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Grid Resilience Reports

Montana

Energy & Resources | Networks
11/19/2024

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Grid Resilience Reports

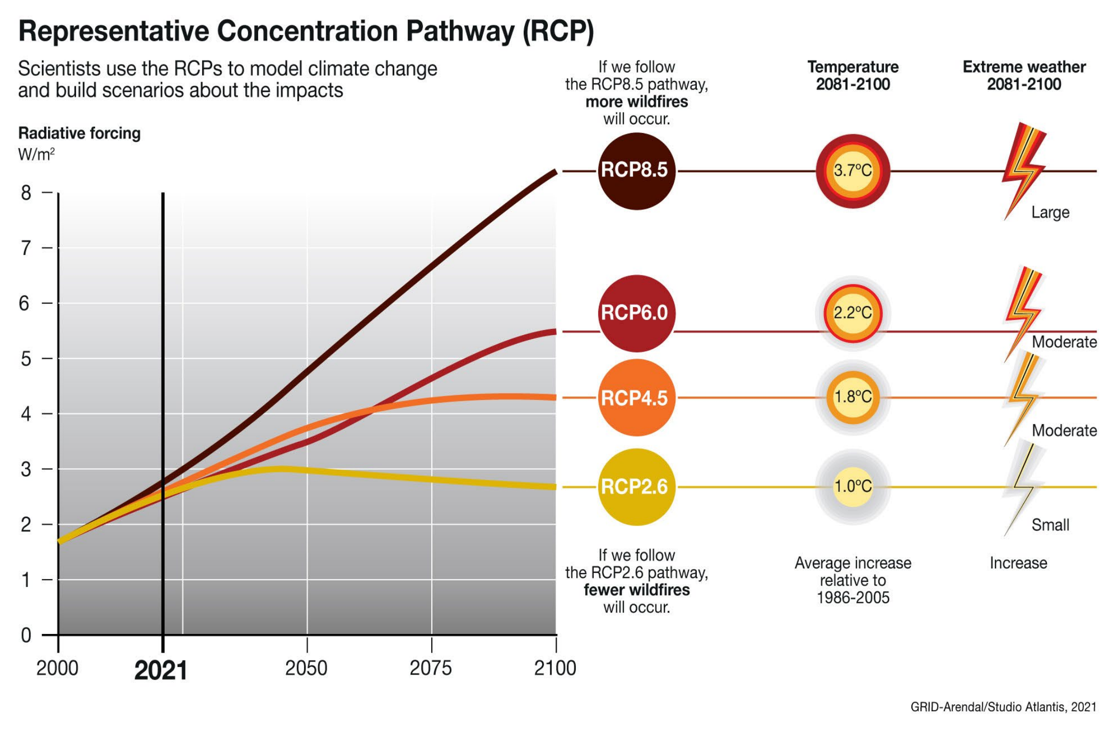
Climate Science Background, Data Sources, and Analysis Approach

RCPs and SSPs provide viable climate pathways for an uncertain future

ipcc INTERGOVERNMENTAL PANEL ON climate change

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]
- CO_2 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 out to end-century.[5]
- CO_2 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

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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 (average across, 1990-2000, 2045-2054, 2085-2094)	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

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 grid cells intersecting 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) • Data set includes pluvial flooding (from flash floods and surface runoff) which 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

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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

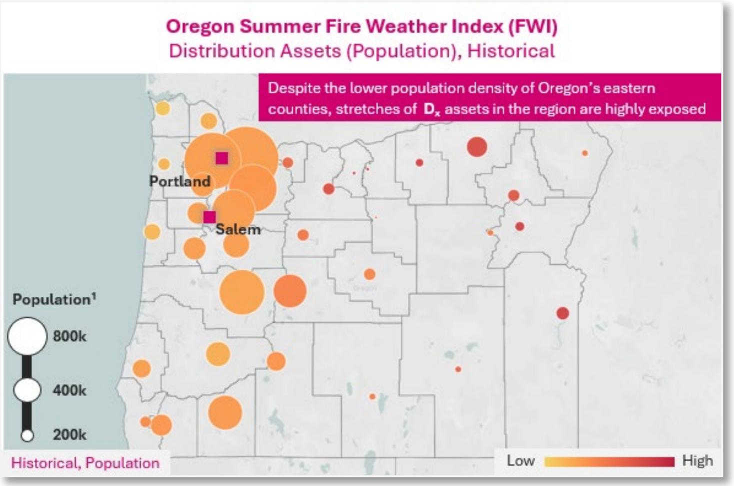
Output: Input metrics applied from a grid cell level to a county level

Flood

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

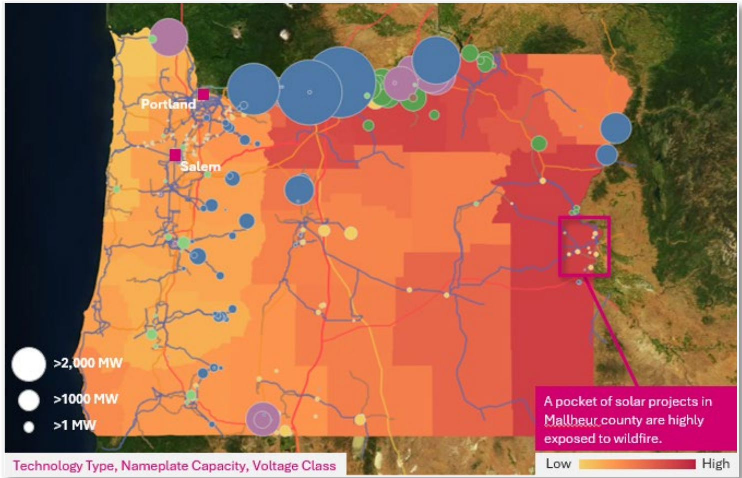
This report is standardized to include 3 different data visualizations that provide insights for Distribution, Transmission, and Generation across 7 extreme weather hazards

1 Distribution Maps



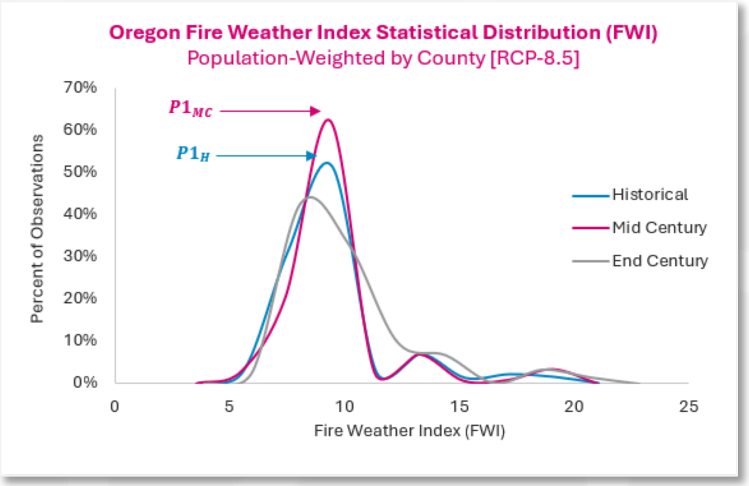
- **Purpose:** Uses population as proxy for volume of distribution assets given that the location of distribution assets is restricted.
- **Interpretation*:** Locate areas of high exposure by identifying counties with coincident large bubbles and dark colors. This indicates a combination of high volume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

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Asset Class Overviews

Summary

* AWPI = Alignment with proposed investment

L Low M Moderate H High

MDEQ could consider new programs to address generator extreme weather exposure, and prioritize heat/fire-related hardening in the SE and cold-related hardening in western counties

Key Takeaways

- Consider focusing on wildfire and heat related T&D hardening in Yellowstone County and on HV lines in southern counties.
- Consider substation upgrades/vegetation management to address extreme heat exposure and explore DER expansion to combat derating from heat.
- Consider new weatherization programs for thermo- and hydroelectric assets in the west and prioritize cold-related T&D hardening in western population centers.

Hazard	Exposure	Change to Mid-Century	Generation	Transmission & Distribution	AWPI*	Description
FIRE	M	↑	**Consider investment in solar O&M/backup power and emergency response planning** • Innovative solar cleaning projects and energy storage projects could help combat low solar capacity factors during fires. • Emergency response planning could decrease restoration times during fires.	**Focus hardening efforts in southern counties, especially Yellowstone County** • Yellowstone County (the most populous county in the state) is highly exposed to fire, posing a threat to a high volume of Dx and Tx assets. • Colstrip lines could be prioritized for hardening given their high exposure and criticality for delivering power to demand centers.	M	**Gen:** No proposed awards address generator wildfire exposure, marking a potential area for future investment. **T&D:** Prevalence of undergrounding and pole upgrades addresses fire exposure, but vegetation management projects could also be considered.
HEAT	M	↑	**Explore flexible DER options to offset derating of supply during heat events** • DER proliferation minimizes reliance on heavily exposed thermoelectric assets. • Weather-adjusted forecasts for the Colstrip plant could be crucial for accurate planning.	**Consider substation upgrades and further Tx hardening in eastern and southern counties** • Significant exposure to days >105 °F in eastern counties requires transformer upgrades to avoid direct failure and combat derating. • Widespread heat exposure could necessitates reconductoring, GETs, or other upgrades that bolster the thermal capacity of lines.	M	**Gen:** No distributed generation projects, which could combat derating. **T&D:** Undergrounding, line upgrades, and substation upgrades address exposure. MDEQ could consider vegetation management programs due to increasing line sag due to heat.
COLD	H	↓	**Focus weatherization technologies on thermoelectric & hydroelectric assets in W** • Many generators face continued exposure to icing and other cold-related failures through mid-century.	**Prioritize investments western population centers** • Peak cold exposure coincides with population centers in the western counties, posing a threat of Dx and Tx icing and asset failure.	M	**Gen:** No proposed awards address generator cold exposure. **T&D:** Awarded projects for pole replacement and undergrounding address cold exposure.

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* AWPI = Alignment with proposed investment

L Low M Moderate H High

MDEQ could prioritize substation upgrades in the face of flood exposure, and enhance data collection and analysis to better understand future drought and precipitation impacts

Key Takeaways

- MDEQ could prioritize substation fortification and pole upgrades NW counties that are heavily exposed to flooding, especially Flathead County.
- Significant increase in drought exposure in the NW by mid-century suggests the importance of using climate-adjusted inputs for hydro generation forecasting.
- MDEQ could seek out more advanced precipitation data to better assess impacts on hydroelectric output and consider dam fortification projects.

