Value of Nuclear Power to Grid Reliability

– Assessment of Impact of Premature Retirements or Extended Outages of Nuclear Power Plants

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Outline

- Team
- Context/Motivation for the study
- NERC Regions Screening Assessment Methodology and Outcome
- Modeling Approach, Assumptions and Results
  - Production Cost Model
- Managing the Flexible Future for Grid Reliability

Team Members

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LWRS
LIGHT WATER REACTOR SUSTAINABILITY

Context and Motivation

- Nuclear Power Plants provide resilient base load across the North American Power System
- Historically in unregulated markets nuclear power has experienced economic challenges that have led to retirements and planned retirements or repurposing towards hybrid processes such as clean hydrogen production
- However, resource adequacy alerts across the western interconnect and MISO particularly in 2023 and drive towards low carbon energy has halted trend towards retirements (e.g., Diablo Canyon)
- Additionally, recent rule making from the environmental protection agency to ban Decabromodiphenyl Ether, a chemical used in components and wiring in NPPs produced an unintended consequence that would have prevented near term extension of maintenance outages had relief not been obtained through cooperation of EPA and NRC
- This activity seeks to quantify the value of Nuclear power plants (NPP's) to the reliability of the electric grid and illustrate the impacts of unplanned retirement and/or long extensions of outages that externalities like the EPA ruling might cause to the grid.

