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Baringa

GRID DEPLOYMENT OFFICE

Grid Resilience Reports

Wyoming

Energy & Resources | Networks
12/06/2024

Table of contents

Grid Resilience Reports

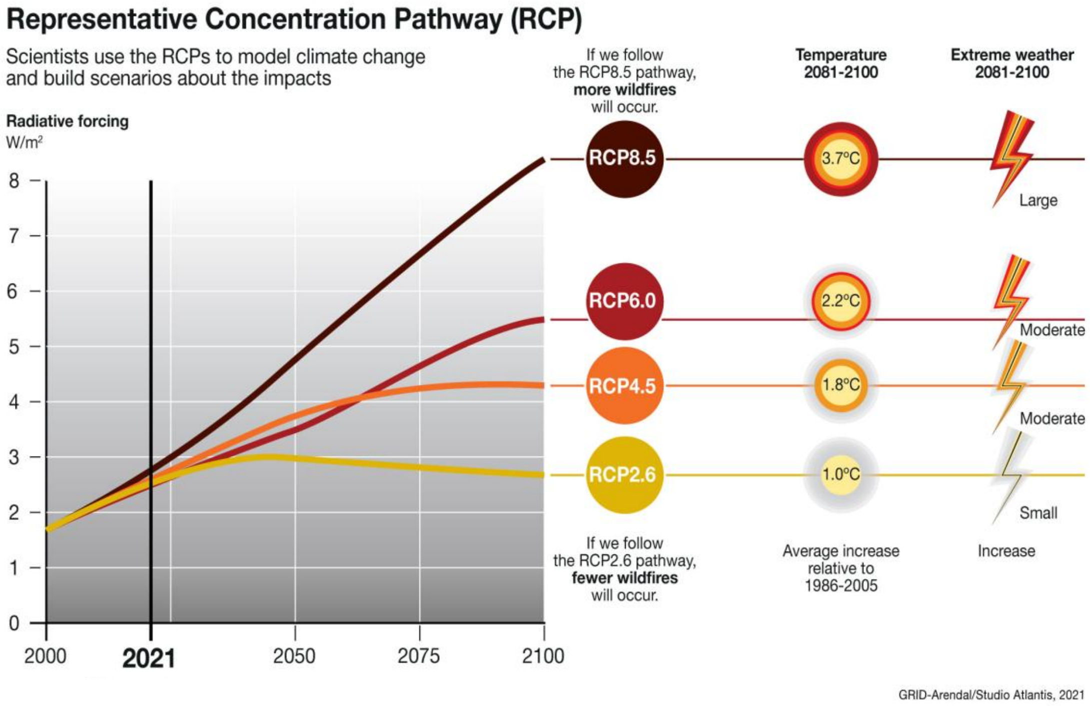
Climate Science Background, Data Sources, and Analysis Approach

RCPs and SSPs provide viable climate pathways for an uncertain future

ipcc

Generating Emission Scenarios

- **Representative concentration pathways (RCPs) project GHG concentrations:** Defined by the IPCC in 2014 as scenarios of future emission concentrations and other radiative forcing that align to climate projections.[1] RCPs use assumptions relating to policy decisions and individual behavior that may change future GHG emissions concentrations.[1] SSPs have largely replaced RCPs.
- **Shared socioeconomic pathways (SSPs) provide 5 'storylines' to contextualize RCPs** and to provide the various future pathways possible.[2] They consider how the world could evolve socioeconomically and politically, including how various levels of climate change mitigation and adaptation could be achieved and will influence future climate scenarios.[3]
- RCPs included in the CLIMRR dataset include RCP 4.5 and RCP 8.5.
- SSPs included in the Hydrosource dataset include SSP585, SSP370, SSP245, and SSP126.



Modeling Scenario: RCP 4.5

- **"Moderate" scenario**: Emissions peak around 2040 and then slowly begin to decline.[4] Temperatures warm about 3.2 °F from a 2000 baseline. [5]
- CO2 emissions plateau before falling mid-century, as energy use sharply declines and there is large scale reforestation. [6]

Modeling Scenario: RCP 8.5

- **"Rapid growth" scenario:** Emissions continue to rise throughout the twenty-first century.[4] Temperatures warm about 6.6 °F from a 2000 baseline. [5]
- CO2 emissions are three times higher than the present by end-century, with a large increase in methane emissions and continued fossil fuel use. [6]

[1] Source: ComEd Vulnerability Study 2023
[2] Source: Jupiter
[3] Source: Carbon Brief
[4] Source: Help (cal-adapt.org)
[5] CoastAdapt
[6] Climate Copernicus

Baringa

Baringa leverages national downscaled climate datasets with high granularity to assign county-level climate exposure

	CLIMRR by Argonne National Lab (ANL)	HydroSource by Oak Ridge National Lab (ORNL)	RAWS by Western Regional Climate Center (WRCC)
Dataset Description	The Climate Risk and Resilience Portal (CLIMRR) provides highly localized climate projections from mid- to end-century using a supercomputer to model 60 climate variables.	HydroSource is a comprehensive national water energy digital platform consisting of hydropower-related data set, models, visualizations, and analytics tools.	The Wildland Fire Remote Automated Weather Stations (RAWS) data set provided by WRCC is a quality-controlled repository of hourly data for 17 select weather metrics from a network of weather stations across western states.
Data Provider Description	Argonne National Lab is a federally-funded science and engineering research center sponsored by the Department of Energy.	Oak Ridge National Lab is a federally funded research and development center sponsored by the Department of Energy.	The Western Regional Climate Center is one of 6 Regional Climate Centers in the United States. WRCC works jointly with NOAA to coordinate climate activities and conduct applied research on climate issues in the West.
Years Covered	Historical, Mid-Century, End-Century	1980-2099	2000-2022
Spatial Resolution	12 km (aggregated to county)	County	Weather station (aggregated to county)
Hazards	RAIN, FIRE, HEAT, COLD, DROUGHT	FLOOD	WIND

Baringa leverages national downscaled climate datasets with high granularity to assign county-level climate exposure (cont.)

	CLIMRR by Argonne National Lab (ANL)	HydroSource by Oak Ridge National Lab (ORNL)	RAWS by Western Regional Climate Center (WRCC)
Key Metrics	Seasonal Fire Weather Index; Annual Precipitation; Cons. Days w/o Precipitation; Days Above X°F Heat Index; Annual Cooling Degree Days; Seasonal Max Temperature; Annual Min Temperature; Annual Heating Degree Days; Seasonal Min Temperature	Annual VIC Runoff (SSP585)	Hourly Max Wind Gust
Mapping/Analysis	Used a Python script that returned the most extreme value (high or low depending on hazard) from the grid cells that intersected a particular county.	Averaged across the 7 different climate model values provided for the SSP585 warming scenario to return a single, composite runoff level for each county in each year. 2000 was used for historical, 2050 for mid-century, and 2090 for end-century.	Mapped weather stations to their respective counties. If a county had multiple weather stations, the station with the highest average hourly value was selected to represent the county. Counties with no stations were mapped to the closest station in a neighboring county. GEV analysis was conducted using the pyextremes EVA function to derive return periods.
Rationale	• Reputable data provider • Accessible, open-source data allows for our methodology to be reproduced/quality checked • Provides climate projections for hazards with a significant climate signal • More than sufficient spatial resolution to gauge climate exposure at a county level	• Reputable data provider • Climate projections forecast change in exposure over time • Same spatial resolution as outage data (county level) • Pluvial flooding is more likely to contribute to outages because it is faster-acting and can hit urban centers	• Reputable data provider • Wind does not have a strong climate signal, so projections were not required • Sufficient density of stations per state to assign to counties • Quality checked • Hourly resolution was sufficient for deriving return periods

Baringa is leveraging forward-looking climate projections to inform its technical assistance work for states in WECC

Wind

Source: **Western Regional Climate Center (WRCC)**
Input metric: Hourly max wind speed (mph)
Output: Wind speed at key return periods via GEV distribution

Wildfire

- Source: **CLIMRR (ANL)**

Input metric: Fire weather index (FWI) by grid cell
Output: Maximum fire weather index by county

Precipitation

Source: **CLIMRR (ANL)**
Input metric: Annual total precipitation (in/year) by grid cell
Output: Max annual total precipitation (in/year) by county

Drought

Source: **CLIMRR (ANL)**
Input metric: Consecutive days with no precipitation by grid cell
Output: Max consecutive days with no precipitation by county

Heat

Source: **CLIMRR (ANL)**
Input metrics:

- Days above 95, 105, 115, 125 °F
- Annual cooling degree days
- Seasonal maximum temperatures

Output: Input metrics applied from a grid cell level to a county level

Cold

Source: **CLIMRR (ANL)**
Input metrics:

- Annual minimum temperature
- Annual heating degree days
- Seasonal minimum temperatures

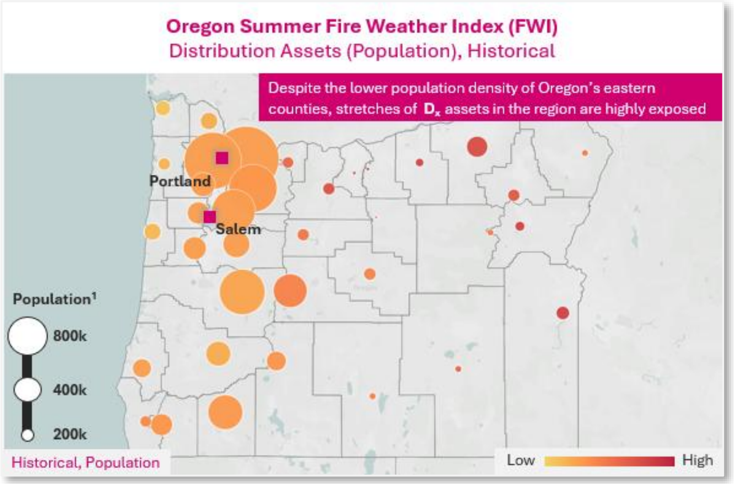
Output: Input metrics applied from a grid cell level to a county level

Flood

Source: **Hydrosource (ORNL)**
Input metric: Annual Variable Infiltration Capacity (VIC) model runoff (mm/year)
Output: Average annual VIC runoff for 4 warming scenarios and 3 time periods (historical, mid-century, end-century)

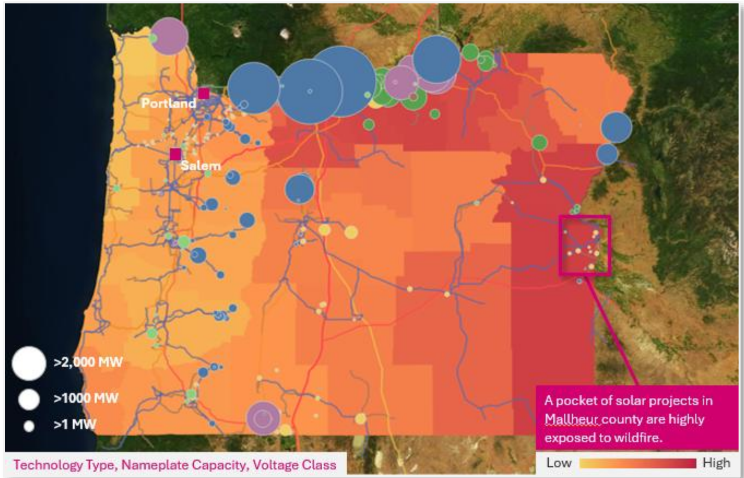
This report is standardized to include a 3 different data visualizations that provide insights for Distribution, Transmission, and Generation across 7 extreme weather hazards

1 Distribution Maps



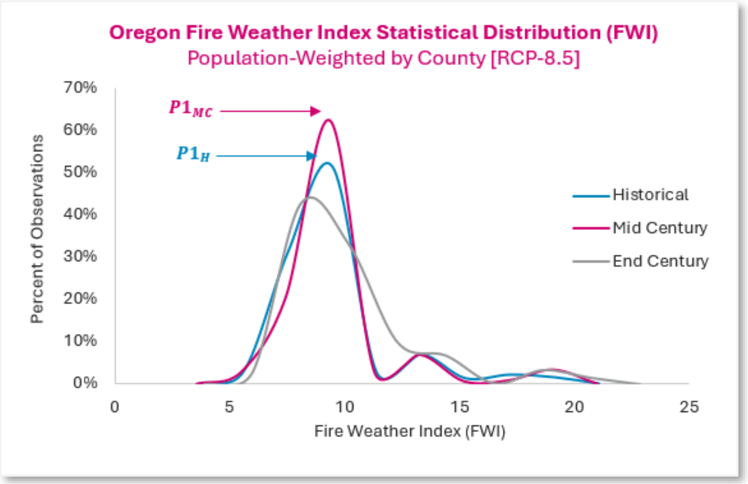
- **Purpose:** Uses population as proxy for volume of distribution assets given that the location of distribution assets is restricted.
- **Interpretation*:** Locate areas of high exposure by identifying counties with coincident large bubbles and dark colors. This indicates a combination of high volume of Dx assets and significantly high extreme weather projections.

2 Transmission & Generation Maps



- **Purpose:** Overlays transmission and generation assets on climate projections by county.
- **Interpretation:** Locate areas of high exposure by identifying assets in counties of high risk. Exposure differs by asset class and will be highlighted in Key Insights tables throughout.