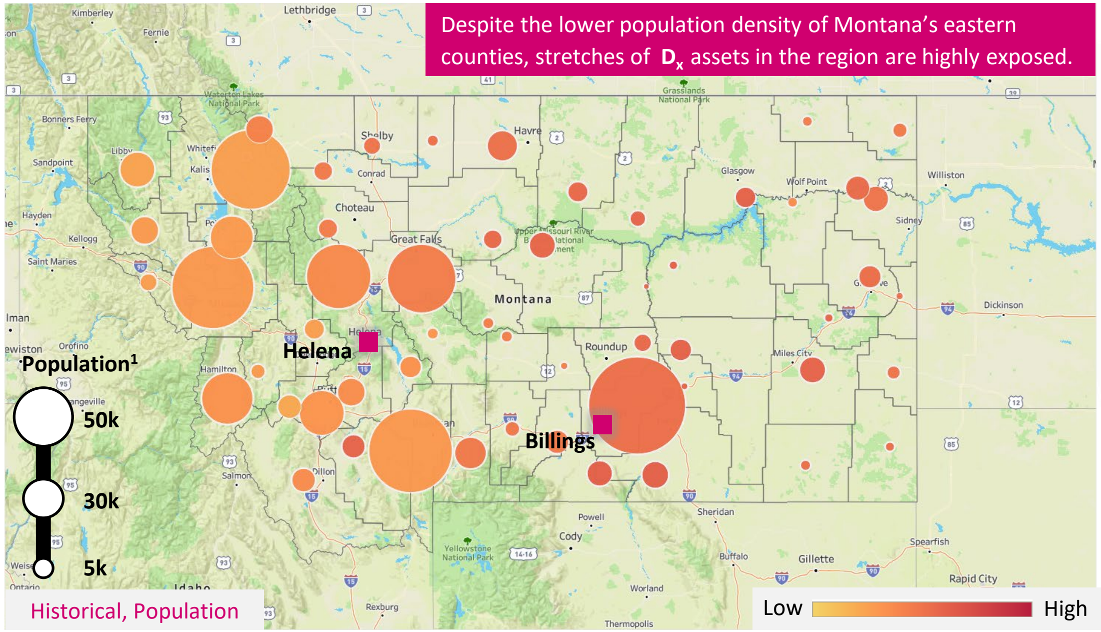
Hazard	Exposure	Change to Mid-Century	Generation	Transmission & Distribution	AWPI*	Description
FLOOD	M	↑	**MDEQ could prioritize addressing flood exposure for renewable generators** • Hydro generators in the NW are highly exposed, which can cause dam overtopping. • Wind/solar projects in southern counties are moderately exposed, posing a threat of failure.	**MDEQ could prioritize substation fortification** • High density of HV substations in NW are heavily exposed to flooding, which can cause direct failure with a high cost of replacement. • MDEQ could also consider continuing upgrades to aging or weak distribution poles.	M	**Gen:** No projects addressing generator exposure. **T&D:** Substation and pole upgrades align with exposure. MDEQ could evaluate whether it is prioritizing the NW for these investments.
WIND	M	→	**MDEQ could prioritize wind farm adaptations** • Consider encouraging the procurement of turbines with higher cutout speeds in NW. • Evaluate design standards of solar facility near Billings, to determine ability to withstand about 90mph wind speeds.	**MDEQ could reinforce Tx structures and encourage upgraded design standards** • Consider reinforcing Tx structures to address high levels of wind exposure. • Encourage utilities to adopt enhanced design standards for wind exposure.	M	**Gen:** No projects addressing generator exposure. **T&D:** Undergrounding & pole upgrades address wind, but MDEQ could consider veg management and upgrading Tx structures as well.
DROUGHT	M	↑	**Grid operators could consider using climate-adjusted inputs for hydro output forecasting** • Drought exposure for a pocket of large hydro facilities in NW increases up to 30% by 2050. • Hydro output decreases could factor into utility and state resource planning.	**Drought exposure does not have a material impact on transmission and distribution assets.**	L	**Gen:** Consider funding distributed generation to counter decreased hydro output. Explore solar cleaning projects and enhanced cooling for thermoelectric generators to address drought exposure.
RAIN	M	→	**MDEQ could consider gathering more hydro forecast input data and funding fortifications** • Consider the effect of warming on snow volume and melt timing. • Explore reinforcing hydro assets to prepare for extreme precipitation and capture excess.	**Precipitation exposure does not have a material impact on transmission and distribution assets.**	M	**Gen:** No proposed projects addressing generator exposure. Weak climate signal makes adaptation less urgent, but MDEQ could consider seeking out additional data to better forecast hydro output.

Wildfire

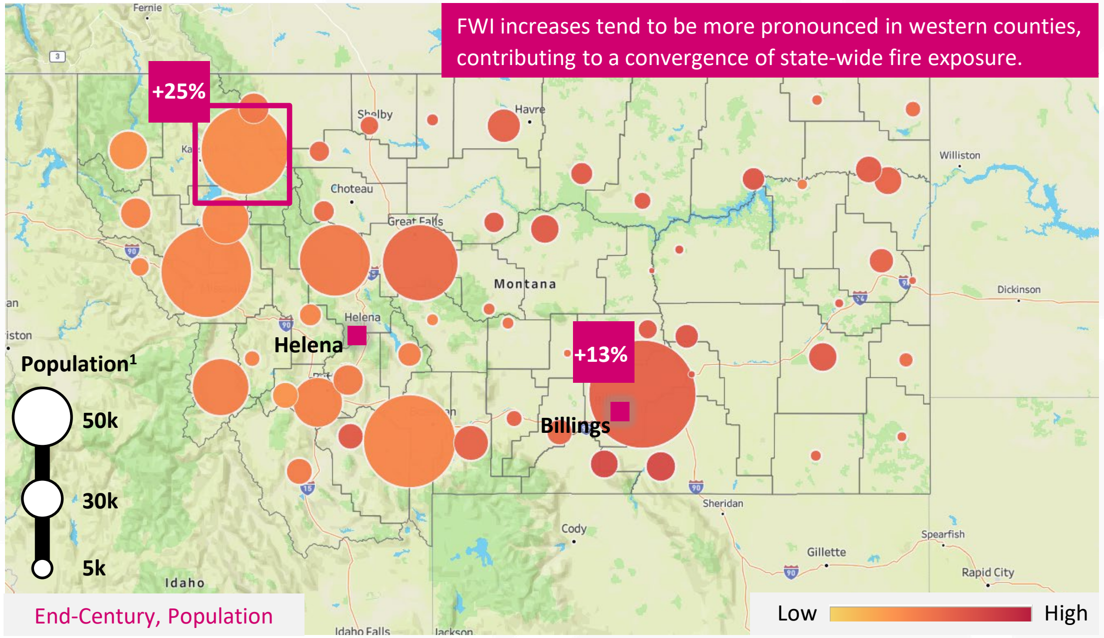
Asset Analysis

MDEQ could consider additional fire mitigation initiatives in western counties which face increasing fire risk over time and have high Dx asset densities

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



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



KEY OBSERVATIONS

- Historical wildfire exposure is concentrated in Montana's eastern **counties.**
- High percentage of undergrounding, pole upgrades, and covered conductor proposals indicate **general alignment with wildfire exposure**, but MDEQ could consider **vegetation management projects** as well.
- **Gallatin and Cascade Counties both border high exposure counties,** putting a high density of Dx assets at risk in the case of fire spread.

KEY OBSERVATIONS

- FWI increases by about 2-5 points across the state, demonstrating the importance of utilizing **forward-looking climate projections for state-wide fire mitigation planning.**

Yellowstone County

Large population center (high density of Dx assets) highly exposed to wildfire, marking a potential priority area for MDEQ investment.

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

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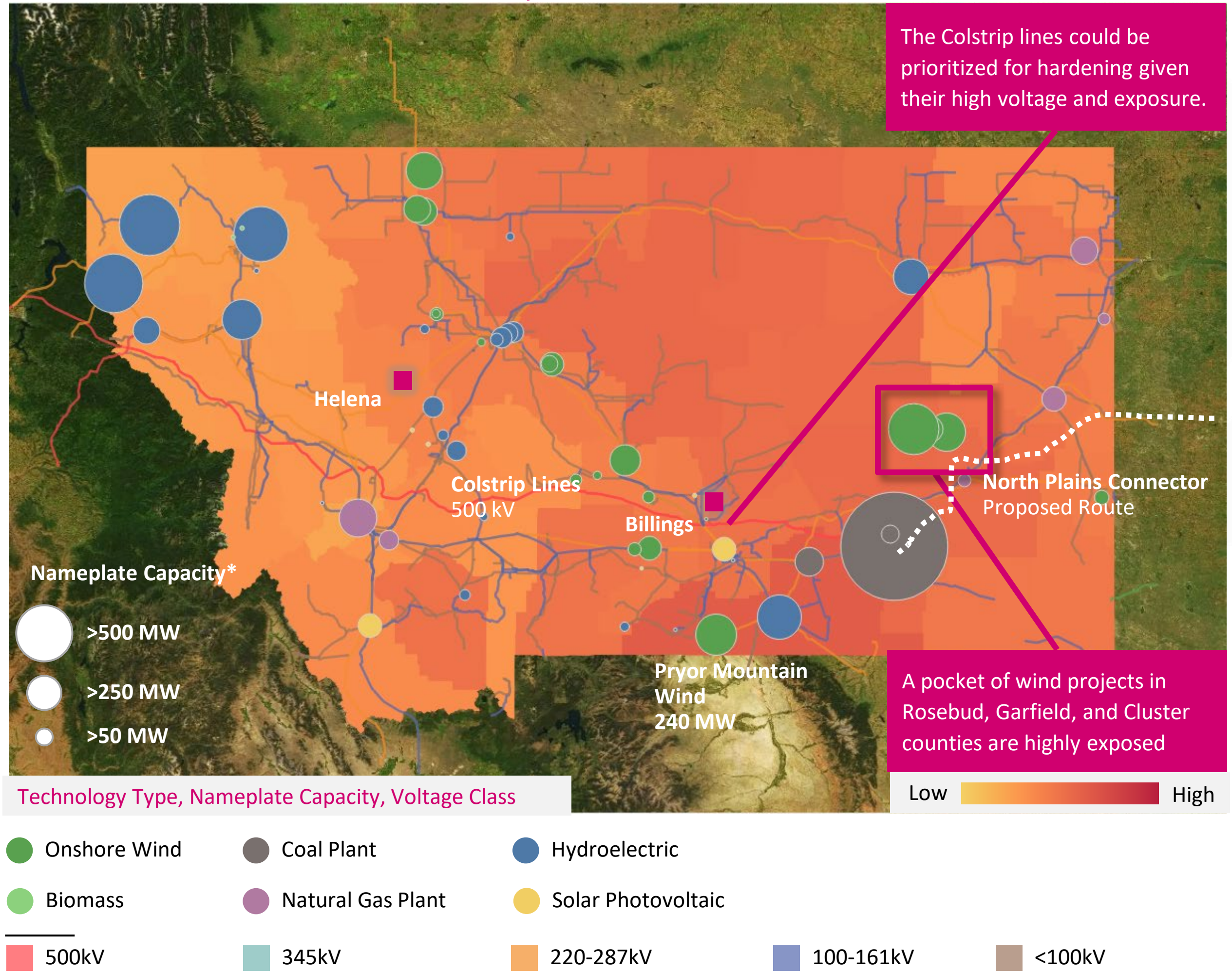
MDEQ could prioritize hardening for highly exposed transmission assets in southern counties and consider new investments to combat renewable capacity factor derates from soot and ash

Montana Summer Fire Weather Index (FWI)

Generators & Transmission, Mid-Century [RCP-8.5]



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

Key Highlights	Analysis
Renewables	• Soot and ash from burns **decrease capacity factors for both wind and solar assets.** • **Very few proposed projects address generator exposure,** indicating an overlooked resilience topic area for the state.
Restoration	• Wildfire causes **ingress/egress issues** through destruction of roads and transportation, slowing restoration times for all assets. • MDEQ could **consider funding projects addressing wildfire-related access issues** given its impact across all asset classes.
Transmission	• **Remote transmission assets are critical** for last mile rural customers and are highly exposed in southern counties. • The Colstrip lines wheeling coal generation to major demand centers in the state are heavily exposed in Rosebud County. • Proposed **North Plains Connector** route will run directly through the highest fire risk portion of the state. MDEQ could with surrounding utilities and Grid United to plan for wildfire risk.