Resource Adequacy Risk

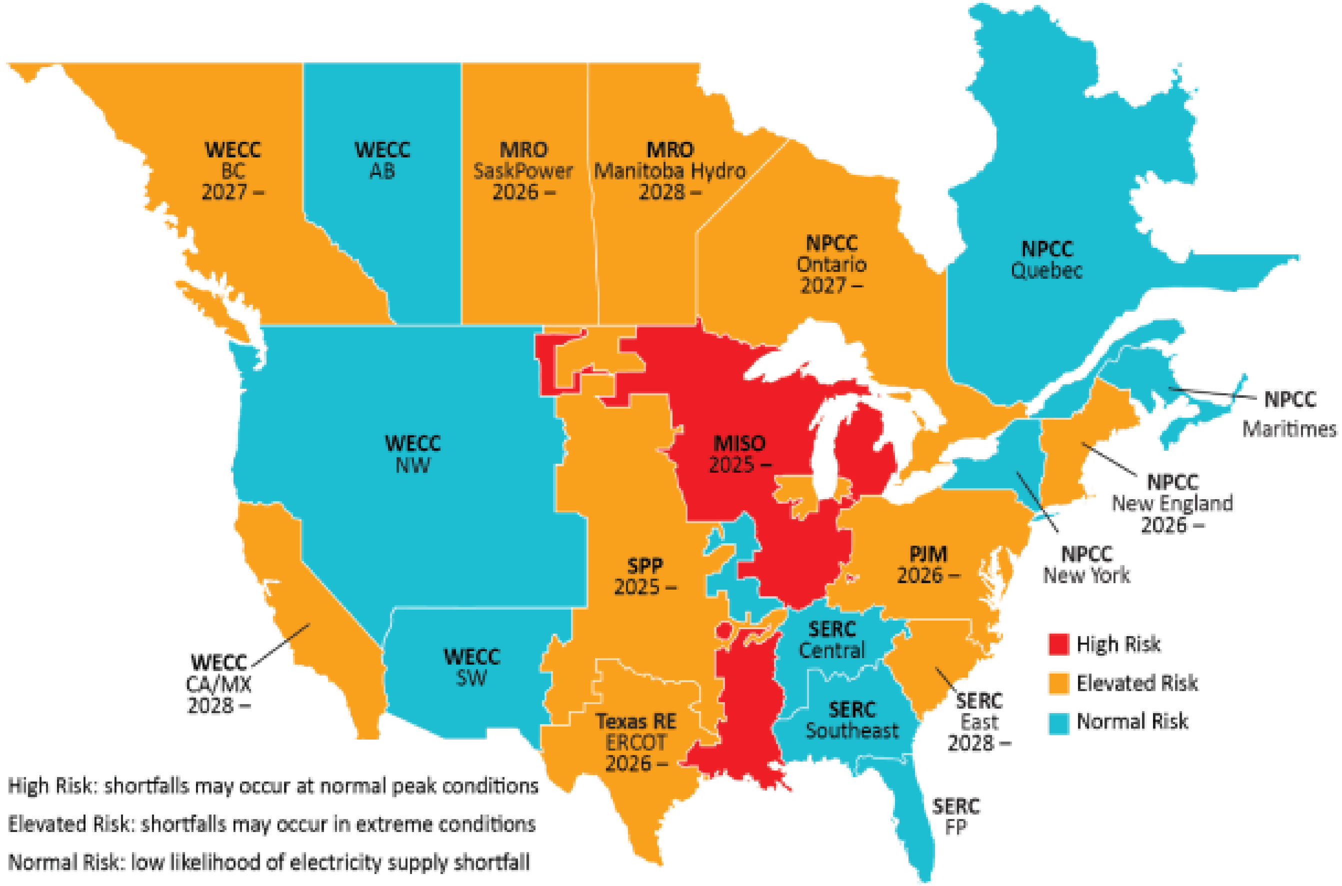


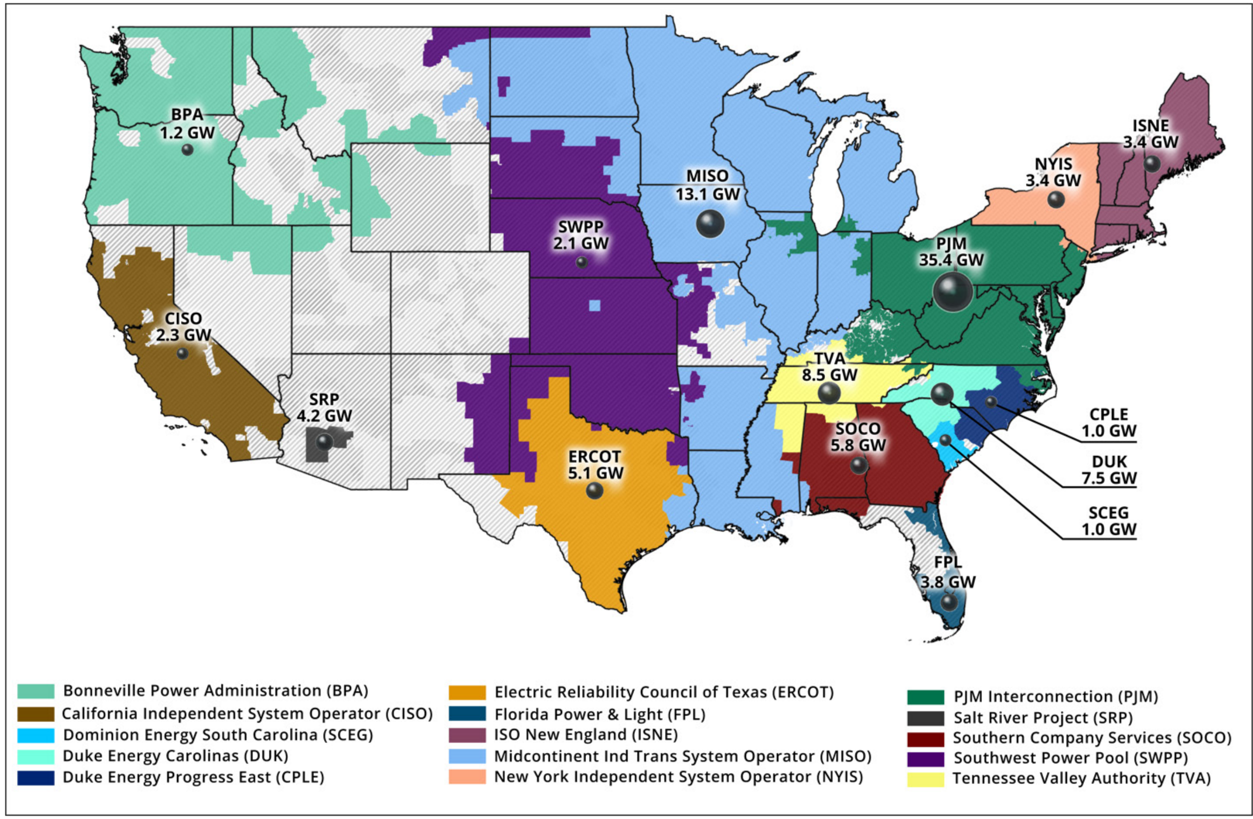
Figure 1: Risk Area Summary 2025–2029

2024 Long-Term Reliability Assessment

https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_Long%20Term%20Reliability%20Assessment_2024.pdf