3 Statistical Distribution Graphs



- **Purpose:** Contains statistical insights related to each metric. Indicates change in dispersion and severity of risk over time on average
- **Interpretation:** A change in the width of the peak indicates a decrease in concentration of exposure., meaning more counties are exposed to more severe weather. A shift right in the curve indicates that on average, the all counties are experiencing more severe weather.

***Note:** Analysis addresses risk given volume of assets and does not account for risk to remote customers at end of radial distribution grids.

Asset Class Overviews

Summary

L Low M Moderate H High

WEA could consider funding a diverse set of projects aside from undergrounding, including vegetation management projects, Dx pole upgrades

Key Takeaways

- Consider emergency response and funding Tx and Dx hardening across the state given relatively evenly distributed levels of wildfire exposure.
- Explore DER programs to reduce reliance on large thermoelectric assets susceptible to derating and consider funding substation upgrade in NE counties.
- Prioritize Tx and Dx hardening in NW counties where sub-freezing annual minimum temperatures persist despite statewide warming.

Hazard	Exposure	Change to Mid-Century	Generation	Transmission & Distribution	AWPI	Description
FIRE	H	↑	**Consider further investment in emergency response and fossil generator fortification** • WEA could encourage wildfire mitigation planning or fund additional access road upgrades to shorten restoration times. • Consider initiatives to mitigate fire spread from flammable fuel stockpiles.	**Consider balancing Tx and Dx investment between well-populated and rural counties** • Relatively evenly distribute fire exposure indicates WEA could split Dx hardening between radial lines and dense pockets of Dx assets. • HV lines in SW counties are mostly export lines, but could be prioritized for hardening given their exposure and revenue	M	**Gen:** No proposals address generator exposure. WEA could consider hardening operational facilities. **T&D:** Undergrounding and access road upgrades align with exposure, but WEA could also consider vegetation management or Dx pole upgrades.
HEAT	M	↑	**Explore funding DERs to offset derating of supply and enhance flexibility** • DERs could reduce reliance on large, highly exposed thermoelectric generators that will derate during extreme heat events.	**Consider substation upgrades in NE counties and more cost-effective Tx hardening methods** • Exposure to days >105 °F in NE could warrant transformer health monitoring software. • Widespread heat exposure necessitates options like reconductoring, GETs, or vegetation to mitigate effects of derating risk.	M	**Gen:** No proposals address generator exposure or propose DERs. **T&D:** Undergrounding and reconductoring address heat, but WEA could also consider vegetation management and dynamic line rating (DLR) to combat line sag and derating.
COLD	H	↓	**Focus weatherization technologies on heavily exposed thermoelectric assets** • Coal assets in Converse and Albany Counties are particularly exposed to cold and could be hardened to avoid startup failure or derating.	**Prioritize Tx and Dx hardening in NW counties, where sub-freezing annual minimums persist** • Despite warming, Dx assets in NW counties are exposed to freezing temps. for much of the year. • MV lines in Fremont County could be prioritized for hardening given extreme cold exposure.	M	**Gen:** No proposed awards address generator cold exposure. **T&D:** Undergrounding projects address cold exposure, but most hardening projects appear geared towards fire.

*** AWPI = Alignment with proposed investment**

L Low M Moderate H High

WEA could prioritize substation fortification in NW counties exposed to flood and wind-related hardening in SE and NW counties.

Key Takeaways

- WEA could consider funding substation fortification and Dx pole upgrades in NW counties that are heavily exposed to flooding.
- Consider hardening for SE generating facilities and Tx structure and Dx pole upgrades in SE and NW counties to address wind exposure.
- Explore the potential to address exposure to multiple climate hazards simultaneously through innovative thermoelectric cooling and solar O&M projects.

Hazard	Exposure	Change to Mid-Century	Generation	Transmission & Distribution	AWPI	Description
FLOOD	L	↑	**Generators are generally not significantly exposed to flood** • Thermoelectric generators are exposed in Lincoln County, which could inundate critical auxiliary equipment and contribute to plant failure.	**WEA could prioritize substation fortification** • Pockets of HV substations are heavily exposed to flooding in NW counties, which can cause direct failure. • WEA could also consider upgrades to aging or weak Dx poles in the NW region.	L	**Gen:** Lack of exposure makes this a lower priority for investment. **T&D:** No projects targeting substations, unaligned with the significant substation exposure.
WIND	M	→	**Consider hardening for SE generating facilities** • WEA could encourage SE wind farms to procure turbines with higher cutout speeds. • Cooling tower hardening could combat wind-related derates at Laramie River Station.	**WEA could consider Tx structure and Dx pole upgrades In SE and NW counties** • WEA could reinforce Tx structures for crucial import/export lines in SE counties. • Harden Dx poles in mountainous NW towns.	M	**Gen:** No projects addressing generator exposure. **T&D:** Undergrounding addresses wind, but WEA could also consider Dx pole and Tx structure upgrades.
DROUGHT	M	↓	**WEA could explore water conservation measures for water-based cooling methods.** • Water scarcity can cause curtailments and emissions increases for coal and natural gas. • Drought conditions can cause dust buildup on solar panels, hurting capacity factors.	**Drought exposure does not have a material impact on transmission and distribution assets**	L	**Gen:** No projects addressing generator drought exposure. WEA could consider that advanced cooling and panel cleaning projects address both drought and heat/fire simultaneously.
RAIN	M	↑	**Consider the impact of increased precipitation and other conditions on hydro output** • Consider the possibility of more frequent extreme rainfall and changing snow patterns.	**Precipitation exposure does not have a material impact on transmission and distribution assets**	M	**Gen:** WEA could consider whether enhanced data collection is more effective in addressing precipitation exposure than physical hardening.

* AWPI = Alignment with proposed investment

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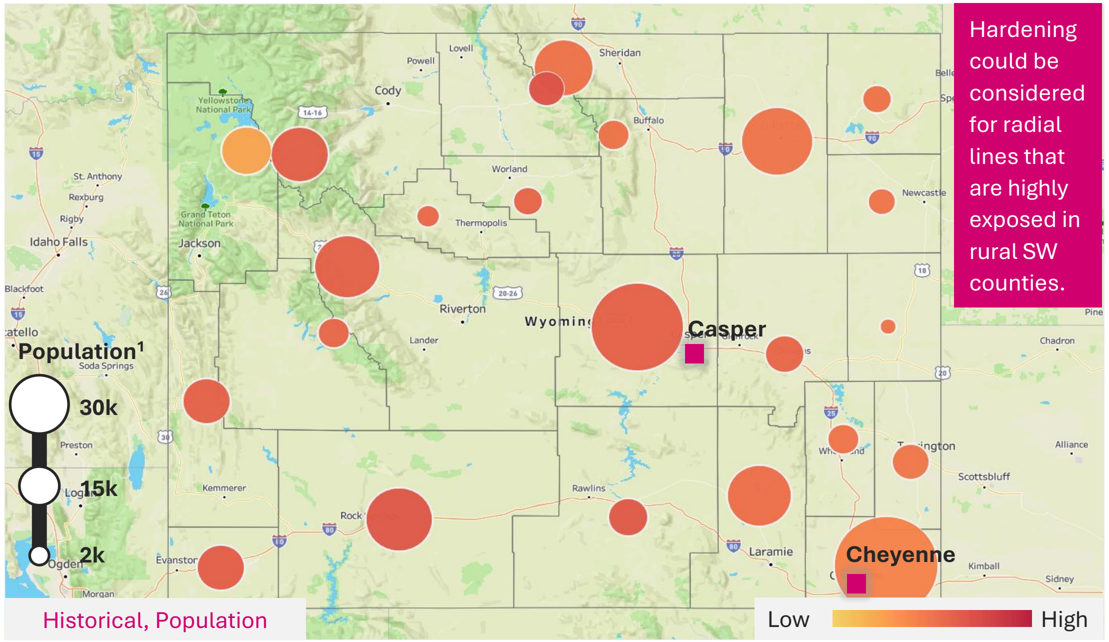
Wildfire

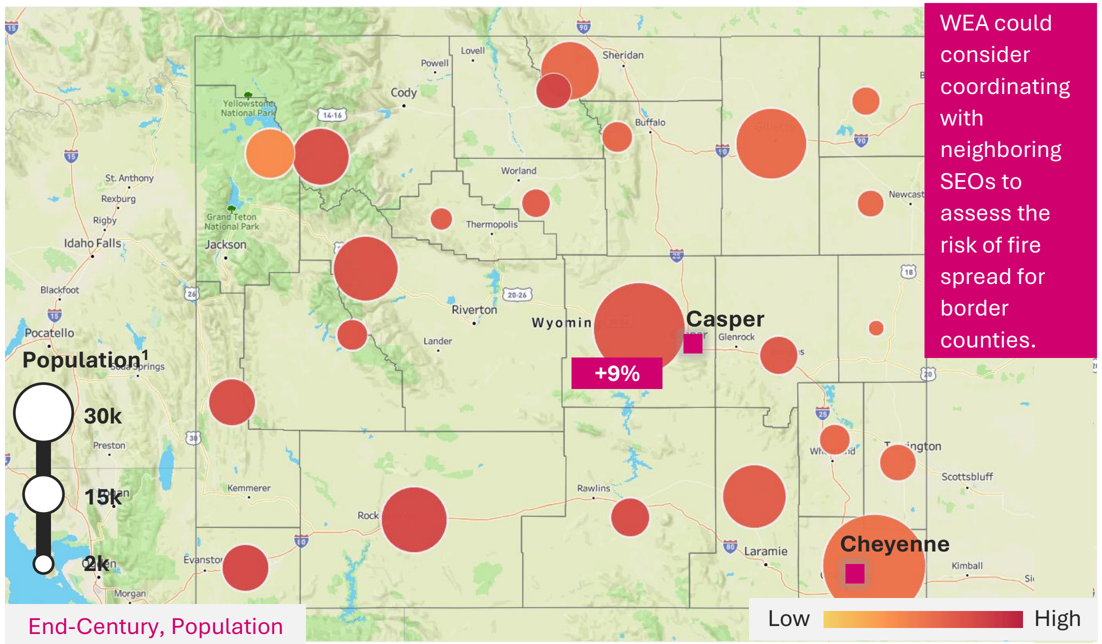
Asset Analysis

Since fire exposure is generally evenly distributed throughout the state, WEA could consider balancing fire mitigation investment between rural radial lines and dense pockets of Dx assets

Wyoming Summer Fire Weather Index (FWI)
Distribution Assets (Population), Historical



Wyoming Summer Fire Weather Index (FWI)
Distribution Assets (Population), End-Century [RCP-8.5]



KEY OBSERVATIONS

- Wildfire exposure is **generally evenly distributed throughout the state** but tends to be **most concentrated in SW counties.**
- **Big Horn County** faces peak statewide wildfire exposure.
- Undergrounding proposals address wildfire exposure, but WEA could also consider **pole wrapping or wildfire mitigation planning.**

KEY OBSERVATIONS

- FWI increases by about 2-6 points across the state, demonstrating the importance of utilizing **forward-looking climate projections for state-wide fire mitigation planning.**

Natrona County Natrona County is relatively well-populated and faces high wildfire exposure, **posing a threat to a high density of Dx assets.**

Source: ClimRR, US Census Bureau, City and Town Population Totals

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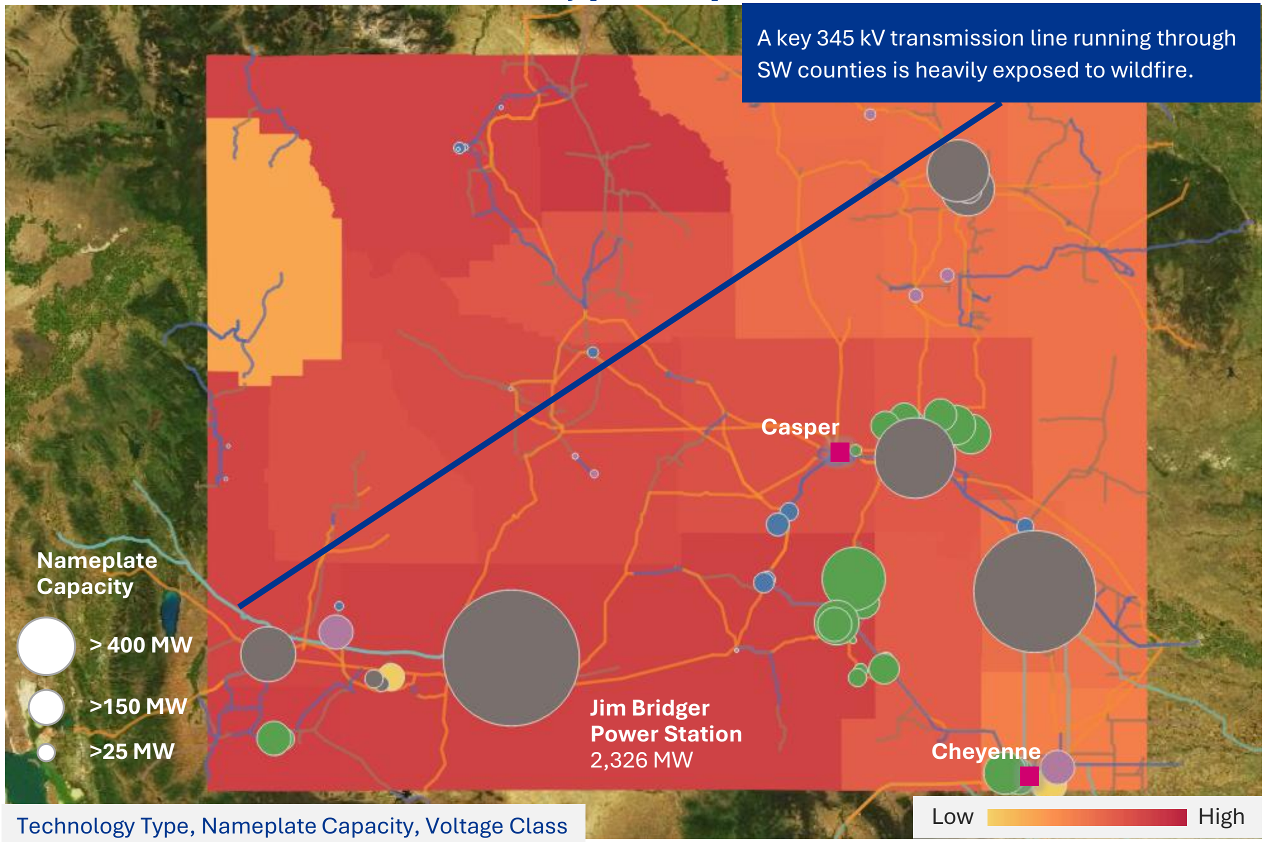
WEA could prioritize transmission hardening, asset access projects, and thermoelectric fortifications in SW counties to address escalating wildfire exposure