*Generator nameplate capacities may exceed those shown in the legend

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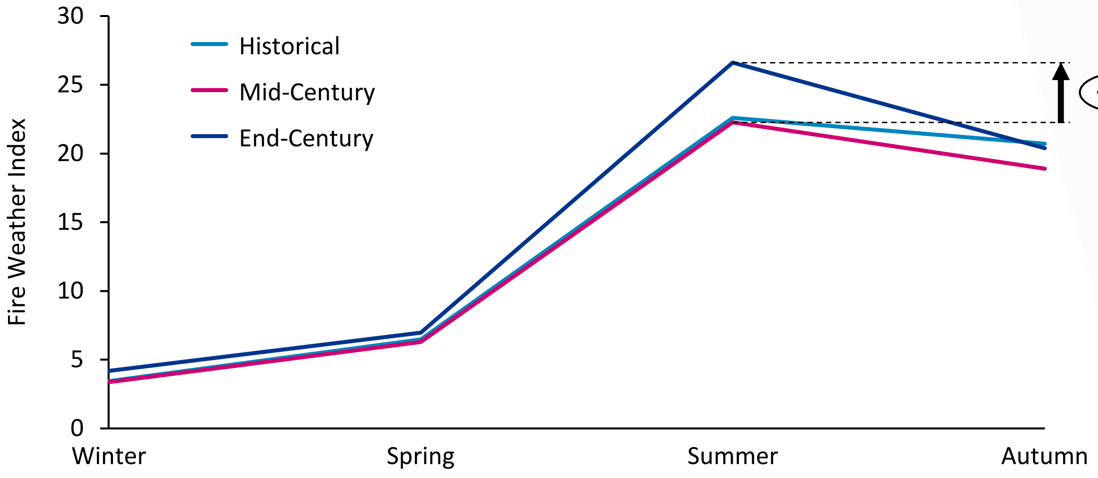
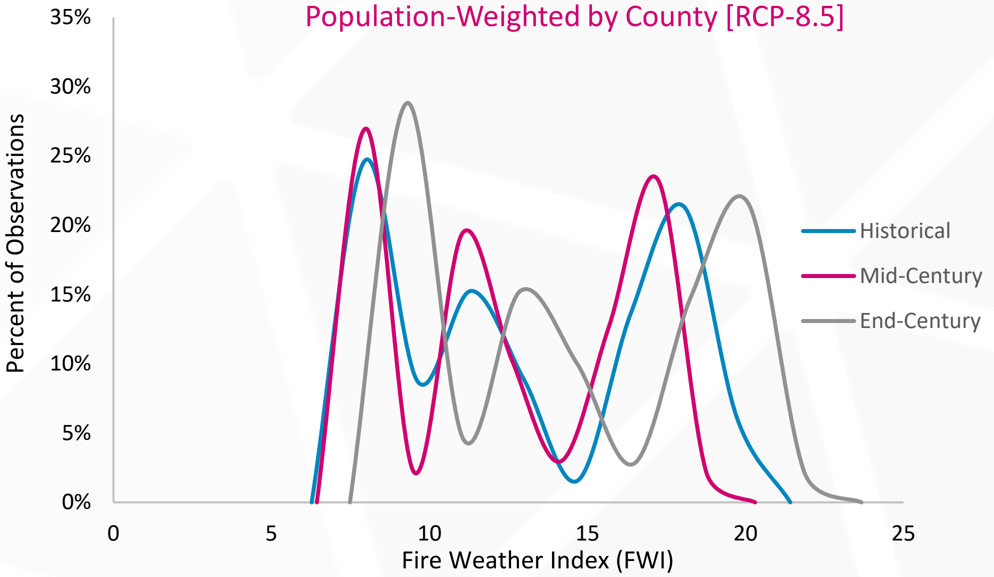
By mid-century, fire exposure decreases between summer and autumn, while by end-century it is expected to increase in severity and duration, shortening the maintenance window

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



Montana 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 20% from historical FWI.
- Elevated wildfire exposure around the summer suggests a **lengthening of the wildfire season** combined with an **increase in severity.**
- The change in length of wildfire seasons suggest that **the window for scheduled maintenance during the shoulder seasons is diminishing.**

KEY OBSERVATIONS

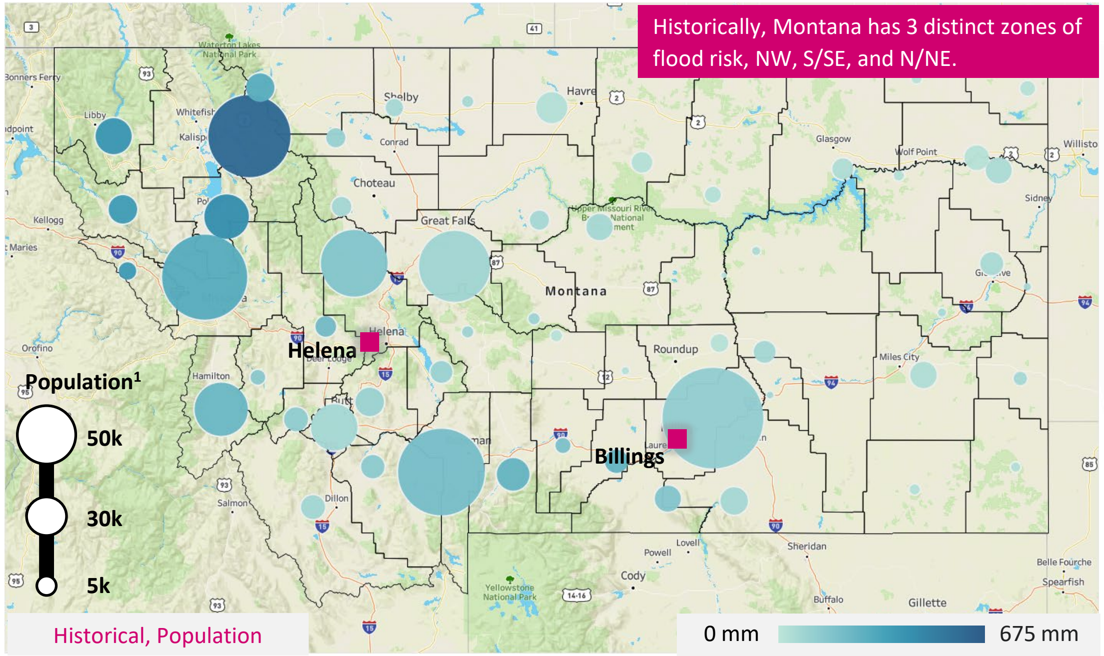
- Peaks shifting up and right be end-century indicates that **wildfire exposure will become more severe over a wider spatial extent in the future.**
- The tri-modal shape of the curve represents **three regions (West, Central, and East) that face distinct levels of fire risk** given differences in climate zones.
- Taller peaks of the mid-century graph indicate that **regional differences in FWI become more distinct over time**, demonstrating that MDEQ may want to prioritize the 20% of area experiencing FWI of about 16-17.

Flood

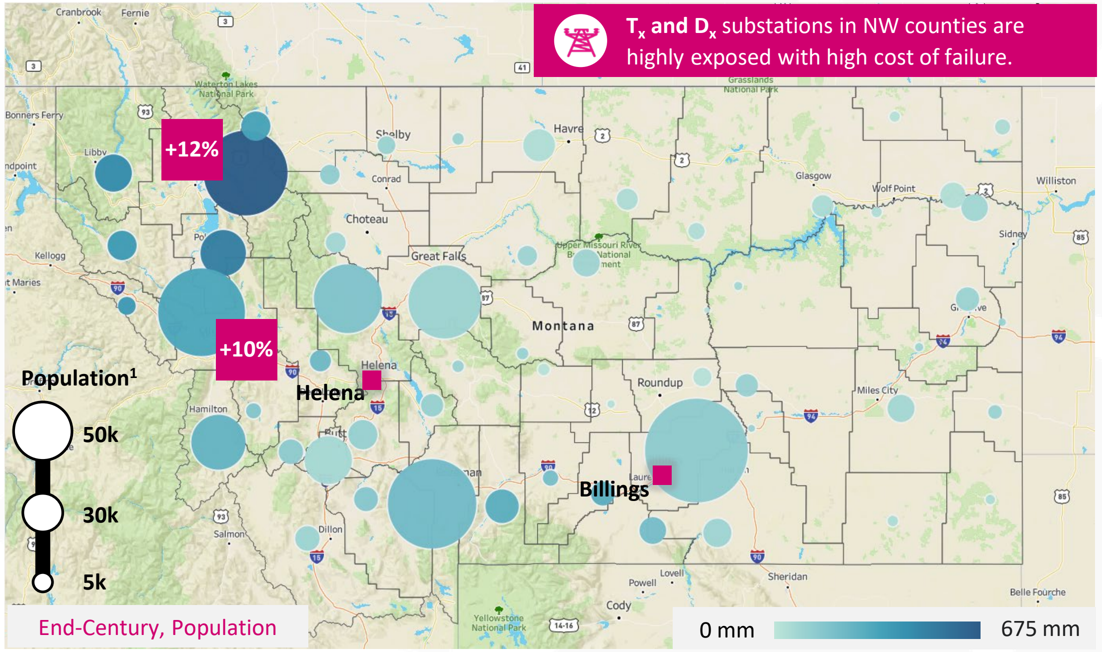
Asset Analysis

While MDEQ has already funded pole and substation upgrade projects, they may want to consider whether these investments align with identified exposure in NW counties

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



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



KEY OBSERVATIONS

- Most flood exposure lies in the **northwest counties** given the high volume of runoff they see from snowmelt of nearby mountain ranges.
- Runoff levels in MT are generally lower than most of WECC, indicating that **flood may not be a top priority hazard for investment.**
- MDEQ is addressing flood exposure through **pole/substation upgrades.**

KEY OBSERVATIONS

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

Flathead County: Highly populated county facing peak flood exposure poses a **substantial threat to a high density of substations and distribution poles.**

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

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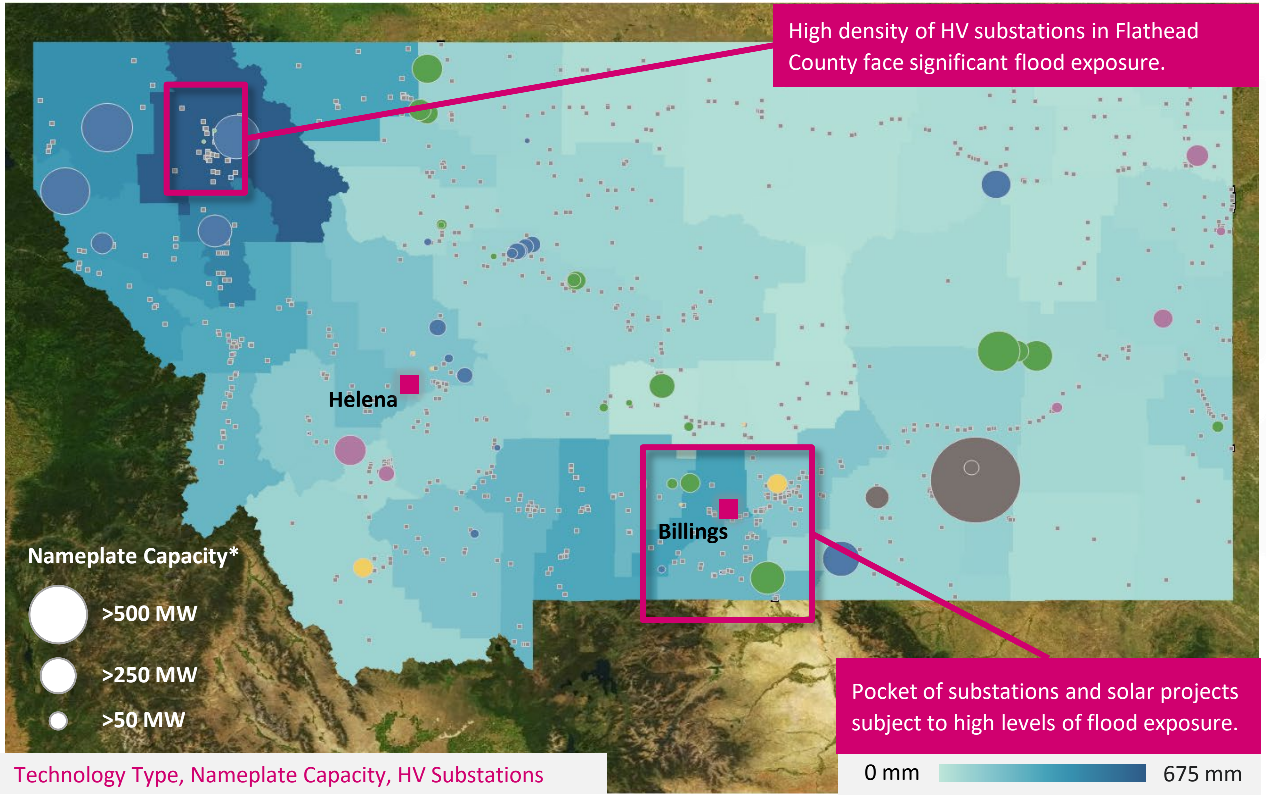
MDEQ could prioritize the fortification of high voltage substations in NW counties and consider projects addressing restoration issues posed by flooding

Montana Average Annual Surface Runoff (mm/year)

Generators, Mid-Century [SSP5-8.5]



Onshore Wind
Coal Plant
Hydroelectric
Biomass
Natural Gas Plant
Solar Photovoltaic
HV Substation

Key Highlights	Analysis
Substation	• High voltage substations will be exposed to pluvial flooding if located in flood plain or riverbank without necessary protections. • High density of **HV substations in NW counties are heavily exposed to flood risk**, marking a priority for future hardening projects. • Billings could see additional investment as well given its density of HV substations.
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	• A handful of hydro plants in NW counties are significantly exposed to flood, which can contribute to dam overtopping/failure and pose a threat to control houses. • Wind and solar projects in southern counties are exposed to flood, which can impact tower bases (wind) and inundate panels or other electronics (solar).

