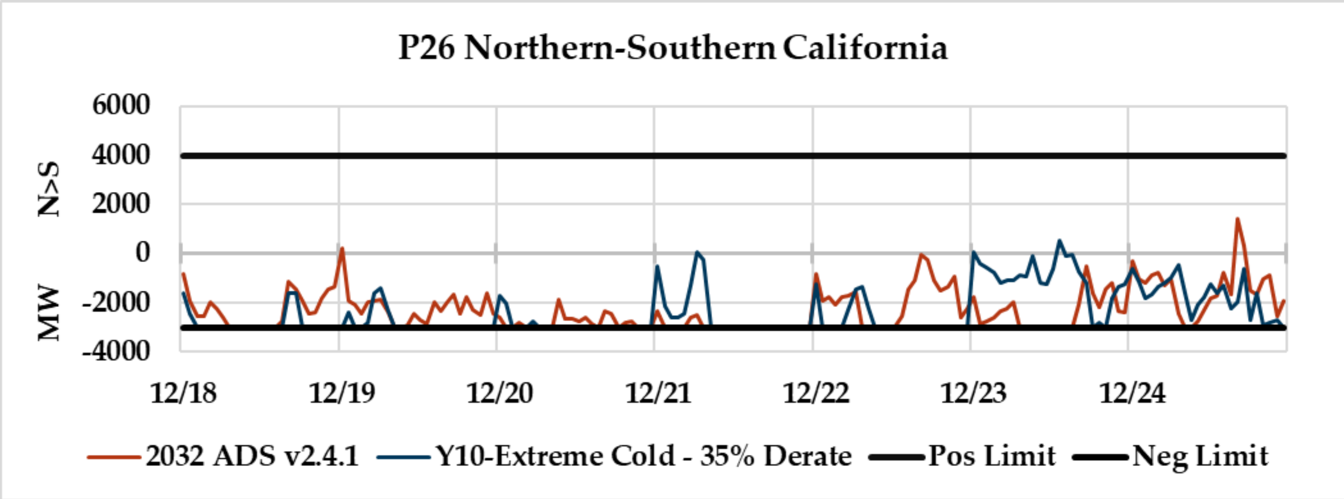


Figure 16: P26 Northern-Southern California Chronological Hourly Flows

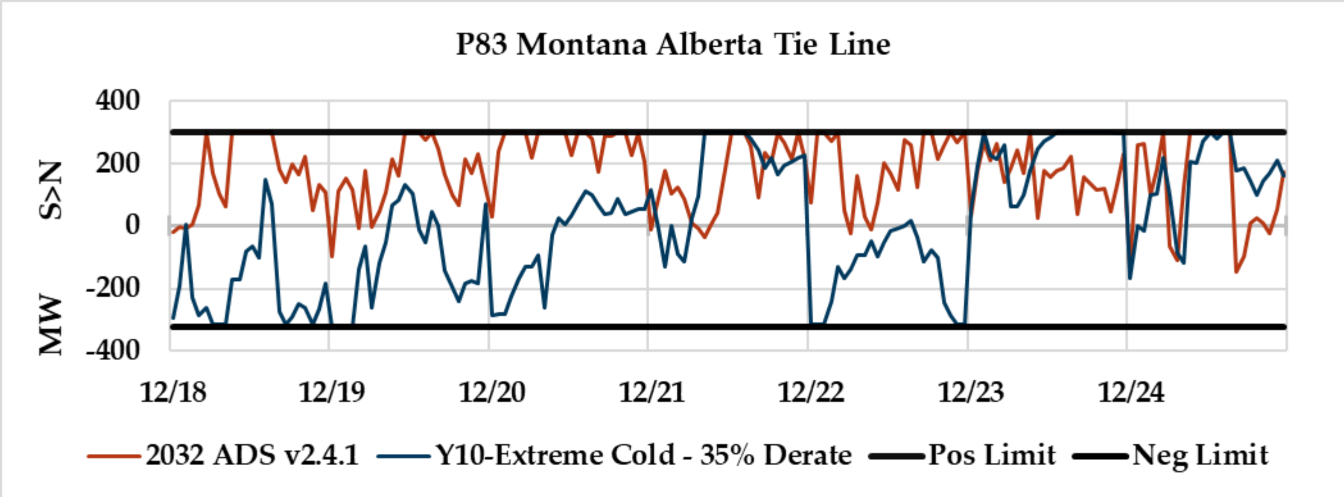


Figure 17: P83 Montana Alberta Tie Line Chronological Hourly Flows

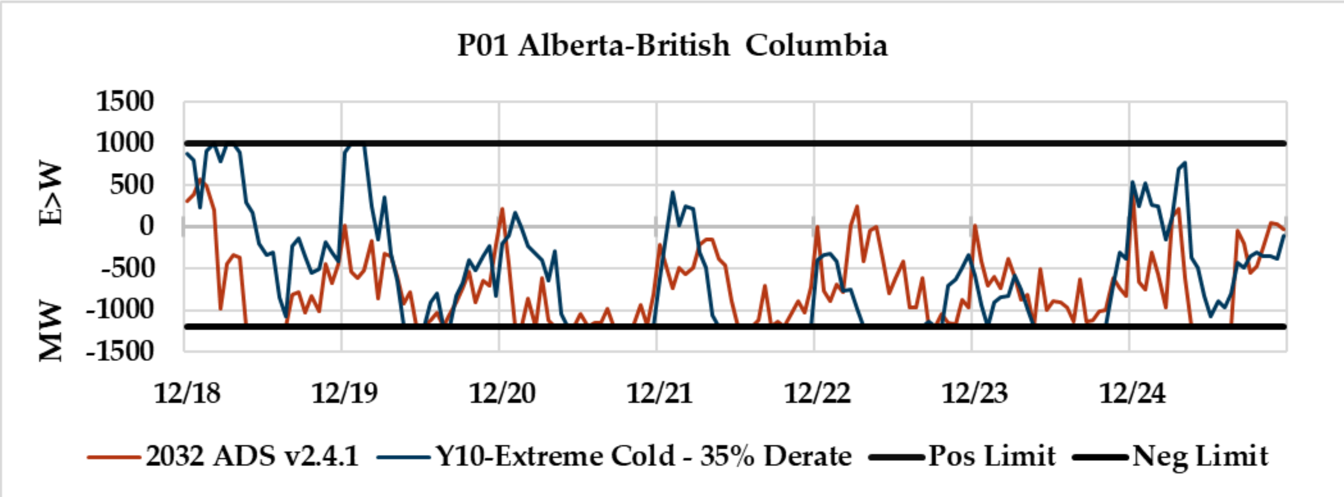


Figure 18: P01 Alberta-British Columbia Chronological Hourly Flows

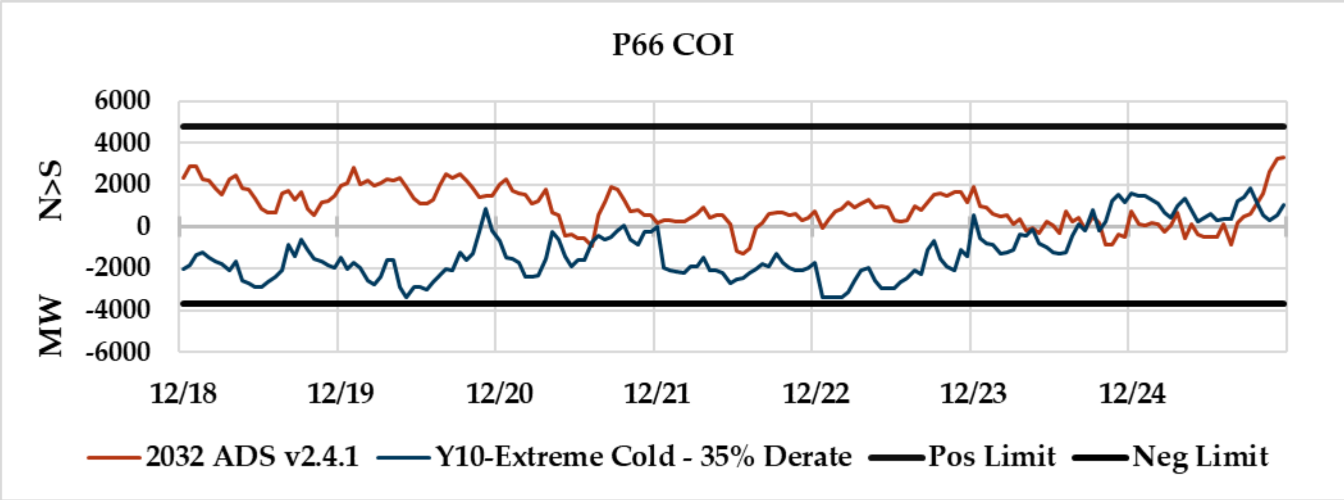


Figure 19: P66 California Oregon Intertie (COI) Chronological Hourly Flows

Recommendations

Given the resource mix assumptions in the 2032 ADS, the reliance on natural gas generation to prevent unserved load is evident when combined with the assumptions in this study to model the extreme cold event, such as an increased load, decreased wind and solar availability, and increased forced outage rates. With all natural gas generators online, no load shedding occurred. However, natural gas derates led to load shedding, highlighting a dependence on natural gas generation during extreme weather events. Given that cold weather events can affect the natural gas system—both on the supply side limiting the fuel to the generators, but also forcing units out so they can't run due to the extreme weather conditions—this is a compound risk that needs further evaluation.

This study 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. Deriving extreme weather event datasets for unprecedented weather events that we are sure to experience in the future, and understanding the effects of natural gas generation shortages on the electric system are going to be crucial.

Recommendation 1: Industry should—

- Explore mitigation strategies for extreme weather conditions, such as high demand and low generation availability. Also, closely monitor natural gas availability under extreme cold conditions;
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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 10 Extreme Cold Weather Event Advisory Group