Wyoming Summer Fire Weather Index (FWI)
Generators & Transmission, Mid-Century [RCP-8.5]



Onshore Wind	Coal Plant	Hydroelectric	Nuclear	Solar Photovoltaic
Biomass	Natural Gas Plant	Pumped Storage	Batteries	Other
500kV	345kV	220-287kV	100-161kV	<100kV

Source: ClimRR, US Census Bureau, City and Town Population Totals

Key Highlights	Analysis
Transmission	• HV Tx lines in **Sweetwater and Lincoln Counties** are heavily exposed to wildfire. • **A key 345kV import/export line connecting Wyoming to Idaho is highly exposed to wildfire,** which could be prioritized for hardening given its crucial role during extreme weather events.
Restoration	• Wildfire causes **ingress/egress issues** through destruction of roads and transportation, slowing restoration times for all assets. • The 40101(d) proposal including access road upgrades could serve as a blueprint for future projects to combat wildfire-related access issues.
Thermoelectric	• **Jim Bridger Generating Station** in Sweetwater County is highly exposed to wildfire. • **Flammable fuel stockpiles can accelerate fire spread** if not fortified.

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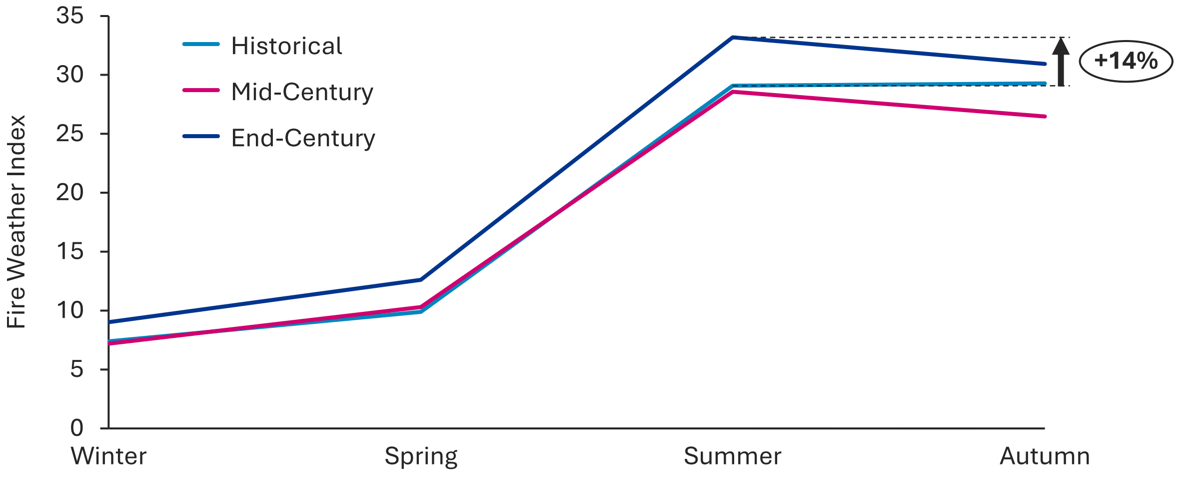
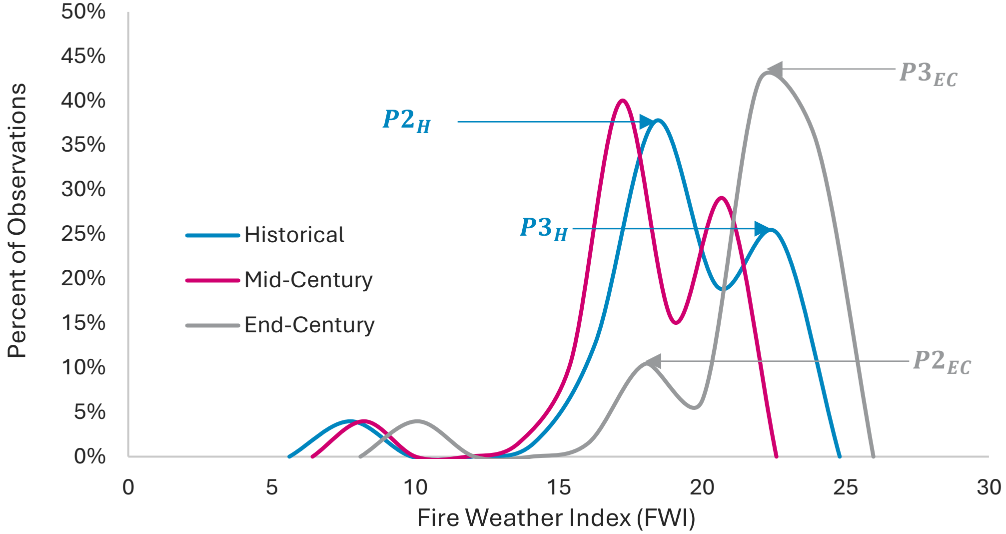
Wildfire exposure appears relatively unchanged by mid-century, but could increase in severity and spatial extent by end-century, posing a more acute threat to a wider range of assets

Wyoming Average Seasonal Fire Weather Index (FWI)
Population-Weighted by County [RCP-8.5]



Wyoming Fire Weather Index Statistical Distribution (FWI)
Population-Weighted by County [RCP-8.5]



KEY OBSERVATIONS

- **End-century wildfire exposure is elevated**, with the sharpest increase occurring between spring and autumn by about 14% from historical FWI.
- Elevated wildfire exposure around the summer suggests a **shift of peak wildfire exposure earlier in the year, a lengthening of the wildfire season, and an increase in severity.**
- The change in length of wildfire season suggests that the window for scheduled maintenance during the shoulder seasons is diminishing.

KEY OBSERVATIONS

- Rightward and upward shift of the curve by end-century demonstrates an **increase in wildfire.**
- The inversion of P2 and P3 indicates a much **wider spatial extent exposed to peak FWI by end-centur**y compared to historical.
- Leftward shift of the mid-century curve indicates that fire exposure may decrease slightly in the near-term, although **increases in fire exposure for neighboring states may counteract this apparent decrease.**

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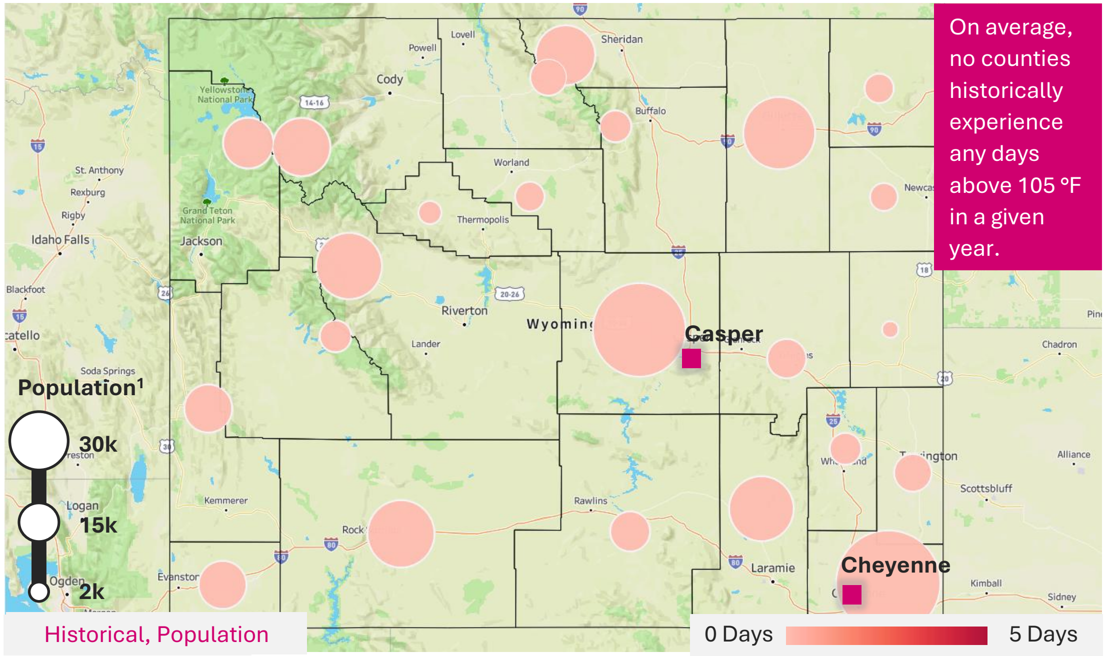
Heat

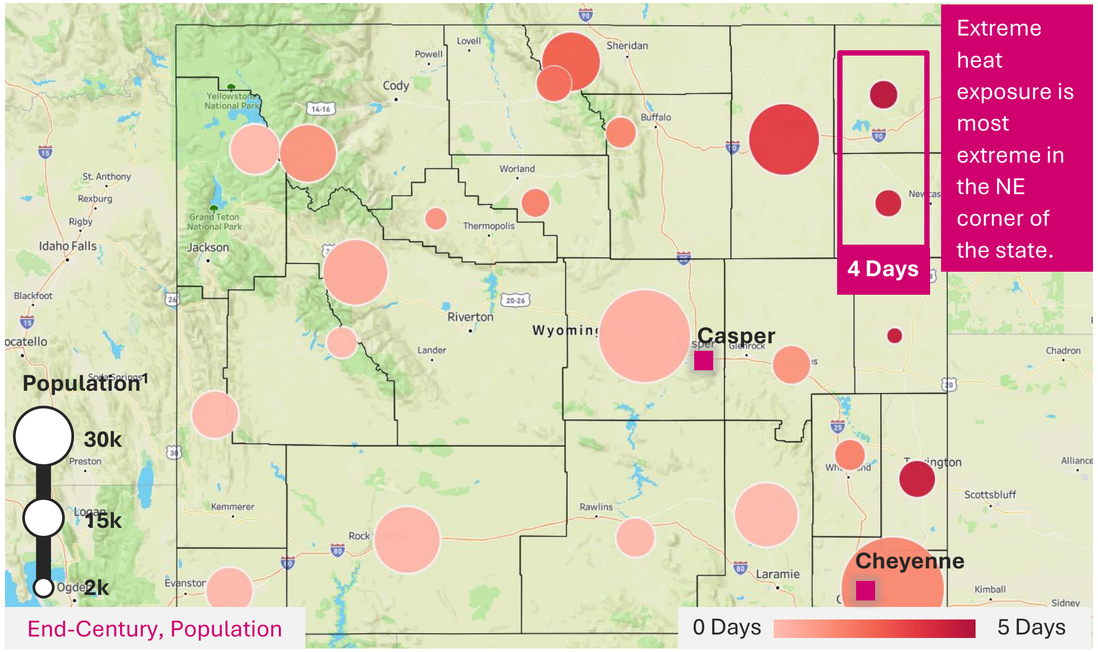
Asset Analysis

WEA could consider Dx upgrades addressing extreme heat in NE counties to mitigate asset degradation, derating, and potential failure given escalating exposure over time

Wyoming Days Above 105 °F
Distribution Assets (Population), Historical



Wyoming Days Above 105 °F
Distribution Assets (Population), End-Century [RCP-8.5]



KEY OBSERVATIONS

- Currently T_x and D_x assets have **no exposure to days above 105 °F.**
- 105 °F is a particularly important threshold for distribution assets and substations, **which can fail when exposed to two consecutive days above 104 °F.**[2]

KEY OBSERVATIONS

- Eastern counties are expected to face **about 1-5 days >105 °F annually, causing high asset utilization, derating, and potential failure.**

Crook County — Crook County will face over 4 days **>105 °F** by end-century, exposing Dx substation assets in the county to derating and potential failure.