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

*Generator nameplate capacities may exceed those shown in the legend

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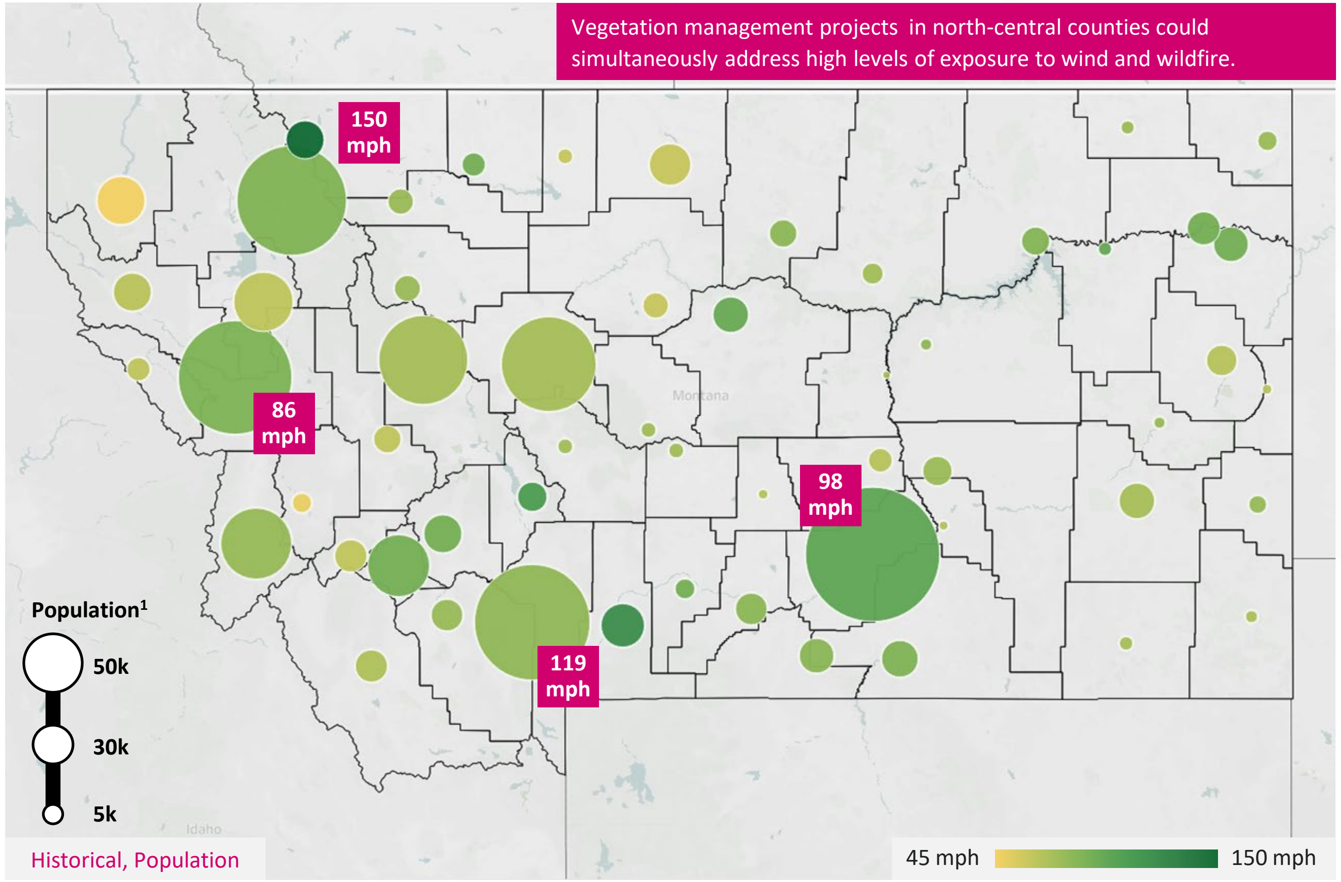
Wind

Asset Analysis

MDEQ could encourage utilities to adopt upgraded design standards relating to wind and consider vegetation management projects for south-central counties

Montana 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.
Yellowstone County	• Yellowstone County has a population of approximately 170k 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.
South-Central Counties	• South-central counties generally exhibit high wind gust speeds, posing a threat to Dx assets in this region. • MDEQ’s undergrounding and pole upgrade projects generally address wind exposure, but vegetation management projects could also be considered in high exposure regions.

Source: DRI, EIA860, HIFLD

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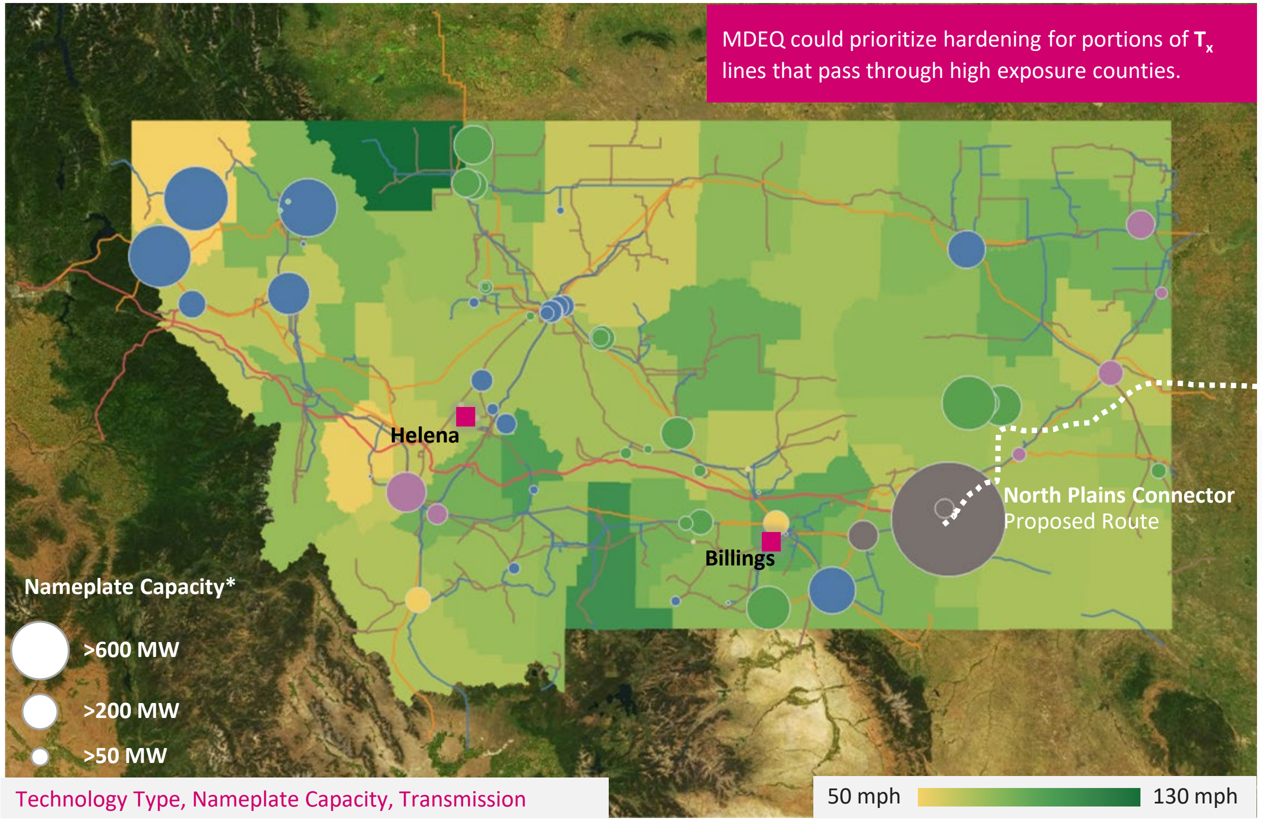
MDEQ could consider reinforcing Tx structures for MV/HV lines and encourage the procurement of wind turbines with higher cutout speeds for projects in NW counties

Montana 100-year Wind Speed (mph)
Historical



Onshore Wind · Coal Plant · Hydroelectric
Biomass · Natural Gas Plant · Solar Photovoltaic

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

Source: DRI, EIA860, HIFLD

Key Highlights	Analysis
Transmission	• Multiple MV-HV transmission lines intersect in Yellowstone and Park Counties, where they are exposed to high wind return values. • LV/MV lines in Glacier County are exposed to peak state wind levels. • MDEQ could consider **reinforcing Tx structures** to complement existing undergrounding and pole upgrade projects to address exposure. • Proposed North Plains Connector has low exposure.
Wind	• Wind farms cutout speeds can vary between 45-70 mph, indicating that in high wind speed events, turbines stop producing. • The cluster of wind farms located Toole County is exposed to 100-year return period values greater than the cutout threshold, however, these assets are known to have off-takers outside of the state.
Solar	• A sizeable solar farm in Yellowstone County is exposed to 100-year return values around 100 mph. • Depending on the supplier, solar panels are only rated to 90 mph, **indicating need for rack reinforcement and vegetation management.**

*Generator nameplate capacities may exceed those shown in the legend

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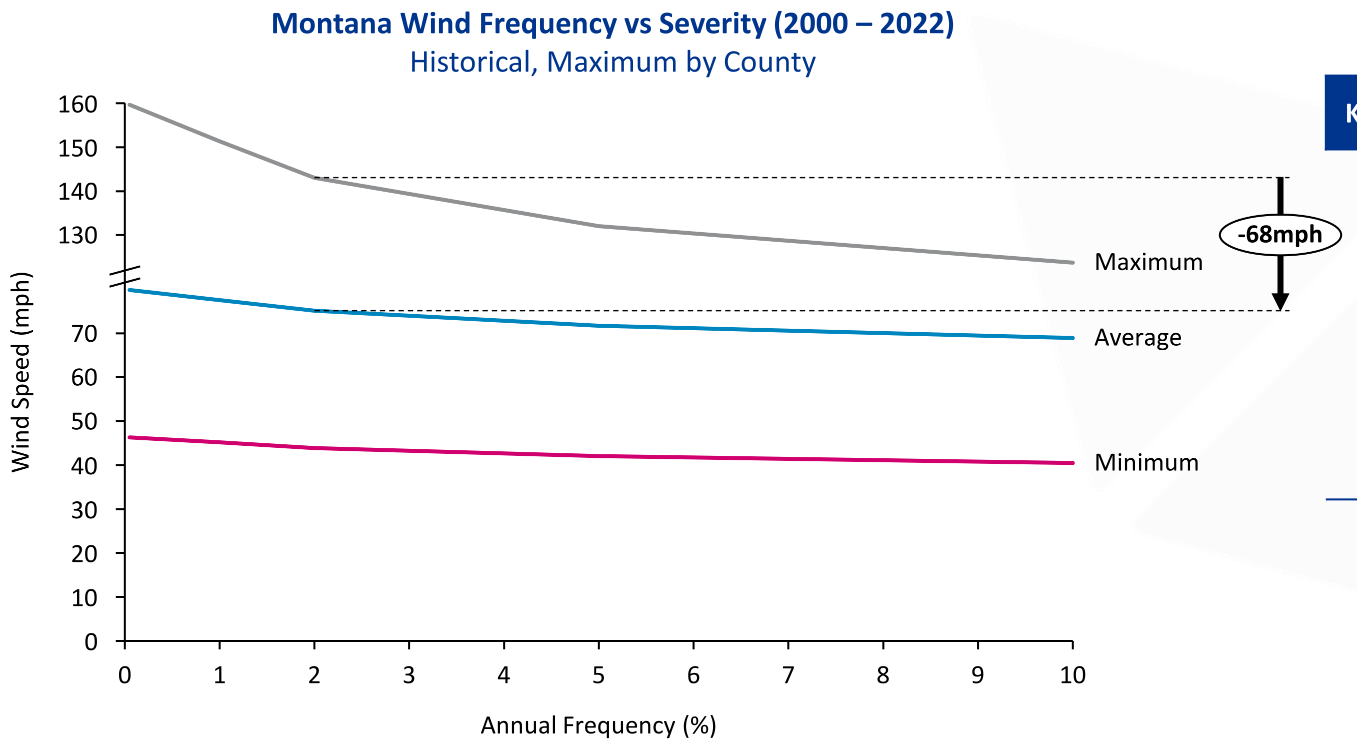
Historically, there is a 1% chance that the average maximum wind speed seen across Montana counties is ~80mph annually.



KEY DEFINTIONS

- **Maximum:** Return values for the county with the highest values across the state
- **Average:** Average return values for all counties in the states
- **Minimum:** Return values for the county with the lowest return values across the state

Key Highlights	Analysis
 **High System Averages**	• Historically, there is a 1% chance that the average maximum wind speed seen across Montana counties is ~77 mph annually. • Further out on the curve, the 10% annual likelihood drops to 69 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.