Capacity by ISO/RTO/BA with Nuclear Plants

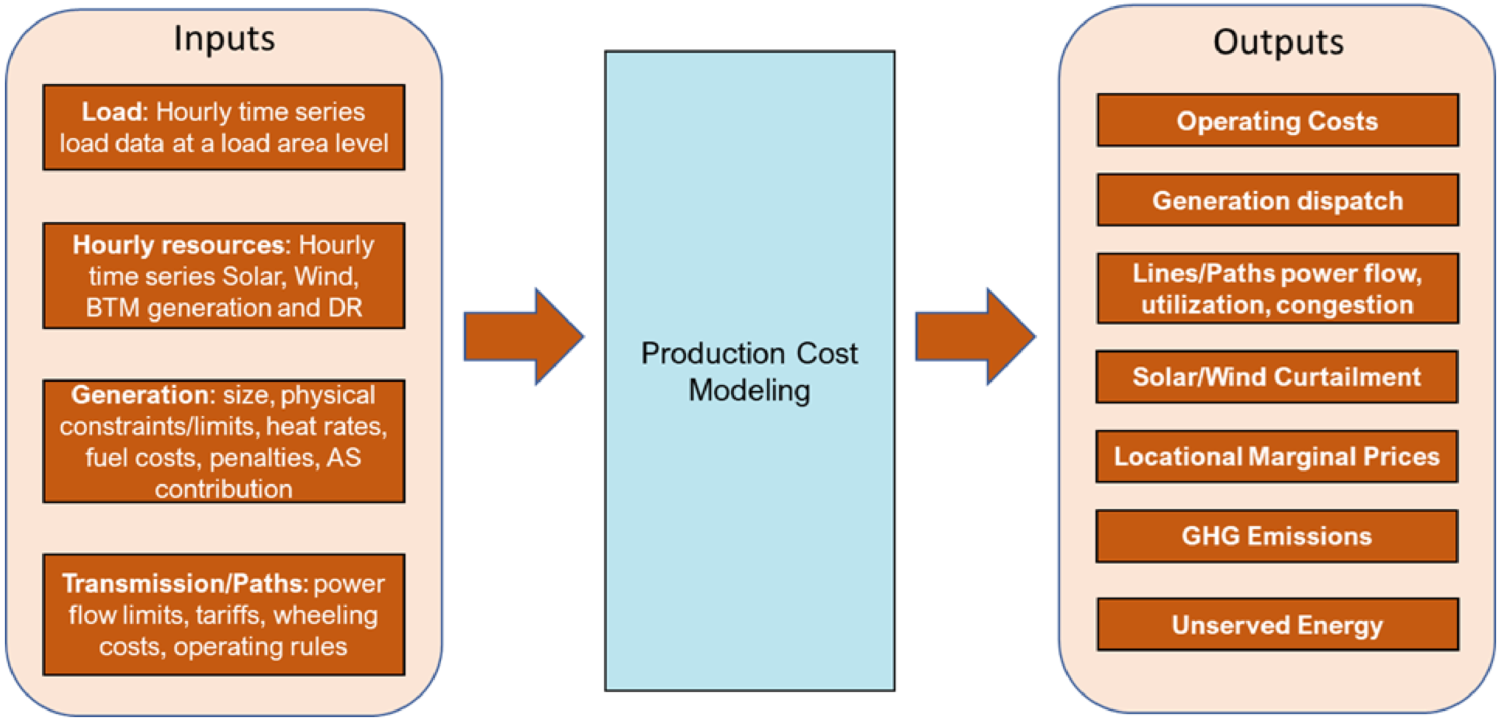
Balancing Authority	Number of Nuclear generating units	Total Capacity (GW)	Nuclear Capacity (GW)	Nuclear %
Duke Energy Carolinas (DUK)	7	29	8	26
Tennessee Valley Authority (TVA)	7	42	8	20
PJM Interconnection, LLC (PJM)	31	212	35	17
Dominion Energy South Carolina (SCEG)	1	7	1	15
Florida Power & Light Company (FPL)	4	28	4	13
Duke Energy Progress East (CPLE)	4	8	1	12
ISO New England Inc. (ISNE)	3	36	3	9
Southern Company Services, Inc. – Trans (SOCO)	6	69	6	8
New York Independent System Operator (NYISO)	4	42	3	8
Midcontinent Independent Transmission System Operator, Inc. (MISO)	13	186	13	7
Southwest Power Pool (SWPP)	2	83	2	2
Salt River Project (SRP)*	4	16	4	27
Bonneville Power Administration (BPA)	1	31	1	4
California Independent System Operator (CISO)	2	64	2	4
Electric Reliability Council of Texas, Inc. (ERCOT)	4	106	5	5