[1]Population bubbles are continuous and therefore labels are approximate. [2]EPRI Climate READi

Source: ClimRR, US Census Bureau, City and Town Population Totals

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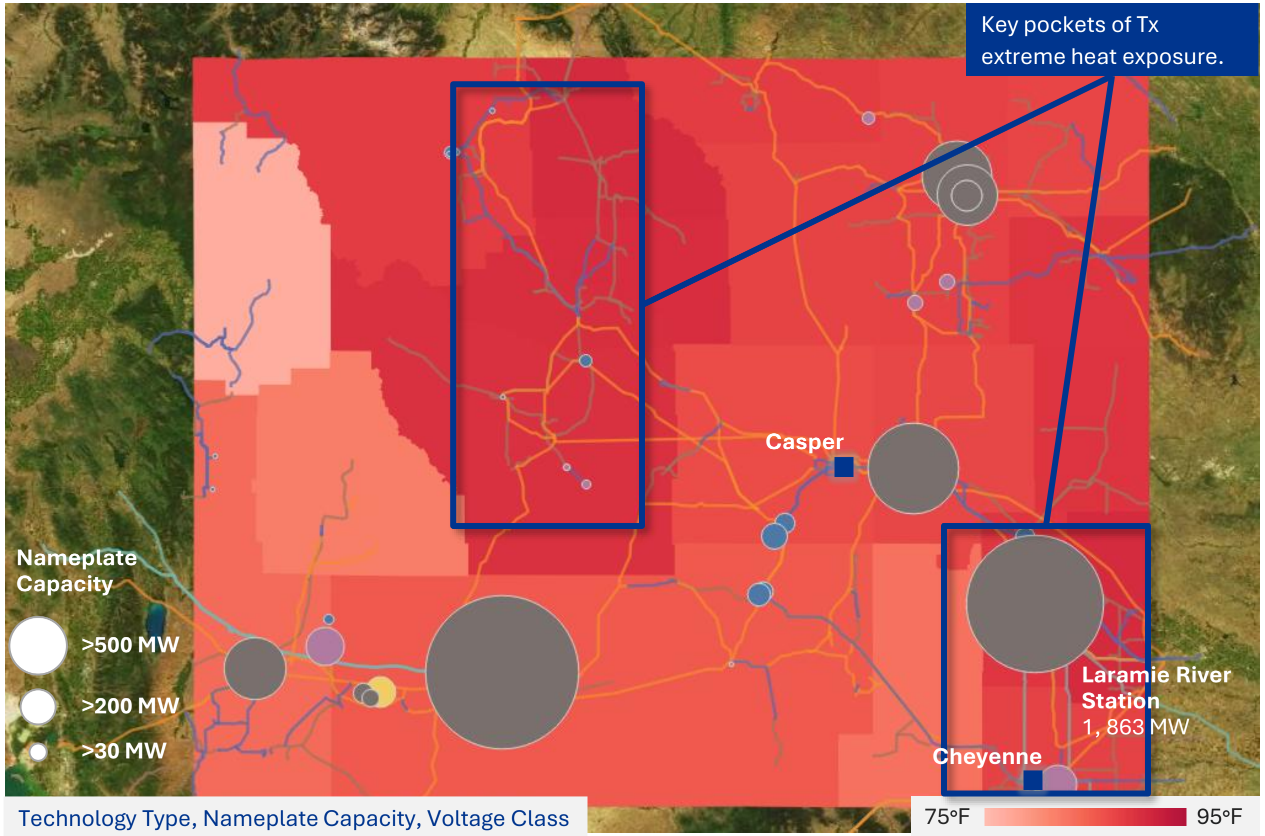
WEA could consider additional investments to combat thermoelectric production and transmission capacity derates due to extreme heat given escalating exposure over time

Wyoming Summer Average Maximum Temperature (°F)
Generators, Mid-Century [RCP-8.5]



Onshore Wind | Coal Plant | Hydroelectric | Nuclear | Solar Photovoltaic
Biomass | Natural Gas Plant | Pumped Storage | Batteries | Other
500kV | 345kV | 220-287kV | 100-161kV | <100kV

Key Highlights	Analysis
Thermoelectric	• Laramie River Station in Platte County is highly exposed to extreme heat, as are natural gas assets in Laramie and Campbell Counties. • Thermoelectric generators that rely on water-based cooling methods will **experience production derates** as extreme heat raises average water temperatures. • WEA could **consider funding DERs to combat thermal derating of large generators.**
Transmission	• A significant portion of transmission lines are exposed to high levels of extreme heat in the central and SE regions of the state, which can cause capacity derates and line sag. • Undergrounding proposals address these issues, but WEA could consider **more cost-effective adaptations like reconductoring or vegetation management to address exposure over longer distances.**

Source: ClimRR, US Census Bureau, City and Town Population Totals

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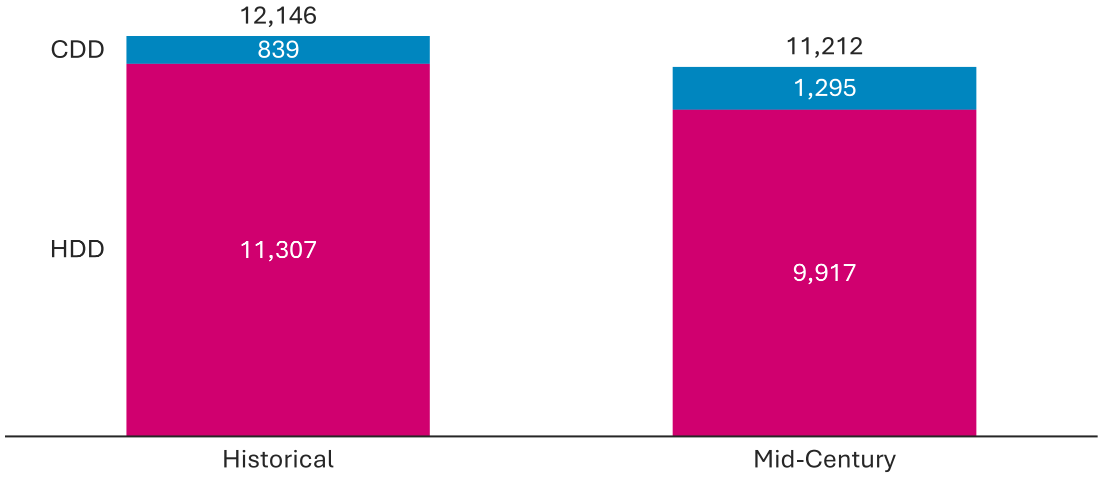
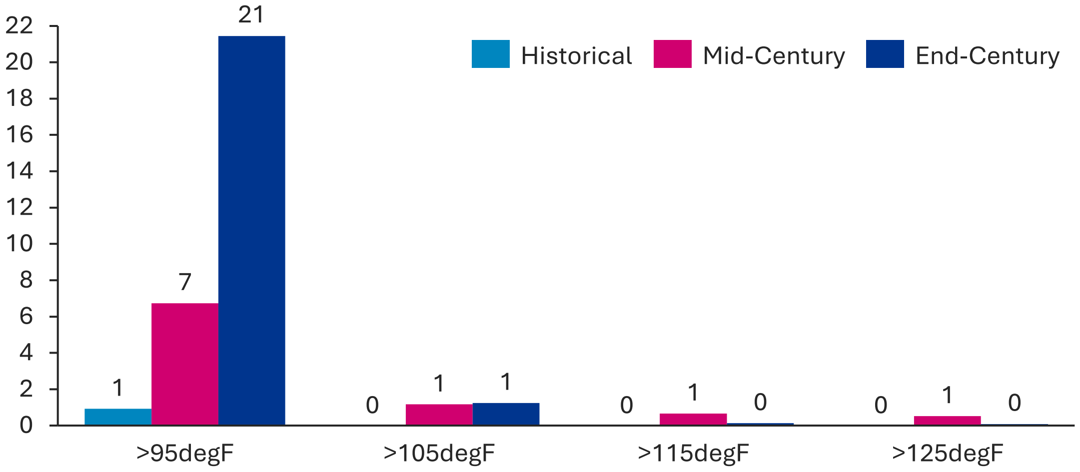
Days above 95 °F are projected to increase drastically over time, making derating and capacity violations key issues for CEO to prioritize

Wyoming Average Annual Cooling & Heating Degree Days (CDD & HDD)
Population-Weighted by County [RCP-8.5]



Wyoming Average Annual Days Exceeding Daily Max Heat Index Thresholds
Population-Weighted by County [RCP-8.5]



KEY OBSERVATIONS

- Between historical and mid century, **the ratio of CDD to HDD increases,** with the share of average number of CDD jumping from about 7% to 13% across historical and mid-century.
- This results in **increased summer asset utilization and degradation**, but **impacts to winter utilization remain unclear** depending on heating electrification trends.
- WEA could be mindful of the **impact of heating electrification on peak load** given significantly higher HHD levels than CDD levels.

KEY OBSERVATIONS

- 7x increase in days with heat index >95 °F by mid-century demonstrates an **increase in peak load** and will likely contribute to **derating** and **capacity violations** for transmission and thermal generating units.
- Significant increase in days > 95 °F by end-century could cause an **increase in asset utilization, decreasing asset lifespans.**
- Utilities could prioritize planning for temperatures between 95-105 °F, making **derating a higher priority than asset failure.**

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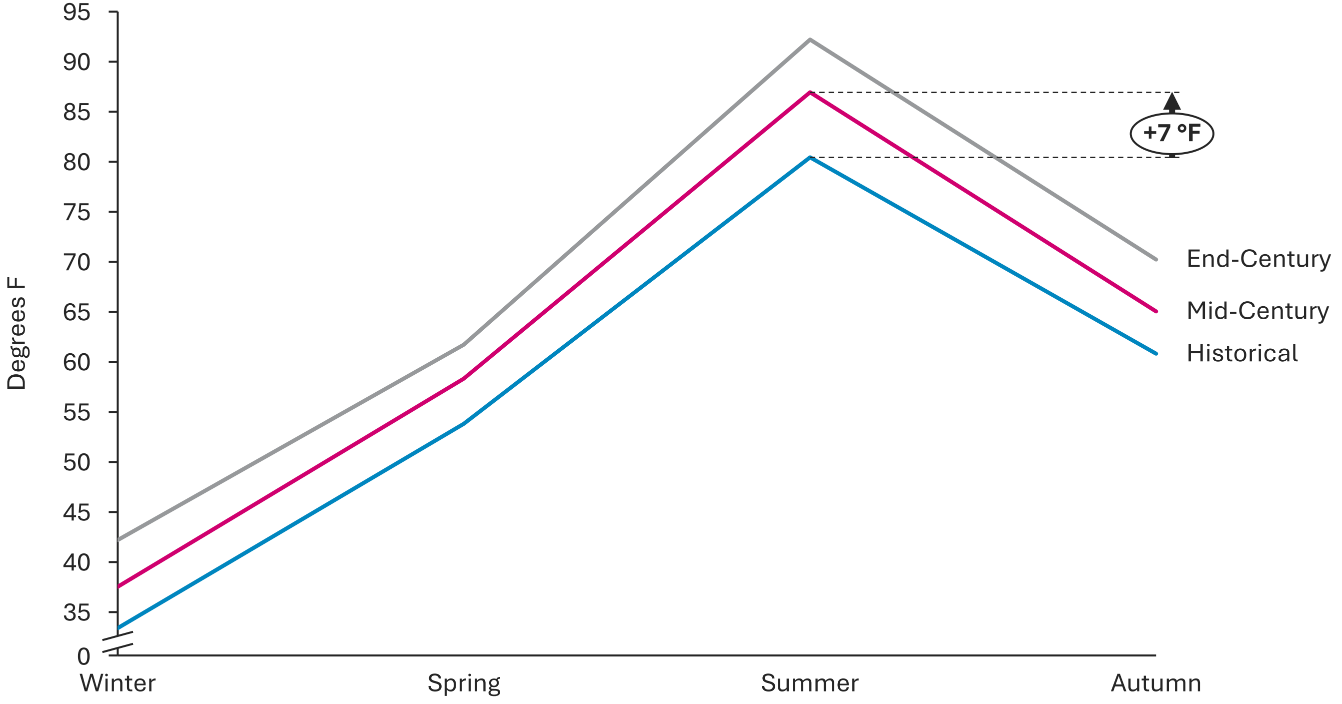
Average summer temperature maximums are projected to increase by mid-century, increasing the duration and magnitude of high system utilization

Wyoming Average Seasonal Maximum Temperature (°F)
Population-Weighted by County [RCP-8.5]



Key Highlights	Analysis
Summer Warming	• **Heat risk increases most drastically in summer**, with a 7 °F increase in the average seasonal max temperatures by mid-century, **increasing system utilization and degradation.**
Shorter Shoulder Seasons	• Less pronounced warming in shoulder seasons, although increased autumn maximums could **extend the duration of high system utilization and shorten maintenance windows.**