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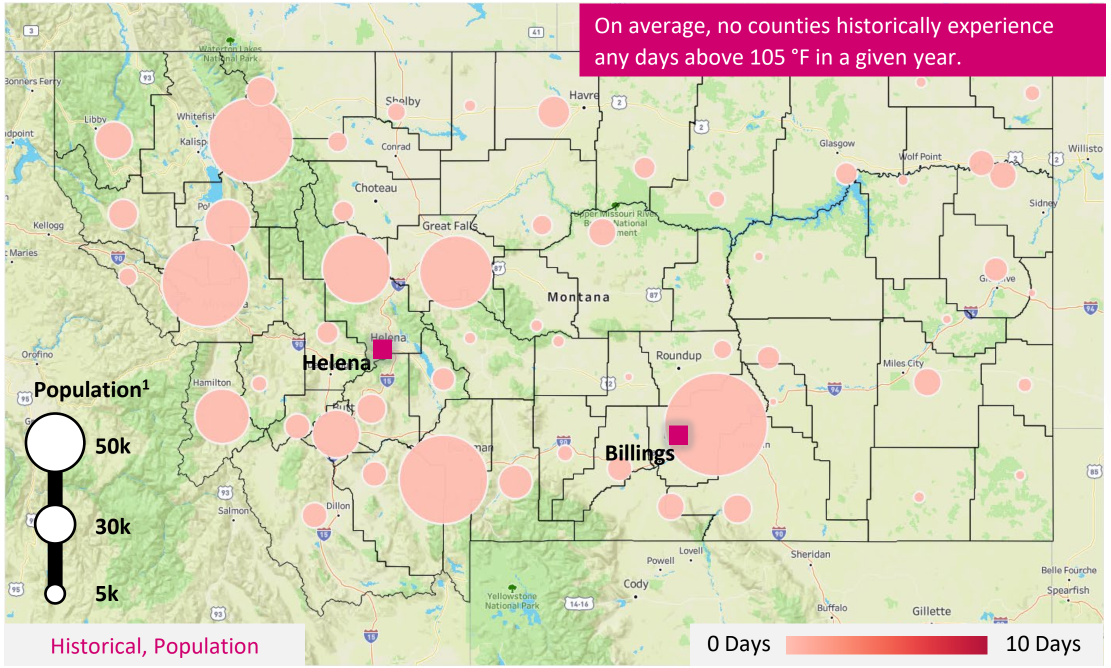
Extreme Heat

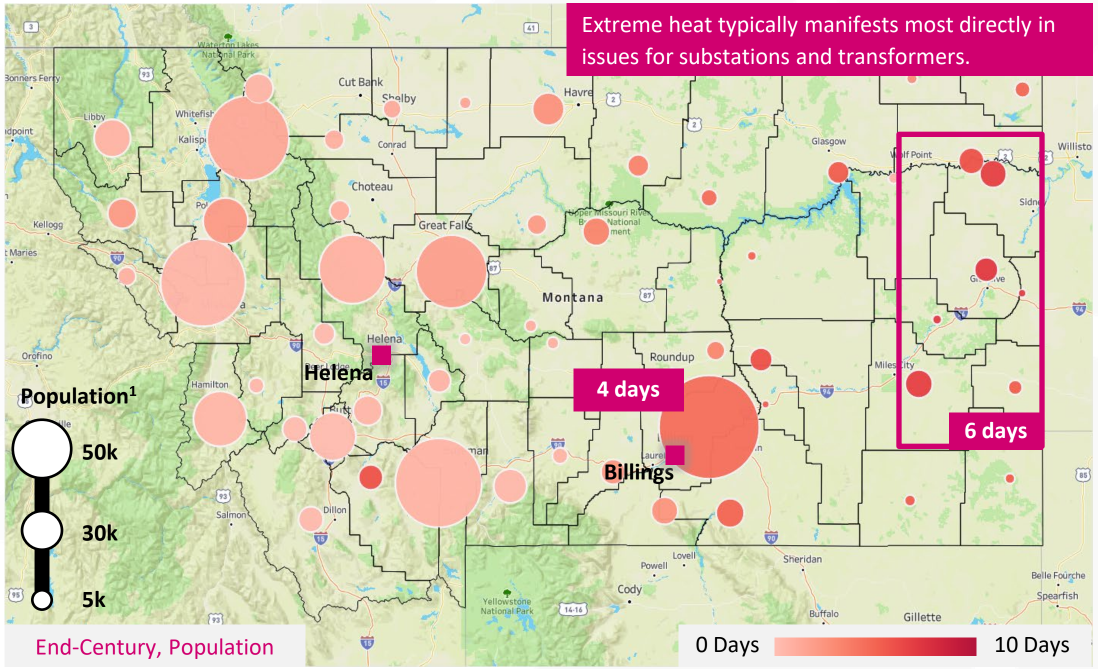
Asset Analysis

Increases in extreme heat exposure across the state suggest that MDEQ could prioritize substation and Dx line upgrades in eastern counties to address derating, degradation, and potential failure

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



Montana 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 an important threshold for distribution assets and substations, **which can fail when exposed to two consecutive days above 104°F.**[2]
- Round 1 projects generally address extreme heat through undergrounding, line upgrades, and substation upgrades.

KEY OBSERVATIONS

- Eastern counties are expected to face **about 5-7 days >105 °F annually by mid-century, causing high Dx asset utilization, derating, and potential failure.**

Yellowstone County — 4 days of >104 °F exposure could justify substation and Dx line upgrades to mitigate potential failure and avoid derating for a high density of Dx assets.

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

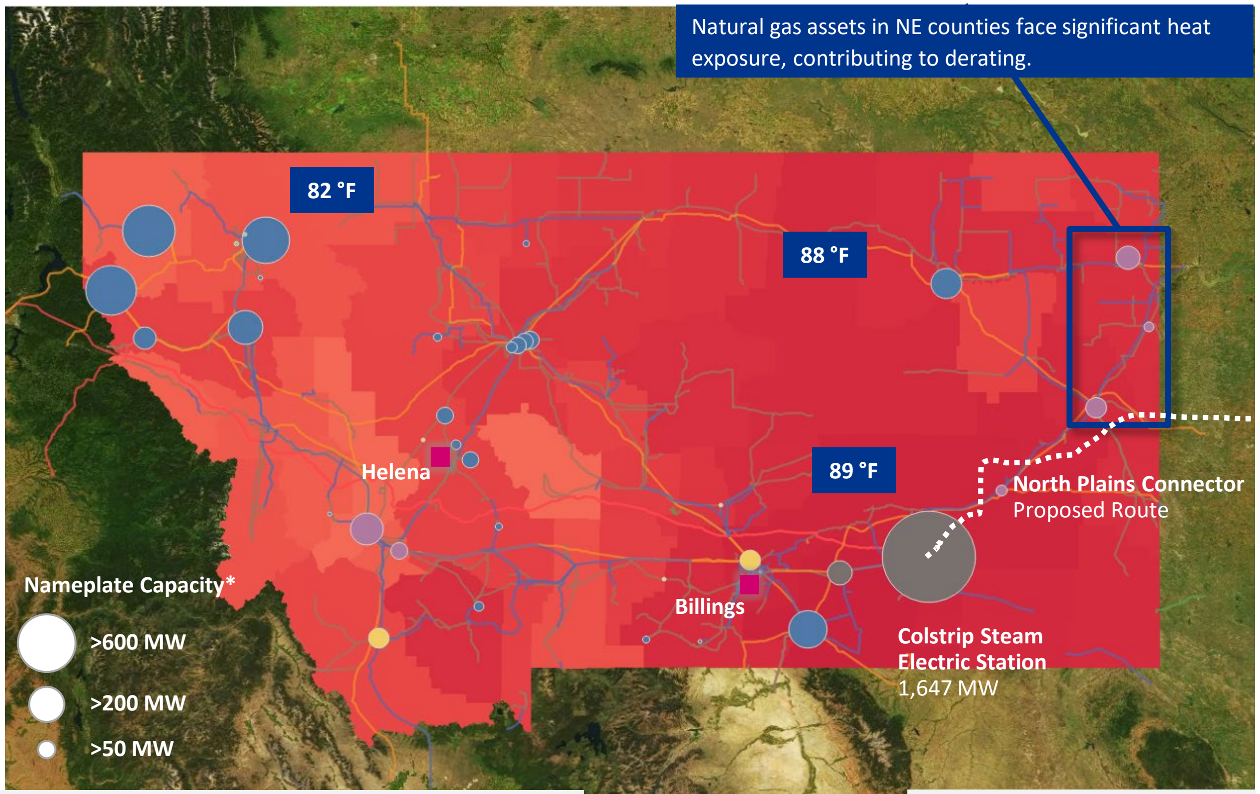
Source: ClimRR, US Census Bureau, City and Town Population Totals

Baringa

MDEQ could consider projects addressing thermoelectric derating and prioritize transmission hardening and vegetation management projects for lines running through southern counties

Montana Summer Average Maximum Temperature (°F)

Generators, Mid-Century [RCP-8.5]



Technology Type, Nameplate Capacity, Voltage Class

Onshore Wind | Coal Plant | Hydroelectric

Biomass | Natural Gas Plant | Solar Photovoltaic

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

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

Key Highlights	Analysis
Thermoelectric	• Thermoelectric generators that rely on water-based cooling methods will **experience production derates** as extreme heat raises average water temperatures.
Colstrip Steam Electric Station	• Given the generator's size, production derating from extreme heat could have significant impacts on the MT grid. • MDEQ could consider projects to **address derating or forecast weather-adjusted output.**
Transmission	• A significant portion of 220kV+ transmission lines are exposed to high levels of extreme heat in southern counties, which can cause capacity derates and line sag. • **North Plains Connector**, which serves as a critical interregional tie, will be exposed to average summer max temperatures of about 89°F, causing likely violations of thermal ratings and deratings. • Undergrounding and line upgrade proposals address these issues, but MDEQ could consider **more cost-effective adaptations to fortify longer portions of transmission lines.**

*Generator nameplate capacities may exceed those shown in the legend

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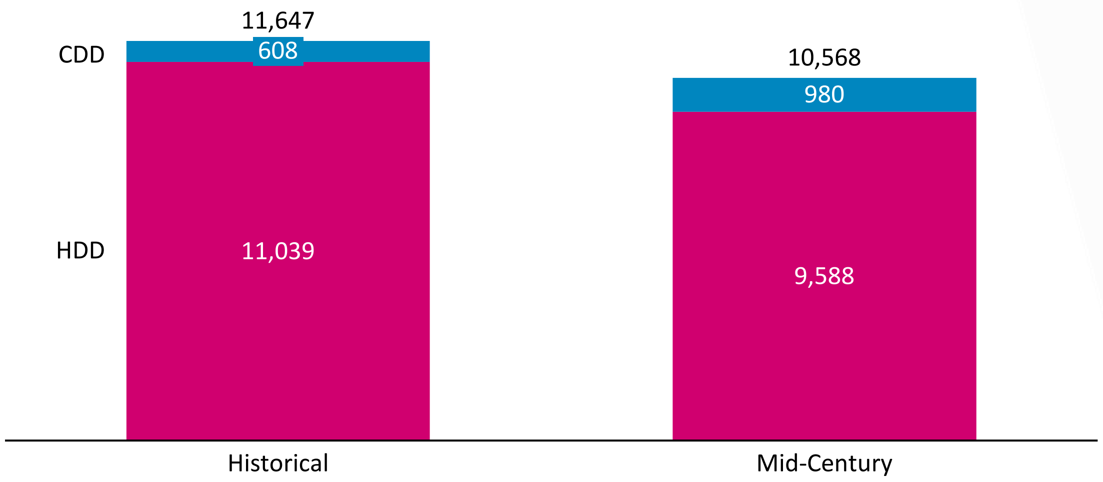
Extreme heat days will become more common in Montana, contributing to derating, capacity violations and substation failure, indicating the potential need for substation upgrades

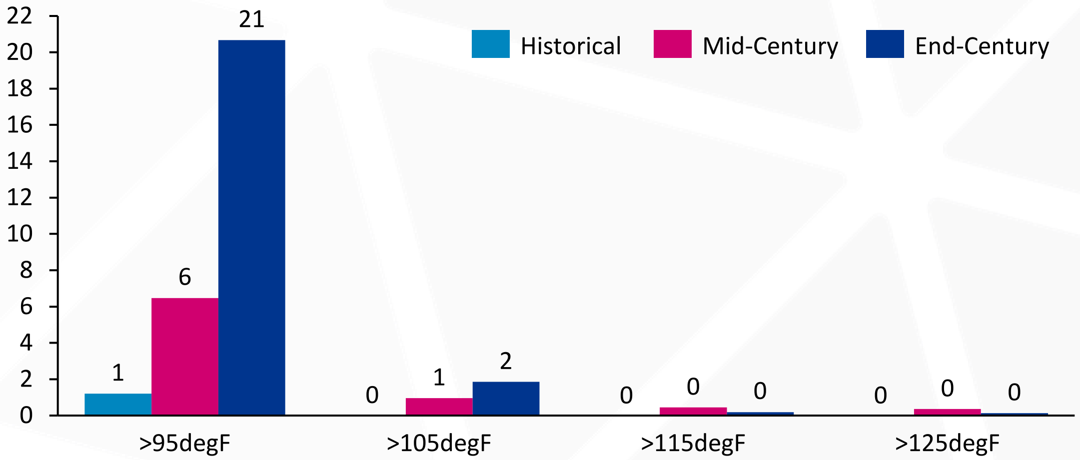
Montana Average Annual Cooling & Heating Degree Days (CDD & HDD)
Population-Weighted by County [RCP-8.5]



KEY OBSERVATIONS

- Between historical and mid-century, **the ratio of CDD to HDD increases,** with average CDD jumping from about 5% to 10% of HDD.
- This results in **increased summer asset utilization and degradation**, but **impacts to winter utilization remain unclear** depending on heating electrification trends.
- **MDEQ could consider the impacts of a significant winter system peak** given the high volume of HDD and heating electrification.