Appendix

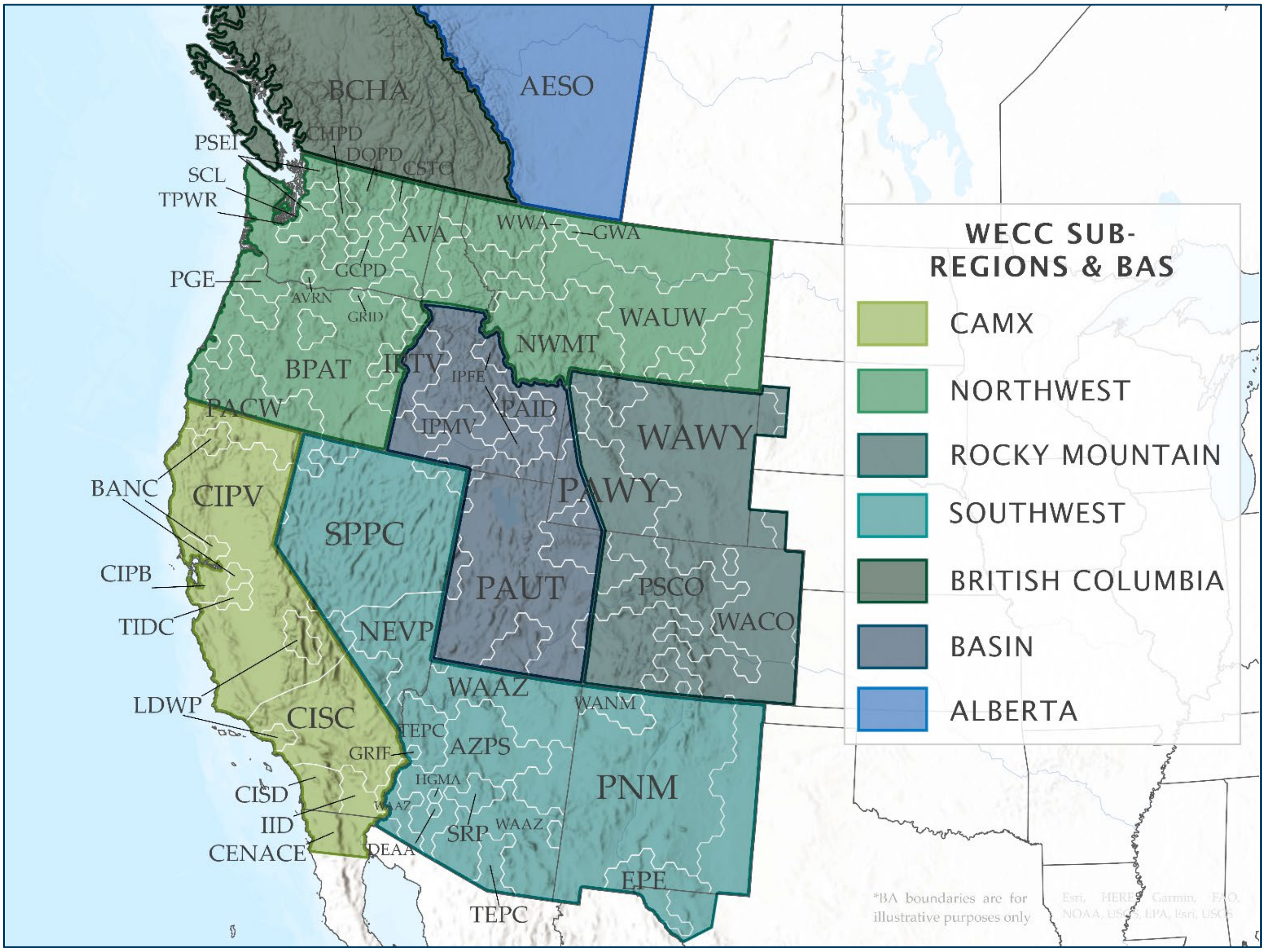

Figure 20: WECC Sub-Region to Balancing Authority Overlay

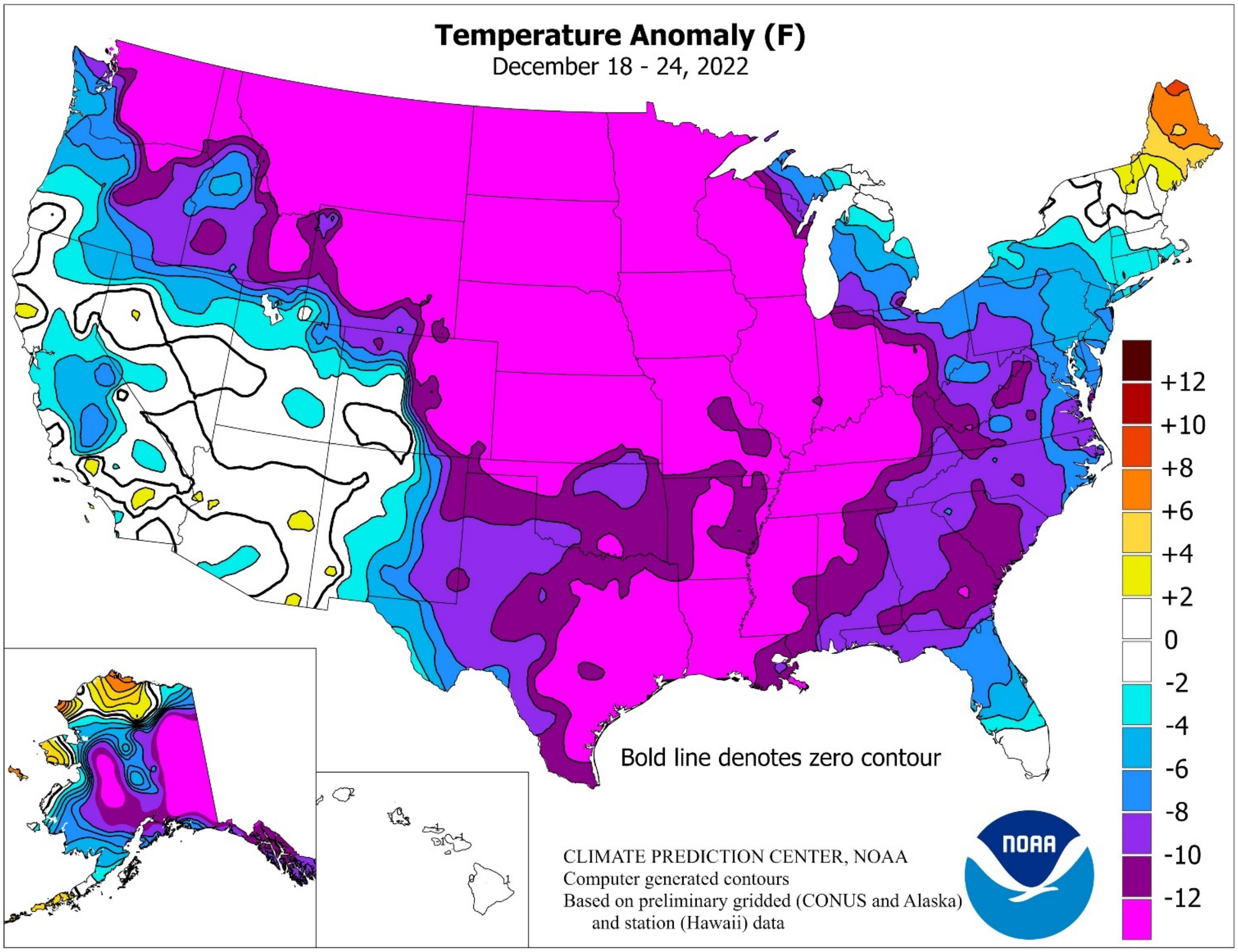