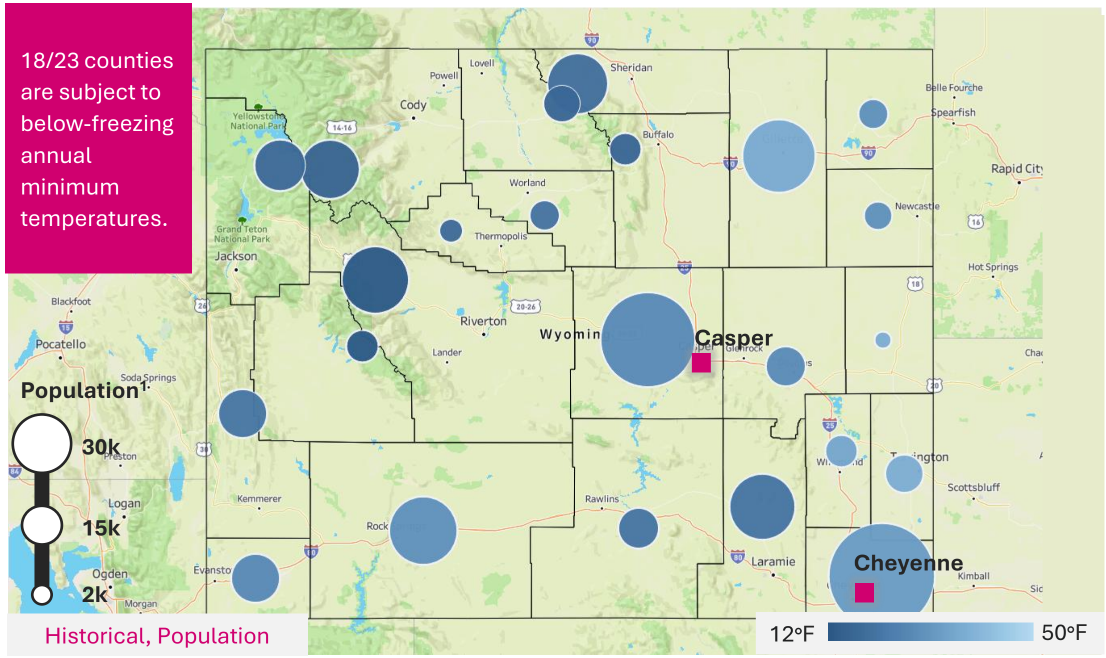
 |

Cold

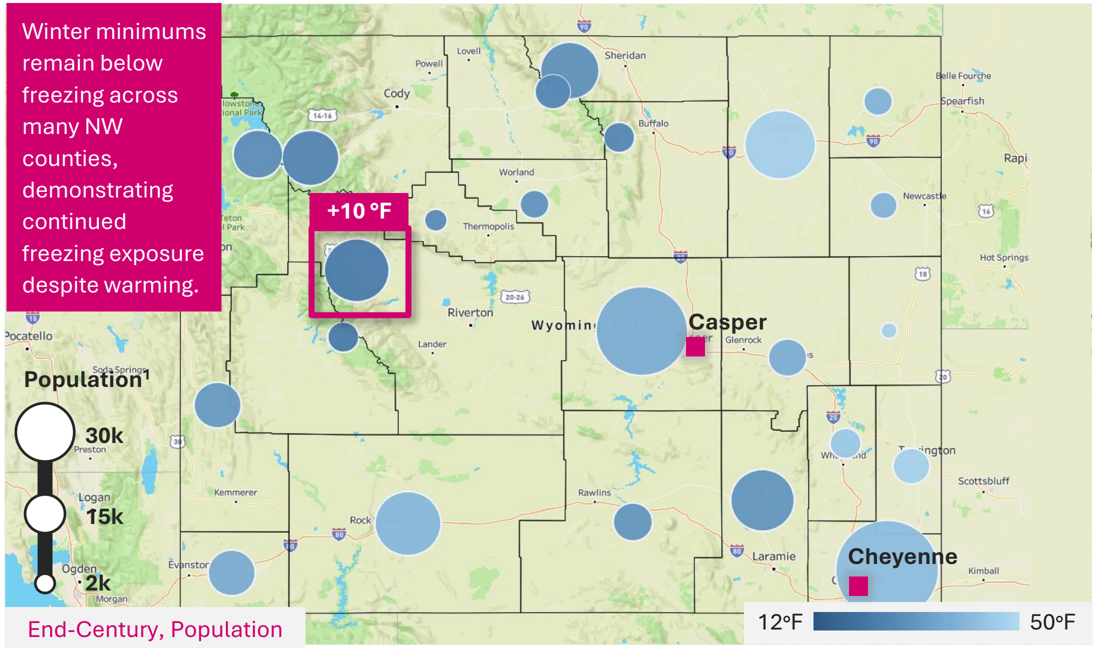
Asset Analysis

NW counties continue to face high extreme cold exposure year-round, prompting consideration of Dx hardening to mitigate line freezing and strengthen poles in these regions.

Wyoming Average Annual Minimum Temperature (°F)
Distribution Assets, (Population) Historical



Wyoming Average Annual Minimum Temperature (°F)
Distribution Assets, (Population), End-Century [RCP-8.5]



KEY OBSERVATIONS

- Extreme cold exposure is **most extreme in NW counties,** although annual minimums are sub-freezing across most of the state.
- Undergrounding projects address cold exposure, but WEA **may want to consider Dx pole upgrades in NW counties to prevent failure due to ice and snow loading.**

KEY OBSERVATIONS

- Climate projections cannot predict acute extreme events like polar vortices and winter storms, **underrepresenting cold exposure.**

Fremont County Fremont County is exposed to average annual minimum temperatures of ~24°F, indicting potential **icing and freezing exposure for distribution assets.**

Source: ClimRR, US Census Bureau, City and Town Population Totals

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WEA could prioritize hardening projects addressing extreme cold for heavily exposed thermoelectric and wind assets as well as MV transmission lines.

Wyoming Average Annual Minimum Temperature (°F)
Generators, Mid-Century [RCP-8.5]

Onshore Wind | Coal Plant | Hydroelectric | Nuclear | Solar Photovoltaic
Biomass | Natural Gas Plant | Pumped Storage | Batteries | Other

500kV | 345kV | 220-287kV | 100-161kV | <100kV

Source: ClimRR, US Census Bureau, City and Town Population Totals

Key Highlights	Analysis
Wind	• Wind assets in Carbon and Albany County are particularly exposed to cold. • Without fortification, extreme cold can contribute to **ice throw, decreased turbine lifespan, and direct asset failure.**
Thermoelectric	• Natural gas and coal plants in Converse and Lincoln Counties are subject to extreme cold exposure, which could cause **ignition failure or a freezing of coal stockpiles.** • **No proposals addressing aging gas infrastructure**, which requires hardening or replacement to mitigate cold exposure.
Transmission	• The **prevalence of below-freezing annual minimums** in many counties contributes to **Tx freezing/icing risk** that can cause asset failure, especially for a group of MV lines passing through Fremont County. • WEA could consider structure reinforcement upgrades to combat icing.

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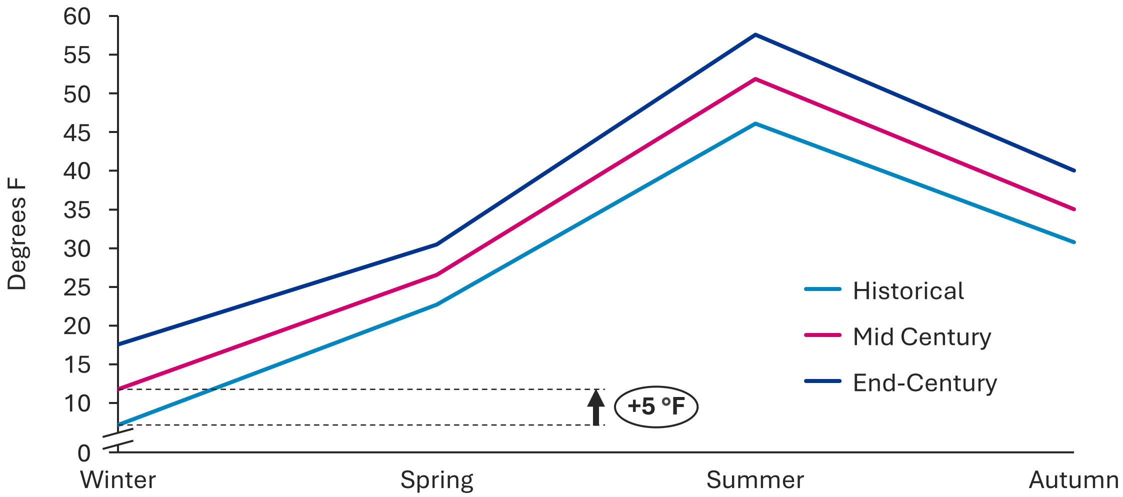
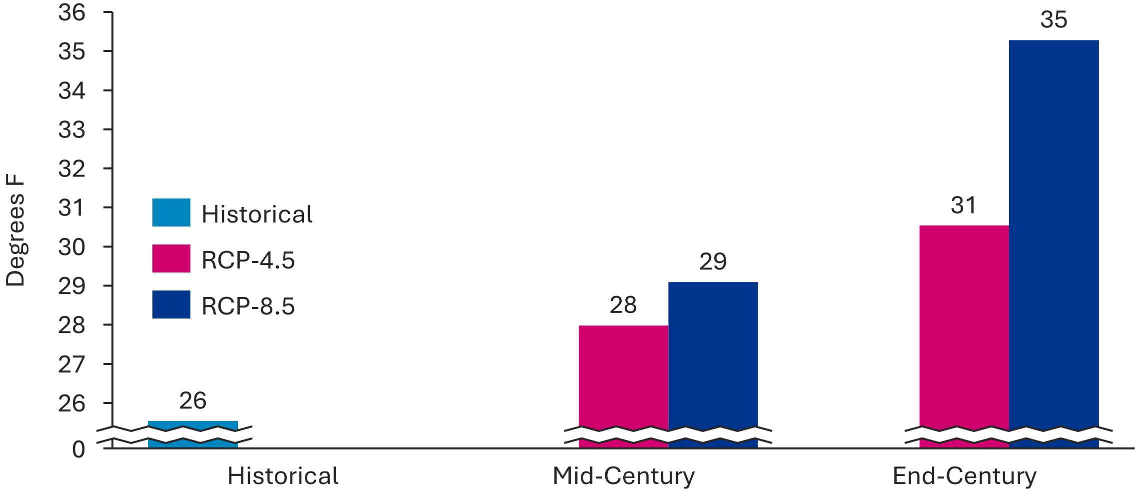
Winter minimum temperatures remain far below 32 °F despite moderate warming over time, indicating adaptations addressing freezing as a priority area for future WEA investment.

Wyoming Average Seasonal Minimum Temperature (°F)
Population-Weighted by County [RCP-8.5]



Wyoming Average Annual Minimum Temperature (°F)
Population-Weighted by County [RCP-4.5, RCP-8.5]



KEY OBSERVATIONS

- Significant winter heating (+5 °F by mid-century) will decrease overall heating load, but the **impact on electricity demand ultimately depends on the speed of heating electrification.**
- Mid-century winter minimums remain well below 32 °F for much of the year, indicating that **freezing exposure persists despite warming.**
- Few proposed projects address freezing and icing risk despite significant exposure, demonstrating a potential priority area for future investment.

KEY OBSERVATIONS

- Annual minimums below 32 °F indicate **significant freezing and icing exposure for most of the year**, demonstrating the need for relevant hardening upgrades such as undergrounding, reconductoring, etc.
- Regarding extreme cold, global climate models do not resolve for extreme cold events like polar vortexes, so **assets could still face similar levels of exposure to cold-related failures** despite moderate projected warming.

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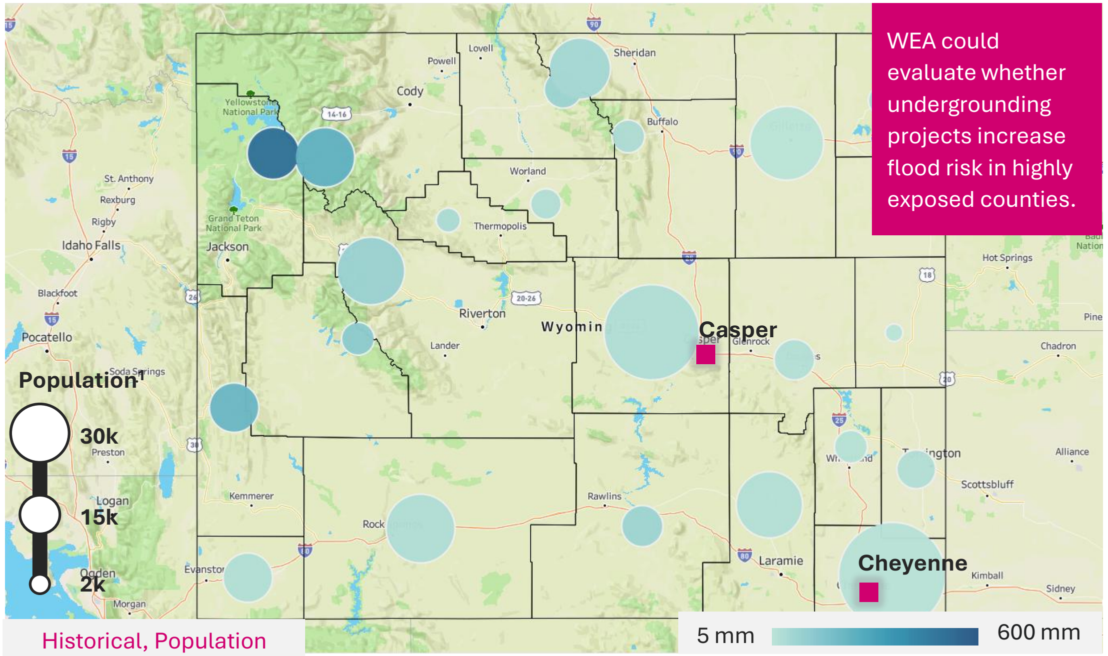
Flood

Asset Analysis

Flood exposure is generally concentrated in mountainous NW counties, where WEA could consider fortifying low-lying Dx substations and hardening weak Dx poles.