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

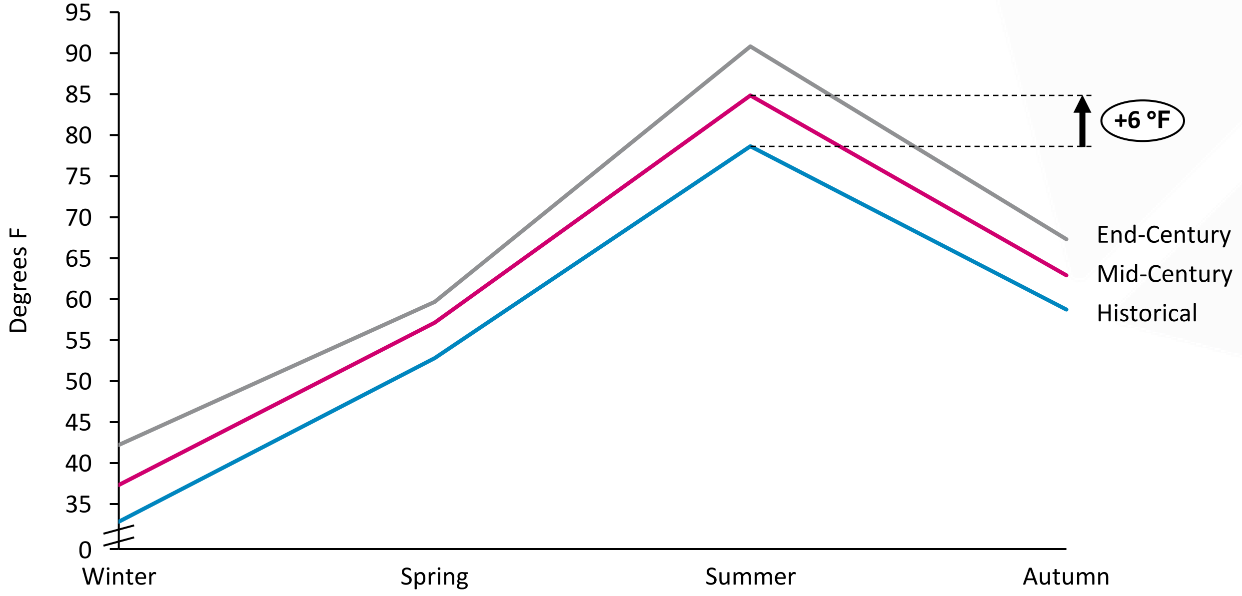


KEY OBSERVATIONS

- 6x increase in days with heat index >95 °F by mid-century and a 21x increase by end-century demonstrates an **increase in asset utilization and accelerated degradation of equipment.**
- Presence of days > 105 °F by mid-century indicates that **MDEQ could consider prioritizing substation upgrades in the warmest regions of the state**, as substations can fail when exposed to 2 consecutive days > 104 °F without sufficient cooling infrastructure.

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

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



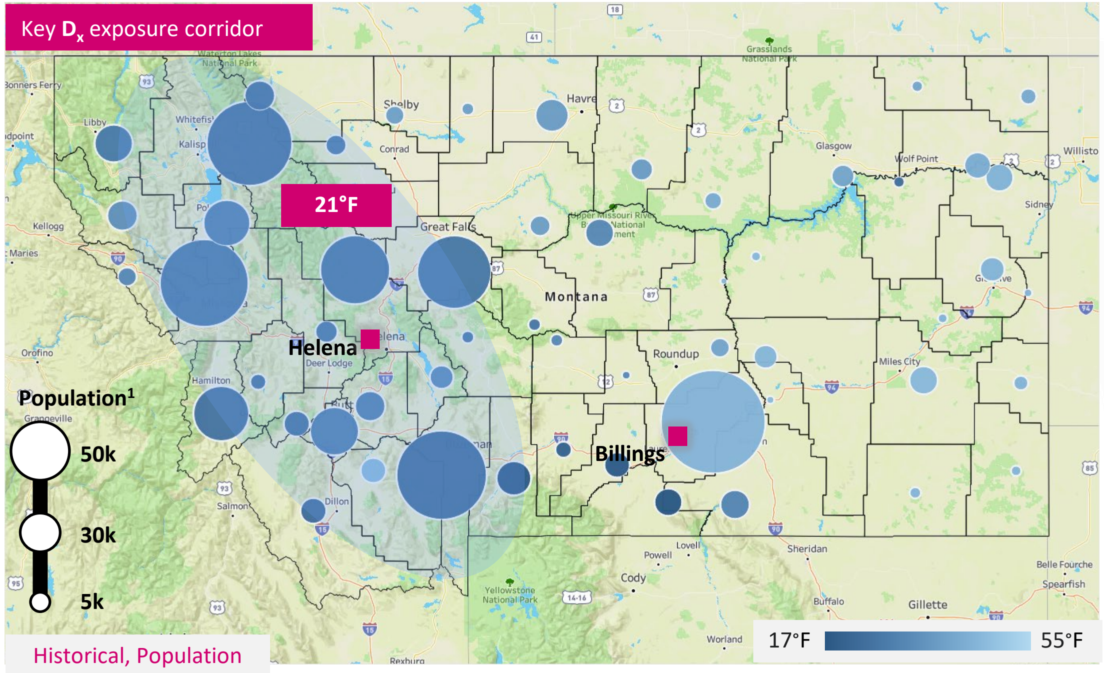
Key Highlights	Analysis
Summer Warming	• Heat risk increases most drastically in summer, with a 6 °F increase in the average seasonal max by mid-century, increasing **summer peaks and resulting in thermal capacity violations.**
Shorter Shoulder Seasons	• There is generally less pronounced warming in shoulder seasons, although increased spring and autumn maximums could **extend the duration of high system utilization and shorten maintenance windows.**

Extreme Cold

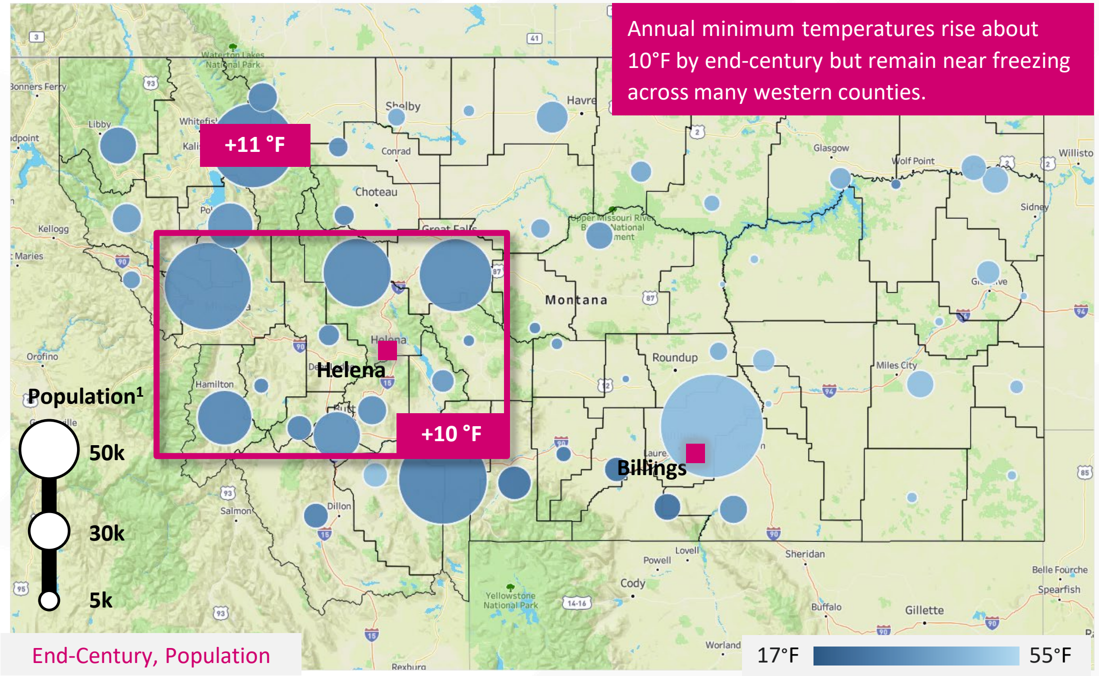
Asset Analysis

MDEQ could continue to fund distribution asset weatherization and ensure that investment is aligned with Dx asset density given continued extreme cold exposure

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



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



KEY OBSERVATIONS

- Extreme cold coincides with large population centers in the western portion of the state, indicating **high levels of Dx asset exposure.**
- Prevalence of proposals including undergrounding and pole upgrades seems to address extreme cold exposure, but MDEQ could **consider Dx asset density in its project awards going forwards.**

KEY OBSERVATIONS

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

Flathead County Flathead County is exposed to average annual minimum temperatures of about 32 °F, indicting continued **icing and freezing exposure for Dx assets.**