Figure 21: December 2022 Cold Event Temperature Anomaly

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

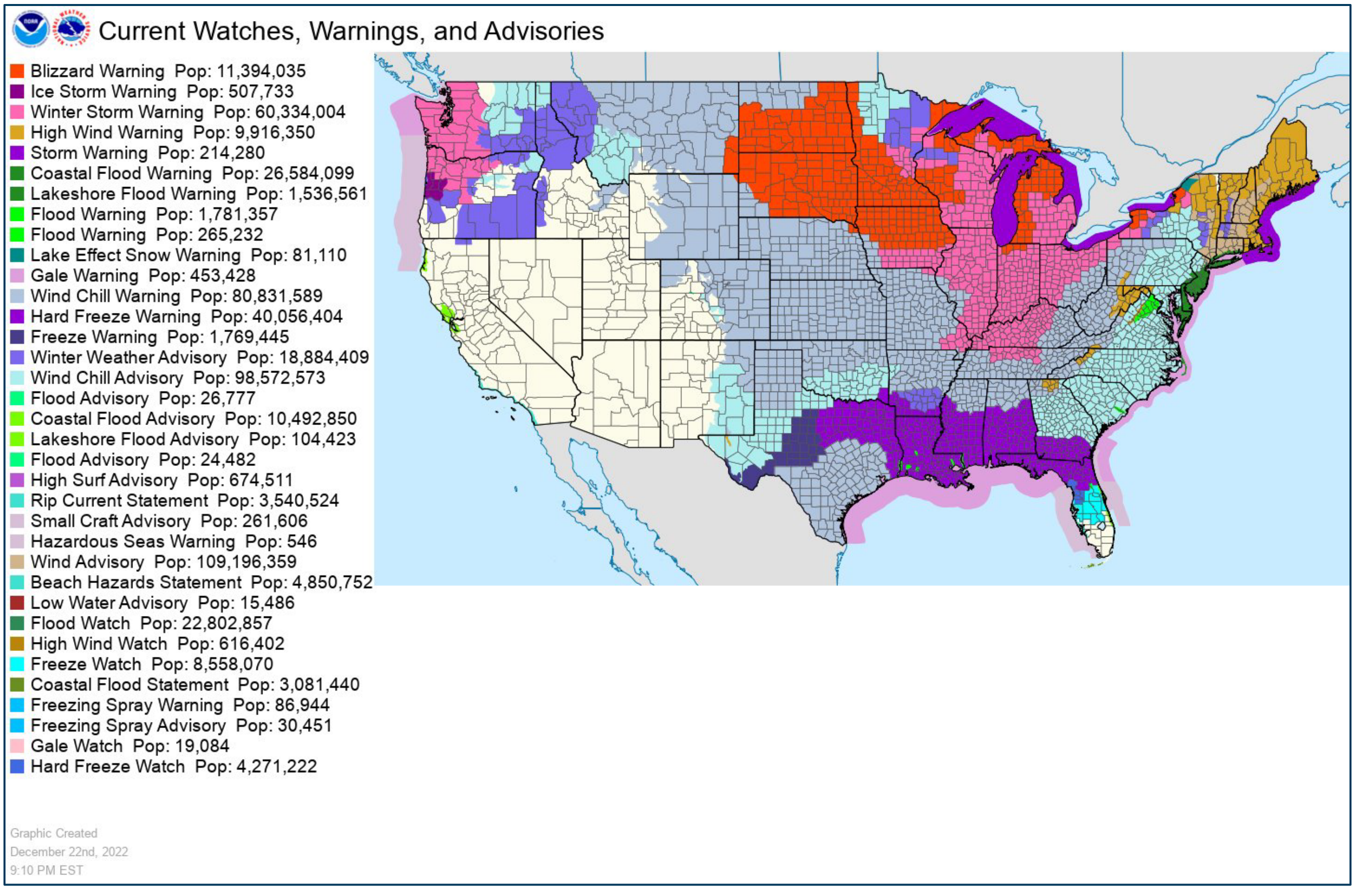

Figure 22: December 2022 Cold Event Watches, Warnings and Advisories

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

Other References

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