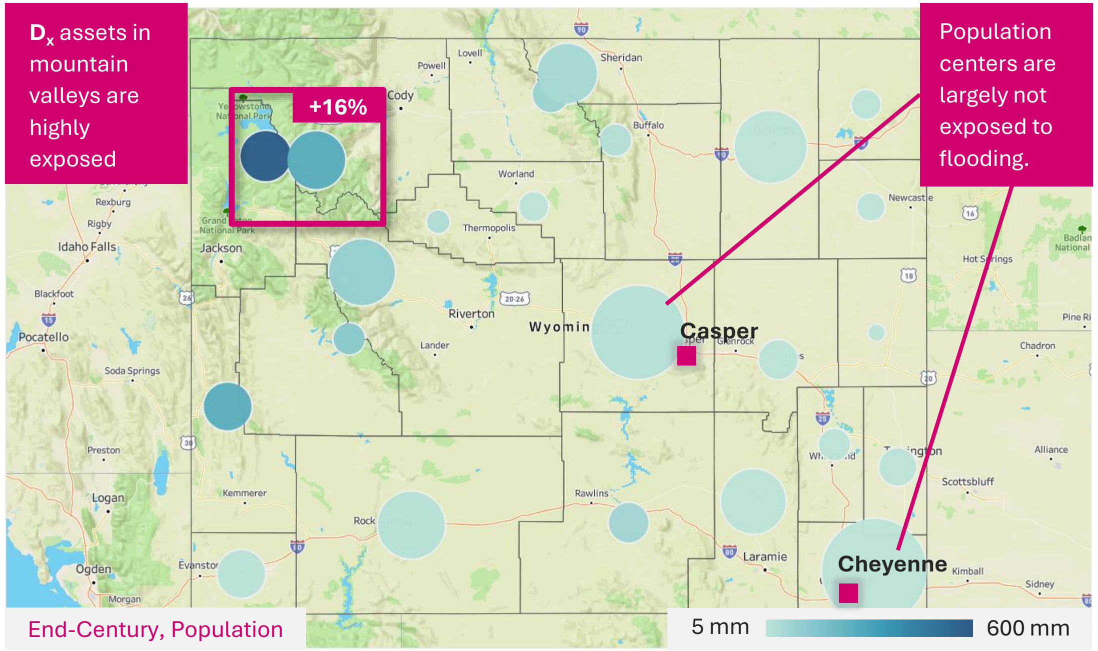
Wyoming Average Annual Surface Runoff (mm/year)
Historical [SSP5-8.5]



KEY OBSERVATIONS

- Most flood exposure lies in the NW **counties** given their mountainous terrain, presence of waterways, and higher precipitation levels.
- Generally **low levels of flood exposure in central and eastern population centers** given their flat terrain and lower precipitation levels.
- Currently no proposed projects explicitly address flood exposure.

Wyoming Average Annual Surface Runoff (mm/year)
End-Century [SSP5-8.5]



KEY OBSERVATIONS

- WEA could consider funding projects to fortify low-lying Dx substations in NW counties given the increase in flood exposure over time.

Teton County — State landmark is exposed to peak flood exposure, **posing a threat to low-lying Dx substations and unfortified Dx poles.**

Source: ClimRR, US Census Bureau, City and Town Population Totals

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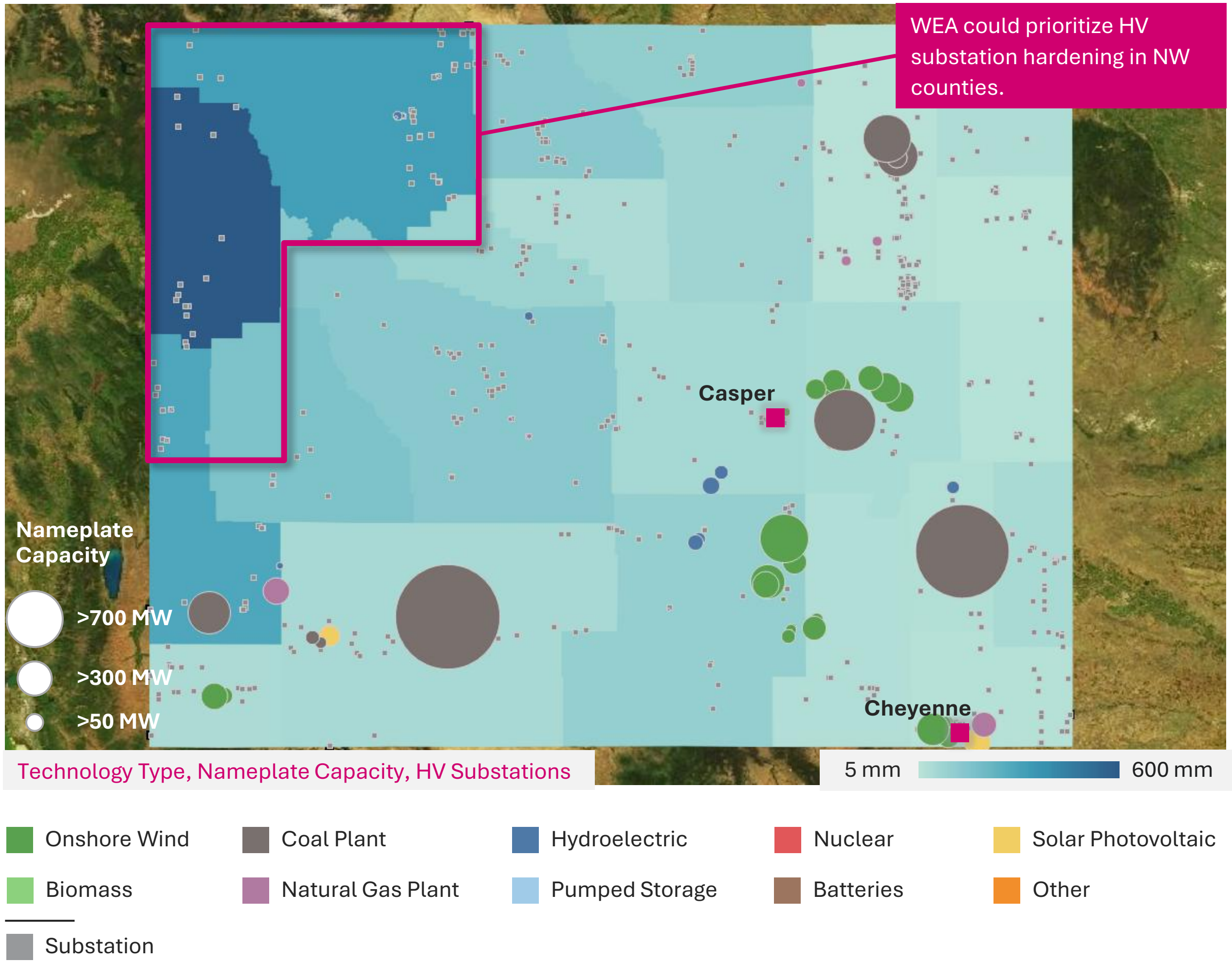
While generators generally face low levels of flood exposure, WEA could prioritize low-lying substation upgrades in a handful of highly exposed NW counties.

Wyoming Average Annual Surface Runoff (mm/year)
Population-Weighted by County [SSP5-8.5]



Key Highlights	Analysis
Substation	• High voltage substations will be exposed to pluvial flooding. Fluvial flooding is a risk if located in flood plain or riverbank without necessary protections. • A pocket of **HV substations in Park, Teton, and Lincoln Counties are heavily exposed to flood risk**, marking a priority for future hardening projects.
Restoration	• Flooding causes **ingress/egress complications** by washing out access roads, contributing to restoration issues. • Flooding can **affect on-site buildings or facilities**, making it more difficult to maintain adequate staffing for oversight and restoration.
Generators	• Generators have minimal flood risk, indicating that **WEA could prioritize Tx & Dx projects to address the hazard.** • A coal and natural gas plant are exposed to flooding in Lincoln County, which could inundate crucial auxiliary equipment and contribute to plant failure.

Source: ClimRR, US Census Bureau, City and Town Population Totals

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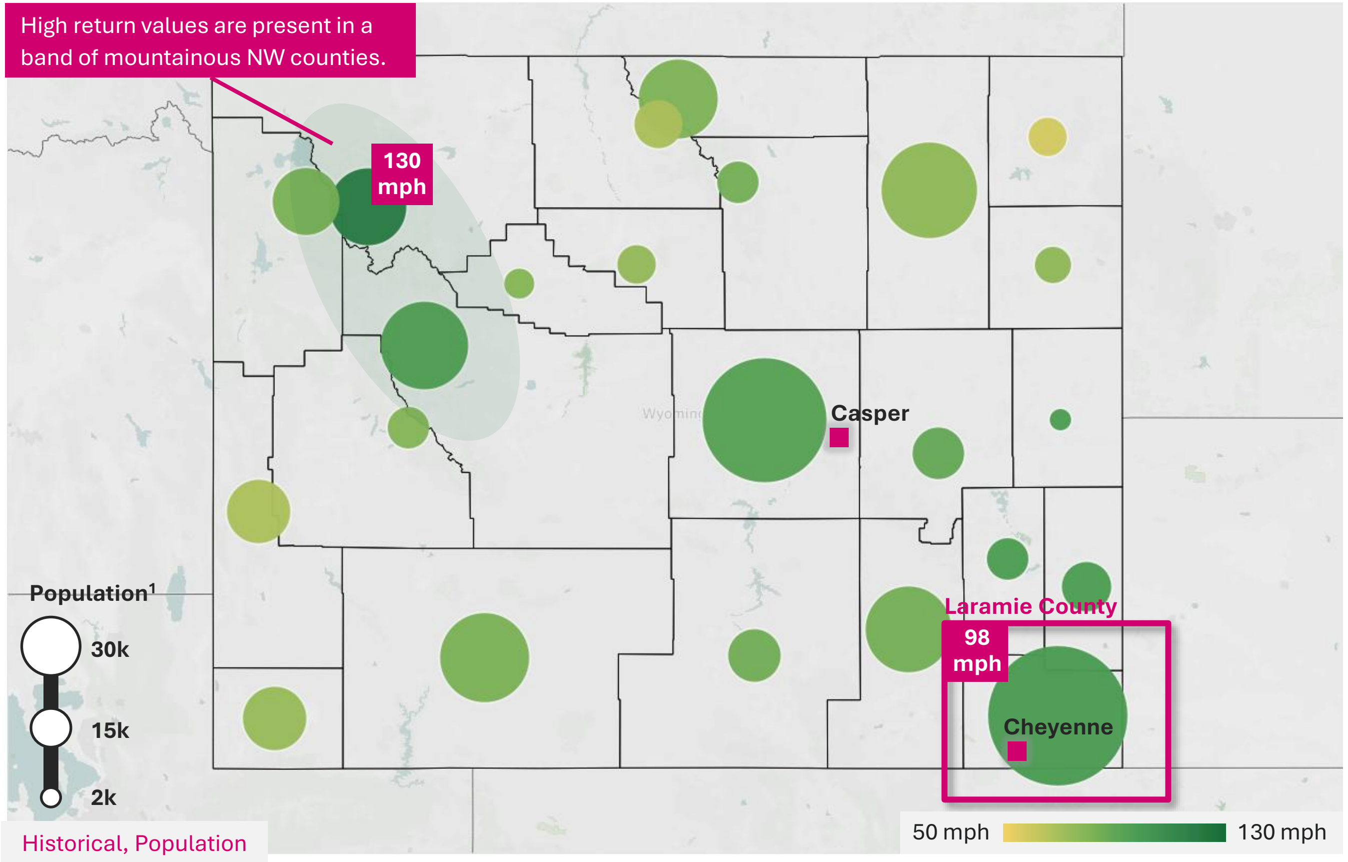
Wind

Asset Analysis

WEA could consider pole upgrades and vegetation management programs to address wind exposure, especially in SE and NW counties that are highly exposed.

Wyoming 100-year Wind Speed (mph)
Historical



Key Highlights	Analysis
Distribution	• Given weak climate signals, wind speeds are derived using historical data and do not vary at high spatial resolution. • Rather than targeted investments, wind exposure could be addressed through **upgraded design standards** across a utility service territory.
Laramie County	• Laramie County has a population of approximately 100k and 100-year return value of 98 mph, **indicating a high exposure area for Dx assets**. • Coincident extreme cold events put Dx lines at risk for galloping and sag.
SE Counties	• Gust speeds are highest in the SE counties of the state. • Undergrounding projects address wind, but **WEA could consider pole upgrades and vegetation management** as alternative methods to address wind exposure at the distribution level.