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

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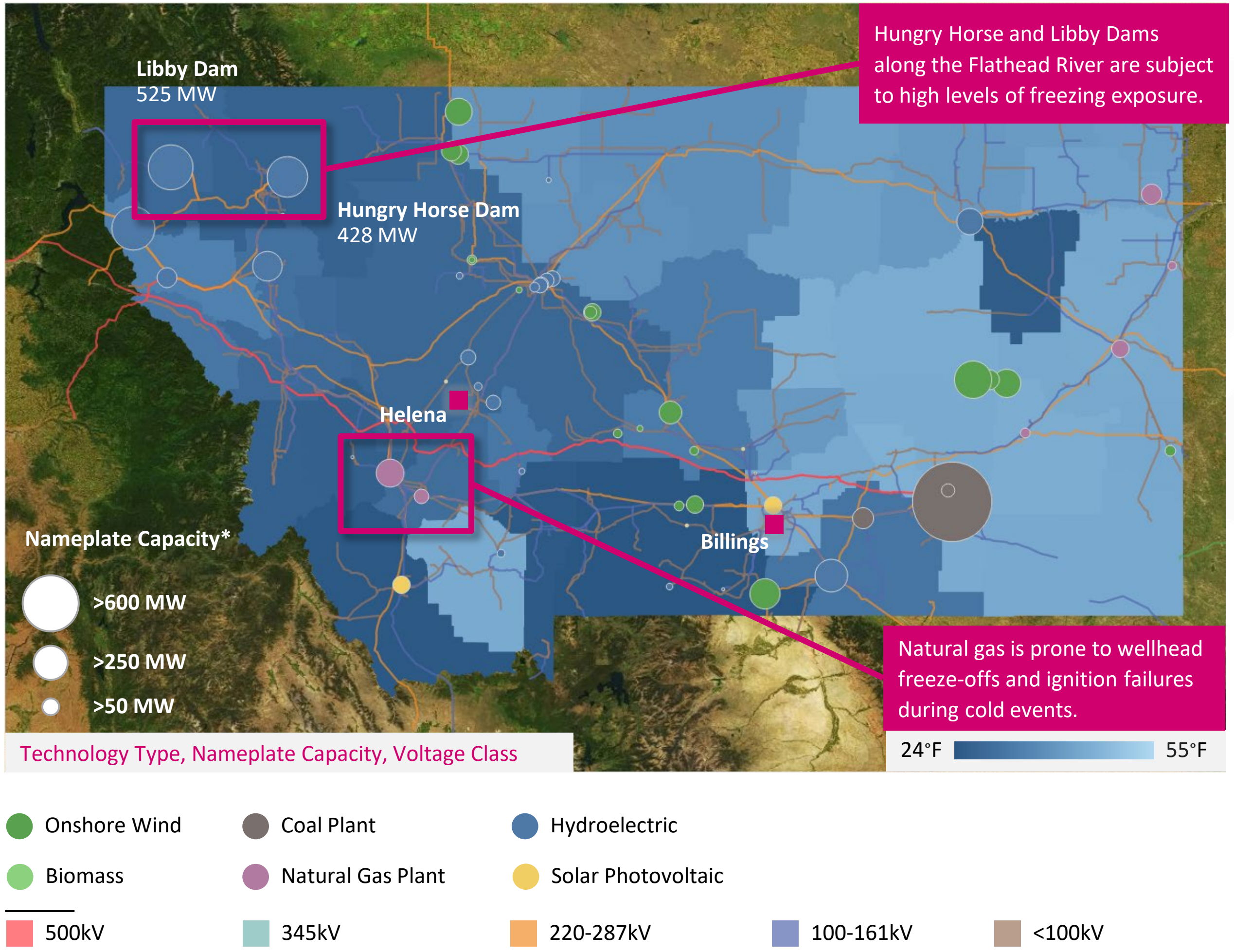
MDEQ could consider resilience upgrades to gas plants and pipeline systems to combat cold exposure, as well as continued transmission weatherization addressing freezing in SW counties

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



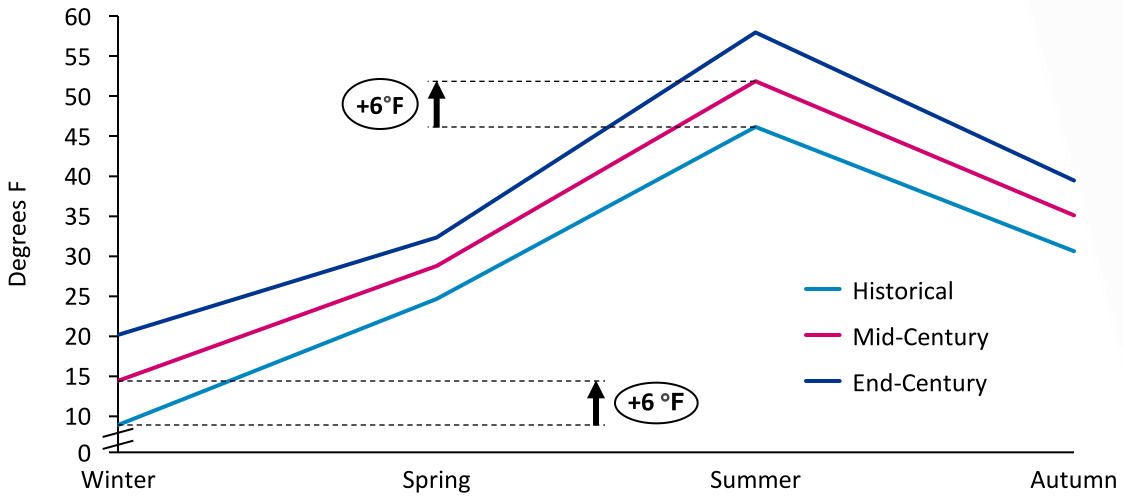
Source: ClimRR, US Census Bureau, City and Town Population Totals

Key Highlights	Analysis
Hydroelectric	• Frazil ice formation and maloperation of spill gate motors can result in **plant faults or production derates.**
Natural Gas	• Natural gas plants in the SW are exposed to average annual minimums of about 27°F, which could cause **ignition failure or performance issues.** • **No proposals addressing aging gas infrastructure**, which requires hardening or replacement to mitigate cold exposure.
Wind	• Wind projects in Toole and Carbon counties face cold exposure that contributes to **asset failure and ice throw.**
Transmission	• Despite warming, the **prevalence of below-freezing annual minimums** in many counties contributes to **Tx freezing/icing risk** that can cause asset failure. • MDEQ could prioritize a network of 220-287kV lines in SW counties for hardening.

*Generator nameplate capacities may exceed those shown in the legend

While seasonal and annual temperatures are projected to warm, minimums remain below freezing, indicating that MDEQ could consider funding projects addressing cold exposure

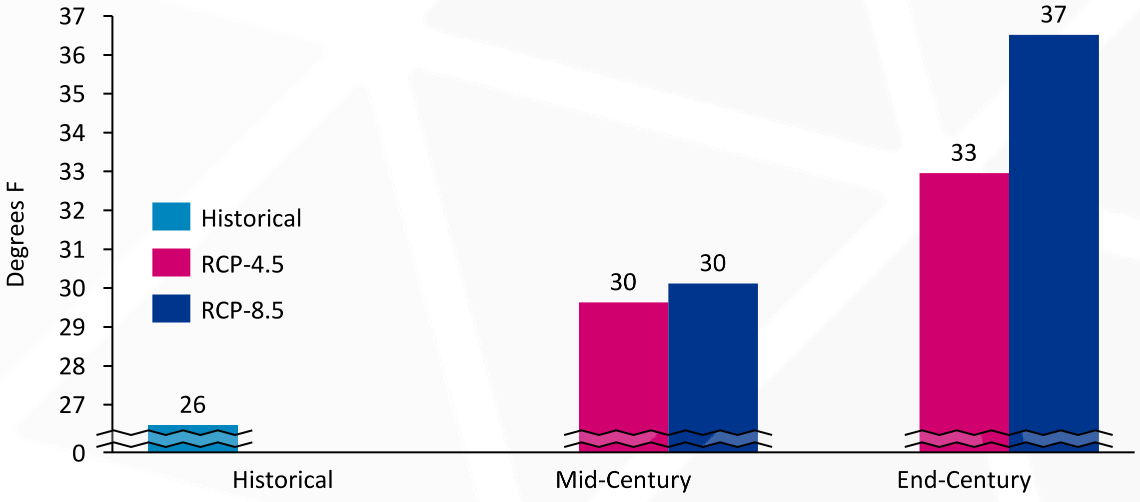
Montana Average Seasonal Minimum Temperature (°F)
Population-Weighted by County [RCP-8.5]



KEY OBSERVATIONS

- Significant winter warming (+6 °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, indicating that **freezing and icing exposure persists despite warming.**
- Resilience upgrades like **undergrounding, pole upgrades, and cable upgrades could address freezing/icing exposure.**

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



KEY OBSERVATIONS

- ~12% increase in average annual temperature minimum by mid-century indicates a reduction in heating load.
- Sustained sub-freezing minimums by mid-century indicate continued freezing exposure over a large portion of the year.
- 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.**

Baringa

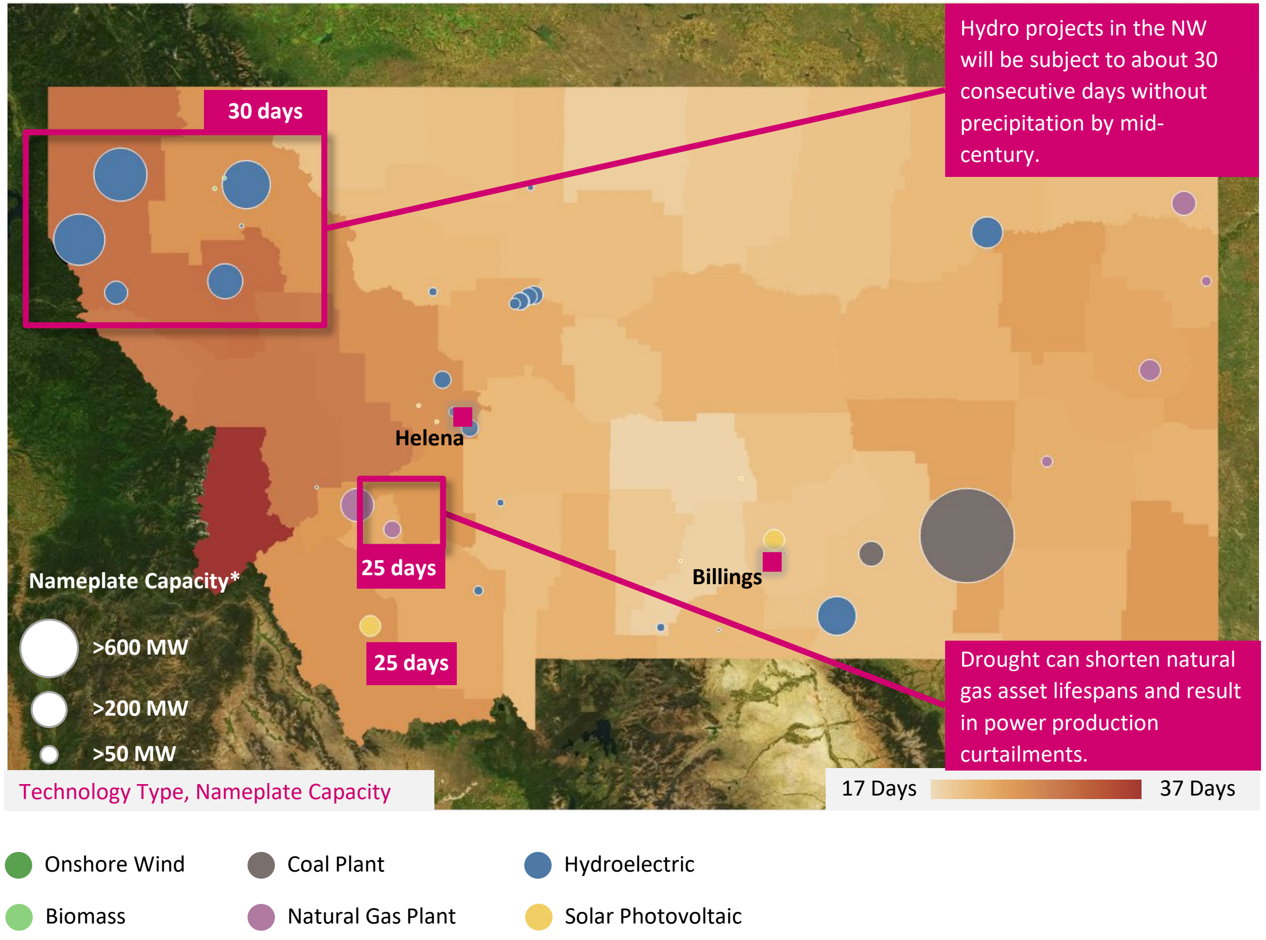
Drought

Asset Analysis

Significant drought exposure increases necessitate climate-adjusted hydroelectric production forecasting and innovative cleaning and cooling solutions for solar and natural gas

Montana Consecutive Days No Precipitation

Generators, Mid-Century [RCP5-8.5]