Source: DRI, EIA860, HIFLD

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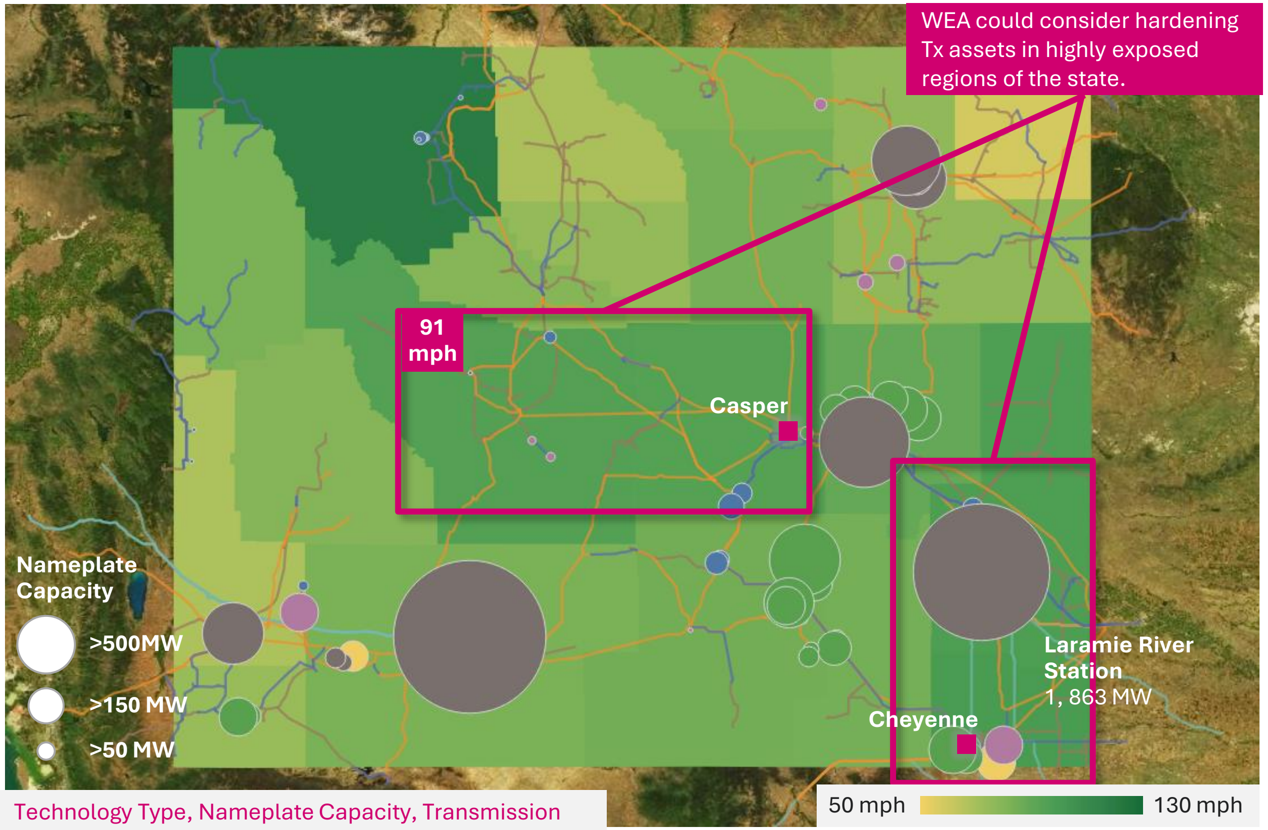
WEA could consider Tx structure reinforcement in central and SE counties, as well as hardening for coal cooling systems and updated wind turbine design standards in SE counties.

Wyoming 100-year Wind Speed (mph)

Historical



Onshore Wind | Coal Plant | Hydroelectric | Nuclear | Solar Photovoltaic

Biomass | Natural Gas Plant | Pumped Storage | Batteries | Other

500kV | 345kV | 220-287kV | 100-161kV

Source: DRI, EIA860, HIFLD

Key Highlights	Analysis
Transmission	• MV/HV transmission lines in the SE portion of the state are exposed to high wind speeds, including import/export lines to NE/CO that could play a critical role during extreme weather events. • MV lines in Fremont and Natrona County are also significantly exposed to wind. • WEA could **consider reinforcing Tx structures in these regions to address the potential for failure.**
Coal	• Laramie River Station is exposed to return values of 97 mph. • High wind speeds can reduce the performance of cooling towers, resulting in production **derates that could significantly impact the WY grid given the generator's size.**
Wind	• Wind farms cutout speeds can vary between 45-70mph, indicating that in high wind speed events, the turbines stop producing. • A cluster of wind farms in Laramie County are exposed to 100-year return period values far greater than the cutout threshold, impacting **critical supply near population centers**.

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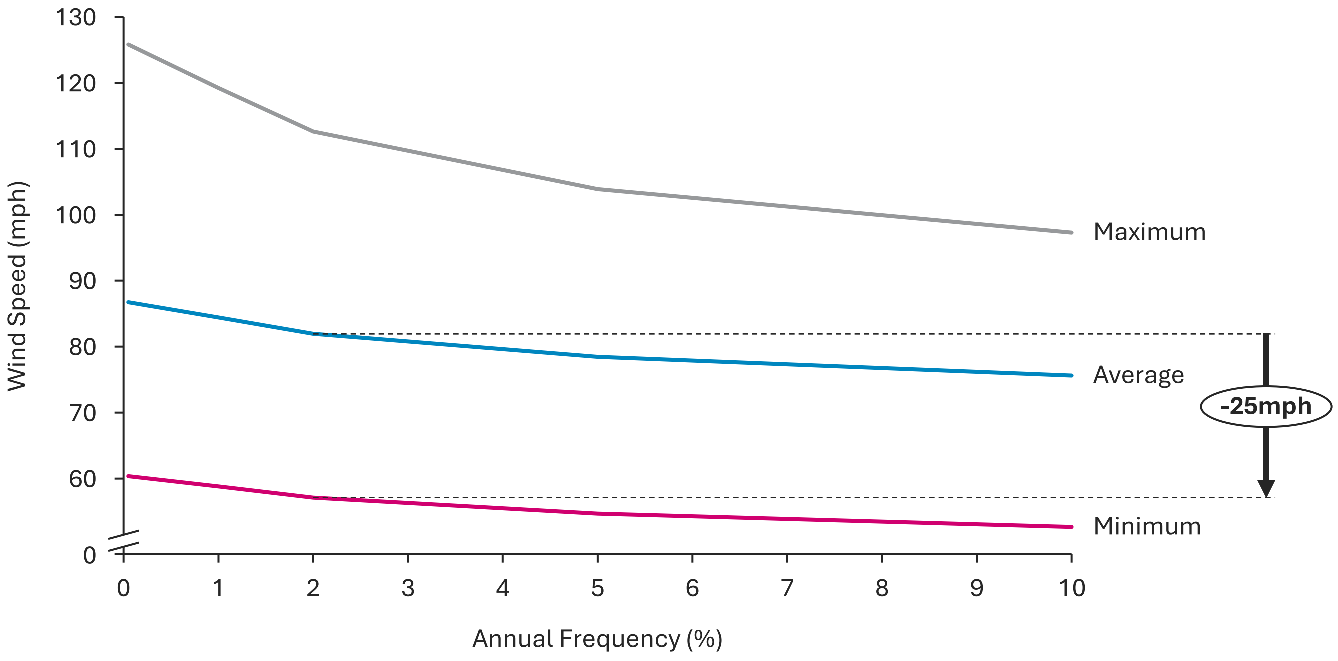
Historically, there is a 1% chance that the average wind speed seen across Wyoming counties is ~86 mph annually, indicating higher levels of wind exposure than most states in WECC.

Wyoming Wind Frequency vs Severity (2000 – 2022)
Historical, Average by County



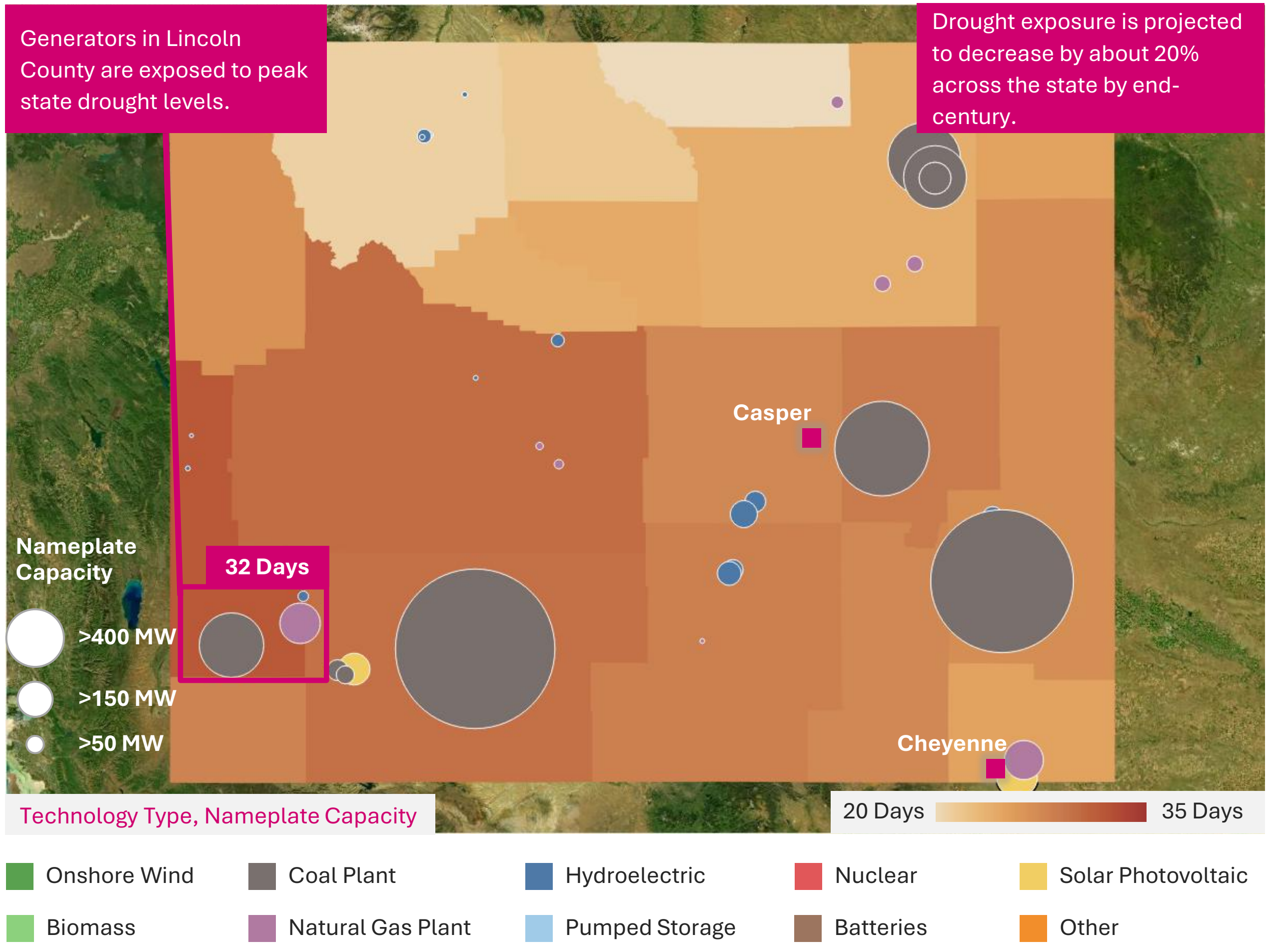
Key Highlights	Analysis
High System Averages	• Historically, there is a 1% chance that the average wind speed seen across Wyoming counties is ~86 mph annually, one of the highest values across WECC. • Further out on the curve, the 10% annual likelihood drops to 75 mph, indicating high system wind speeds are common across counties.
Volatility Across Counties	• There is a wide band between the maximum and minimum counties around the mean. • This indicates that wind adaptations should be focused on a county basis rather than over large service territories.

Drought

Asset Analysis

WEA could continue to monitor drought trends to assess the impact on hydroelectric production and consider thermoelectric cooling and solar panel cleaning projects.

Wyoming Consecutive Days No Precipitation
Generators, Mid-Century [RCP5-8.5]



Key Highlights	Analysis
Hydroelectric	• A string of **hydroelectric plants along the N. Platte River** are exposed to above average state-wide drought levels. • Asset owners and grid operators could consider monitoring **drought trends throughout the river basin,** which can vary throughout the state.
Thermoelectric	• Coal and natural gas generators are exposed to peak statewide drought exposure in Lincoln County. • Lack of water availability can **reduce plant cooling ability and disrupt flue gas desulfurization systems (coal)**, resulting in power production curtailments and increased emissions.
Solar	• Drought conditions can contribute to dust buildup on panels, decreasing solar capacity factors • In areas that also have high wildfire exposure, such as Sweetwater County, **panel cleaning projects address two hazards simultaneously.**

Source: ClimRR, US Census Bureau, City and Town Population Totals

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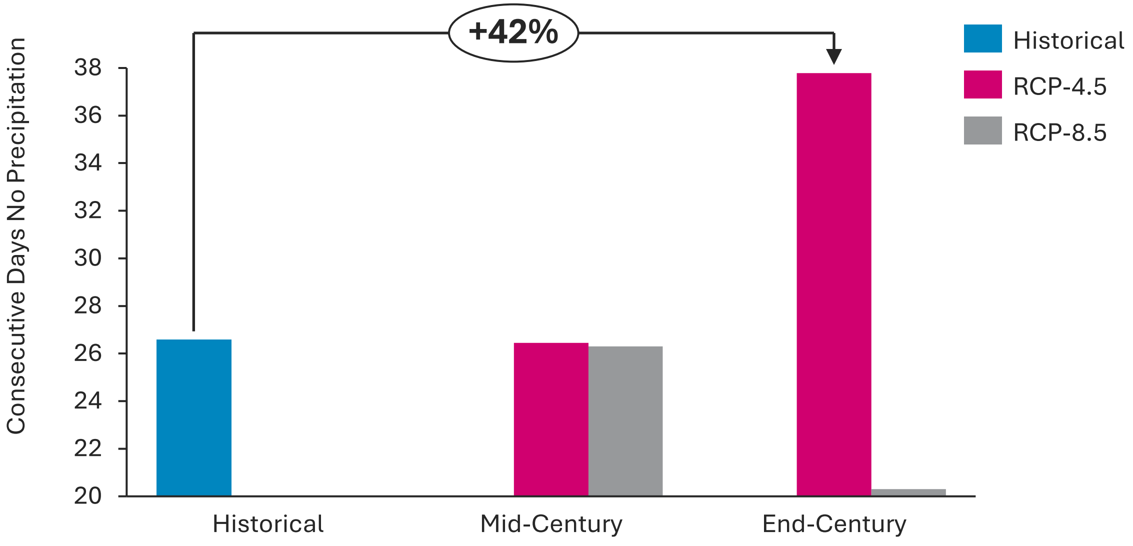
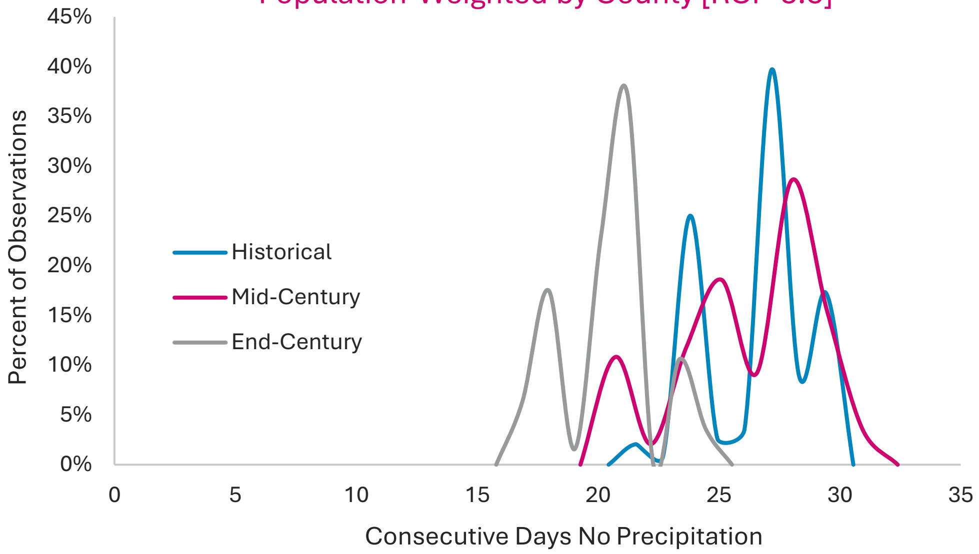
Drought exposure remains relatively constant to mid-century, but end-century projection diverge widely by warming scenario, indicating that they should be monitored closely.

Wyoming Average Annual Consecutive Days with No Precipitation
Population-Weighted by County [RCP 4.5, RCP-8.5]



Wyoming Average Consecutive Days with No Precipitation Statistical Distribution
Population-Weighted by County [RCP-8.5]



KEY OBSERVATIONS

- **Drought exposure increases by ~42% by end-century** (under RCP 4.5), contributing to potential asset cooling failures and reduced hydroelectric generation.
- Significant gap between drought exposure under the RCP-4.5 and RCP-8.5 warming scenarios indicates that **drought does not scale linearly with temperature** and could be monitored closely by asset owners and grid operators to determine which trajectory it is following.

KEY OBSERVATIONS

- Leftward shift of end-century graph generally indicates **decreasing drought severity across the state.**
- The shift from a quad-modal to tri-modal shape by mid-century indicates that drought exposure converges from 4 to 3 distinct climate zones.
- P3 in the mid-century graph indicates that the **largest climate zone will experience about 28 consecutive days without precipitation,** more than the 26 faced by the largest zone historically.

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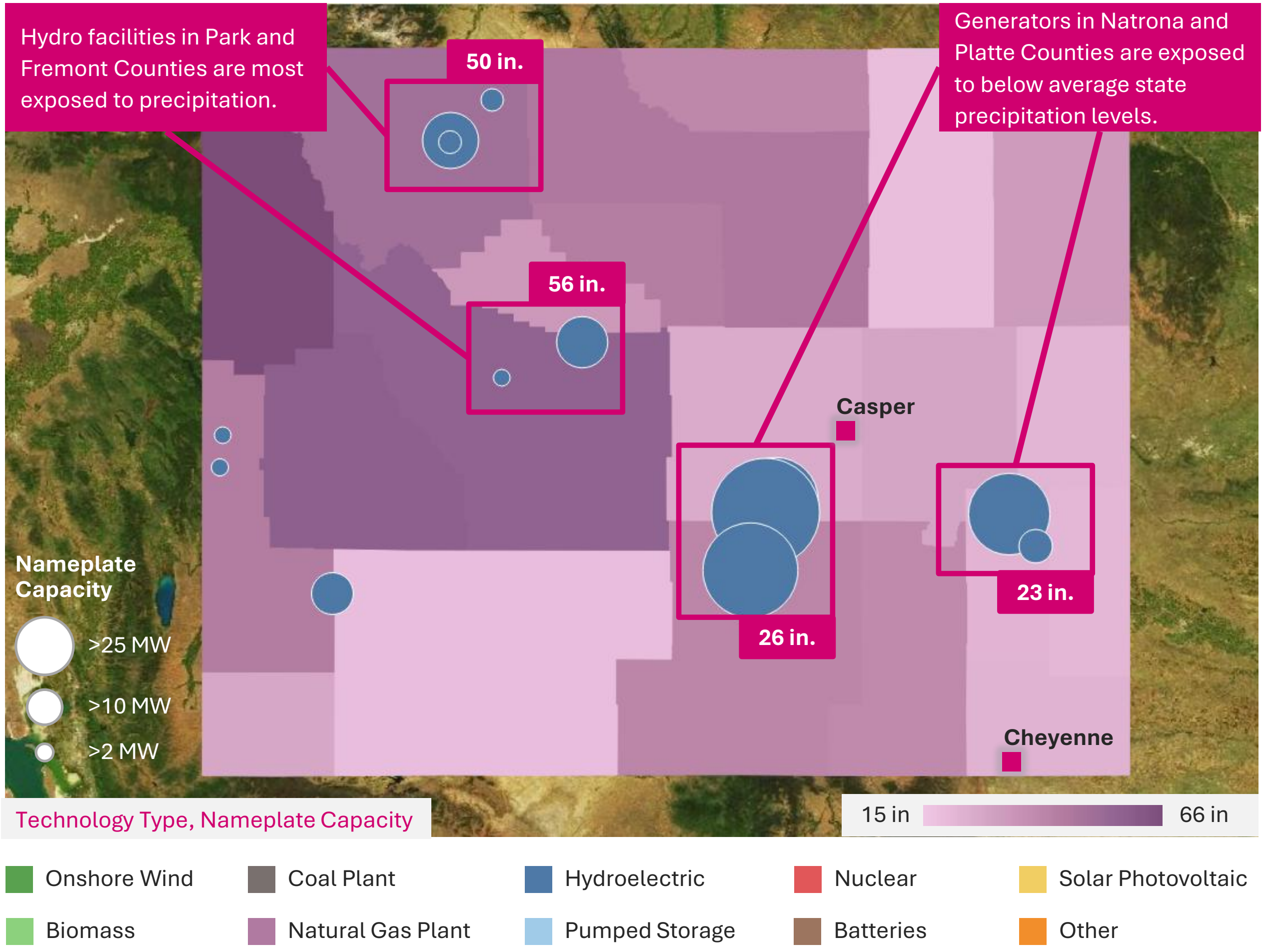
Precipitation

Asset Analysis

Precipitation levels are projected to increase, but WEA could also consider the impacts of precipitation timing, upstream conditions, and changes to snow patterns on hydro production

Wyoming Annual Max Precipitation (in)

Generators, Mid-Century [RCP5-8.5]



Key Highlights	Analysis
Timing	• Timing of precipitation has an important impact of hydro output. • Extreme rainfall events may overflow reservoirs and put more pressure on dams, increasing risk of failure. • Increasing precipitation levels indicate that **extreme precipitation events may become more common, potentially justifying dam hardening projects.**
Upstream Coordination	• **Consider coordinating with CEO** to gather data on N. Platte River flows to more accurately forecast hydroelectric production from key facilities downstream.
Changes to Snow Patterns	• While precipitation levels remain relatively constant to mid-century, precipitation type and timing is likely to change due to warming and could be monitored. • Grid operators could **consider the impacts of less snowfall and earlier snow melt when conducting long-term planning.**

Source: ClimRR, US Census Bureau, City and Town Population Totals

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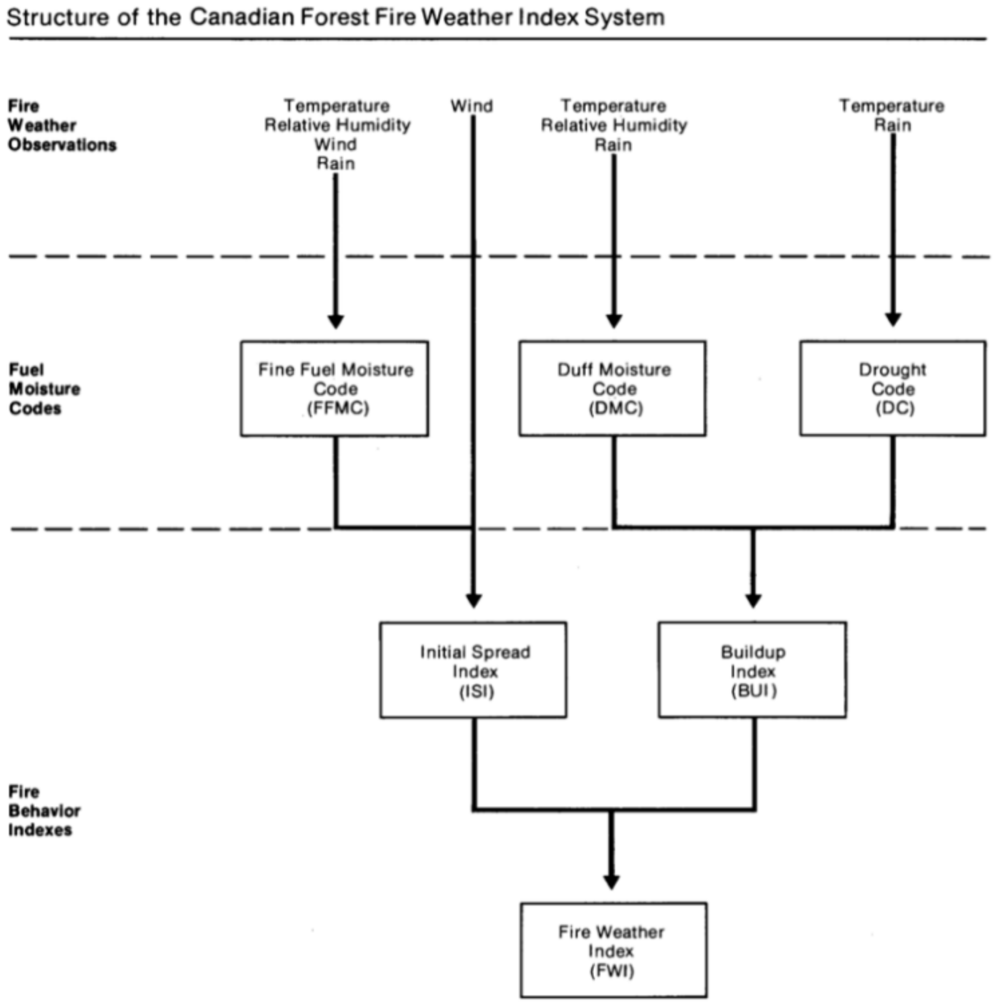
Appendix

Fire Weather Index synthesizes weather and moisture content data into a normalized value representing the danger of fire spread once ignition has occurred.



KEY TAKEAWAYS

- FWI is a useful metric for evaluating weather-based conditions that heighten the **danger of wildfire spread once ignition has occurred.**
- **Initial Spread Index**: Measures the **expected rate of fire spread,** based on wind speed and moisture content of fine fuels/forest litter (Fine Fuel Moisture Code).
- **Buildup Index:** Measures **the total amount of forest fuel available for consumption,** based on the **moisture content of intermediate organic layers**, such as decomposing plant matter (Duff Moisture Code), and the **moisture content of deep organic layers and soils,** which corresponds to drought measures (Drought Code).
- Daily FWI values were calculated using readings from Argonne's downscaled 12km climate data and averaged annually or seasonally across RCP-4.5 and RCP-8.5.
- Percentiles (below) were calculated based on **FWI values across all 12km grid cells in the contiguous U.S.**

FWI Class	Percentile range in historical period	FWI values in Class
Low	0–25th percentile	0–9 FWI
Medium	25–50th percentile	9–21 FWI
High	50–75th percentile	21–34 FWI
Very High	75–90th percentile	34–39 FWI
Extreme	90–98th percentile	39–53 FWI
Very Extreme	Above 98th percentile	Above 53 FWI

Source: ClimRR, US Census Bureau, City and Town Population Totals

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