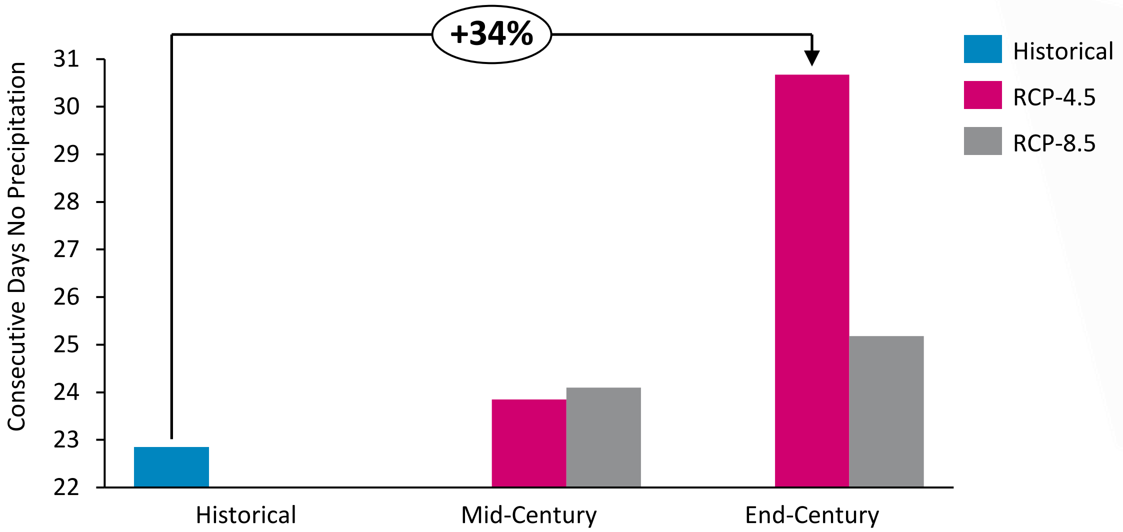
Key Highlights	Analysis
Hydroelectric	• A pocket of hydroelectric projects in the NW are exposed to significant drought levels. • Asset owners could be forecasting long-term production from these hydro facilities with **climate-adjusted inputs, as drought exposure in these counties increases by up to 30% by end-century.**
Natural Gas	• In arid conditions, **air intakes for CCGTs and CTs can clog and degrade** due to buildup of dust and sand particles, decreasing efficiency and longevity of generator. • Lack of water availability can **reduce natural gas cooling ability**, resulting in power production curtailments.
Renewables	• Drought conditions cause dust buildup on solar panels, hurting capacity factors. • In areas that also have high wildfire exposure, **panel cleaning projects address derating from two hazards simultaneously.**

*Generator nameplate capacities may exceed those shown in the legend

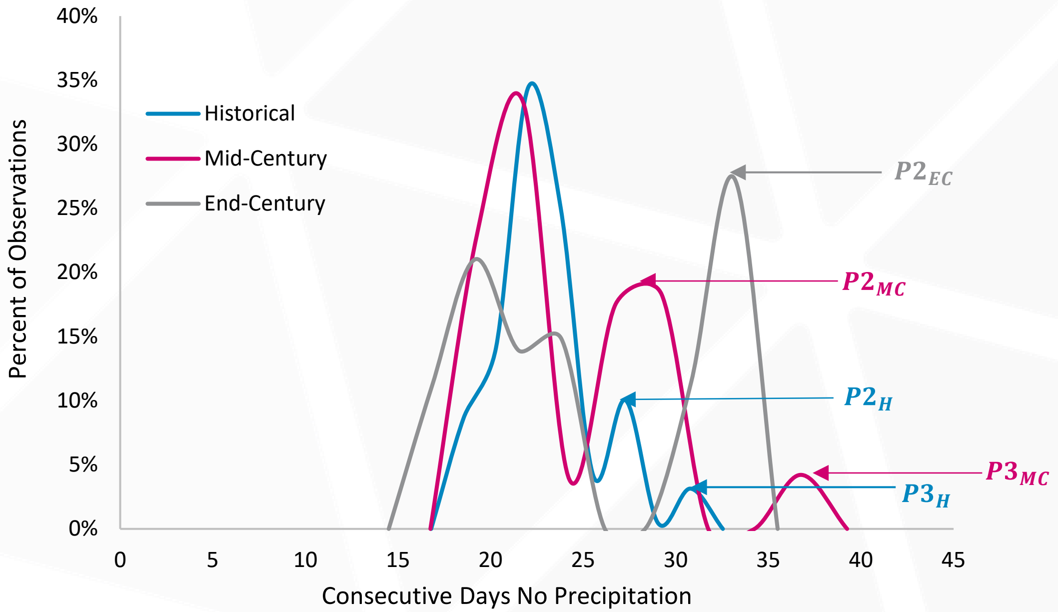
Source: ClimRR, US Census Bureau, City and Town Population Totals

Drought exposure will increase in spatial extent and severity by mid-century, but will become more evenly distributed by end-century

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



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



KEY OBSERVATIONS

- **Drought exposure increases ~34% by end-century** (under RCP-4.5), contributing to potential asset cooling failures and reduced hydroelectric generation.
- Significantly higher drought exposure for RCP-4.5 then RCP-8.5 by end-century demonstrates that **drought risk does not scale linearly with temperature.** This results in drought exposed areas not necessarily overlapping with high temperature exposed areas.

KEY OBSERVATIONS

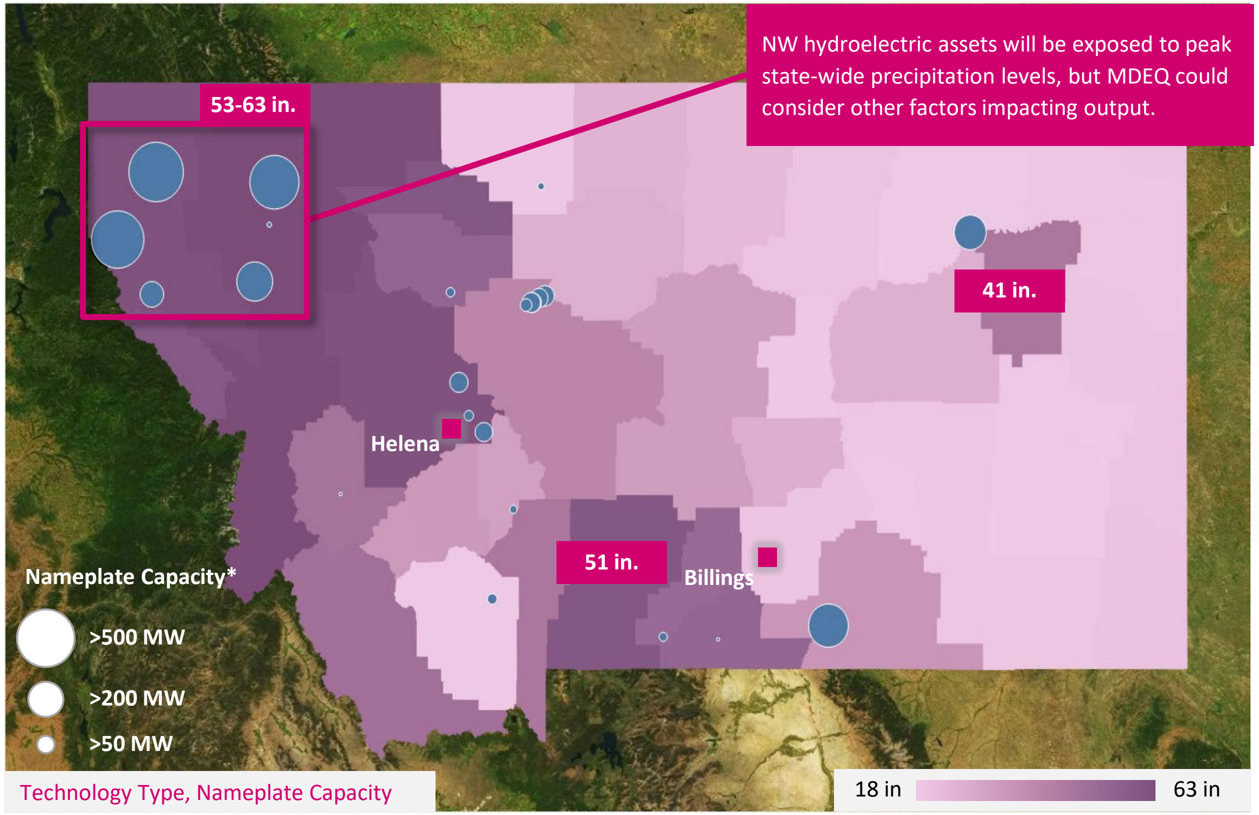
- By mid-century, P3 shifting right indicates that **drought exposure will become more severe in the most highly exposed regions of the state.**
- Shift of P2 upwards and right by end-century indicates that **a greater portion of the state (25%) will face drought exposure greater than 30 days.**
- Tri-model distribution for historical and mid-century indicate **three distinct regions of drought exposure** within the state, but this largely **converges to two regions by end-century.**

Precipitation

Asset Analysis

While precipitation is projected to increase over time, MDEQ could consider other factors that impact hydro production, such as precipitation timing and changing snow patterns

Montana Annual Max Precipitation (in)
Generators, Mid-Century [RCP5-8.5]



Onshore Wind | Coal Plant | Hydroelectric
Biomass | Natural Gas Plant | Solar Photovoltaic

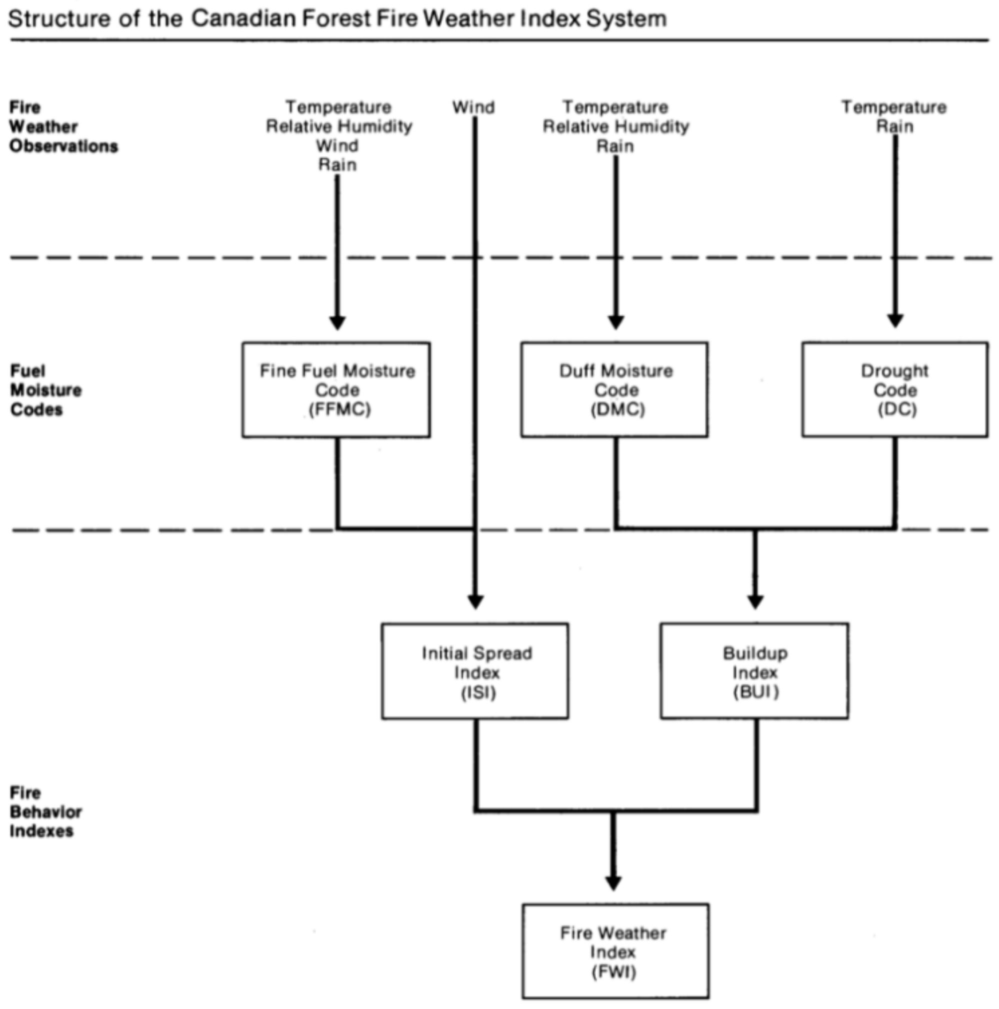
Key Highlights	Analysis
Timing	• Timing of precipitation has an important impact on hydro output. • Extreme rainfall events may overflow reservoirs and put more pressure on dams, increasing risk of failure. • Projections of increased drought and increased precipitation in NW counties indicate that **extreme precipitation events may become more likely over time.**
Increased Precipitation	• **Precipitation is expected to increase 2-6 inches** statewide by end-century. • MDEQ could consider **reinforcements for existing hydro assets** or **methods to capture more precipitation during extreme events** to combat drought.
Changes to Snow Patterns	• While precipitation levels remain relatively constant to mid-century, precipitation type and timing is likely to change and could be monitored. • Grid operators could **consider the impacts of less snow and earlier snow melt when conducting long-term planning.**

*Generator nameplate capacities may exceed those shown in the legend

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

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

Baringa