- Grouped by Interconnect / sorted by % Nuclear

Production Cost Modeling

- Production cost models solve the chronological unit commitment (UC) and economic dispatch (ED) model to minimize power systems' operating costs of meeting electricity demand and reserve requirements while simultaneously satisfying a wide variety of operating constraints **full nodal power flow models**.
- Production Cost models:
  - Mimic electricity market operations
  - Identify periods of unserved energy and transmission congestion (reliability)
  - Calculate spot prices at buses and shadow prices on lines
  - Dispatch generators to minimize the production cost given unit characteristics (cost, as well as physical) and chronological load
  - Perform a dispatch such that transmission line limits are not violated under normal, as well as contingency conditions.

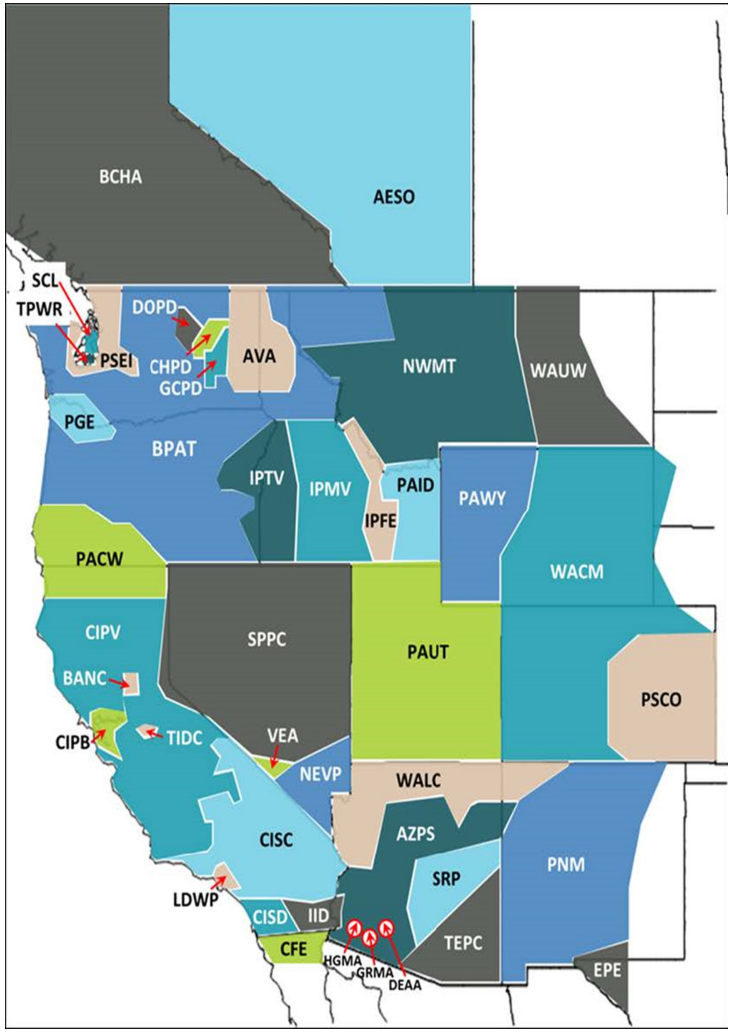


Production Cost Modeling Evaluation Metrices

- Unserved Load
- Reserve shortage
- Generation mix change & Variable Generation Curtailment
- Greenhous Gas Emission
- Localize Marginal Prices

WECC Anchor Datasets (ADS)

- Best available data for the western interconnection (WI): The WECC 2030 Anchor Data Set (ADS)
  - Best available projection of new generation, generation retirements, transmission assets, and load growth **10 years in the future from a given reference year (e.g., 2030, 2032)**
- There are **38 functional Balancing Authorities** (BA) in the Western Interconnection.
- The WECC 2030 ADS provides a detailed nodal representation of the WI power grid topology:
  ~22k nodes and ~26k transmission lines
- The WECC 2030 ADS is designed to be analyzed using PCM and Power Flow commercial software packages used widely by utility planning engineers.

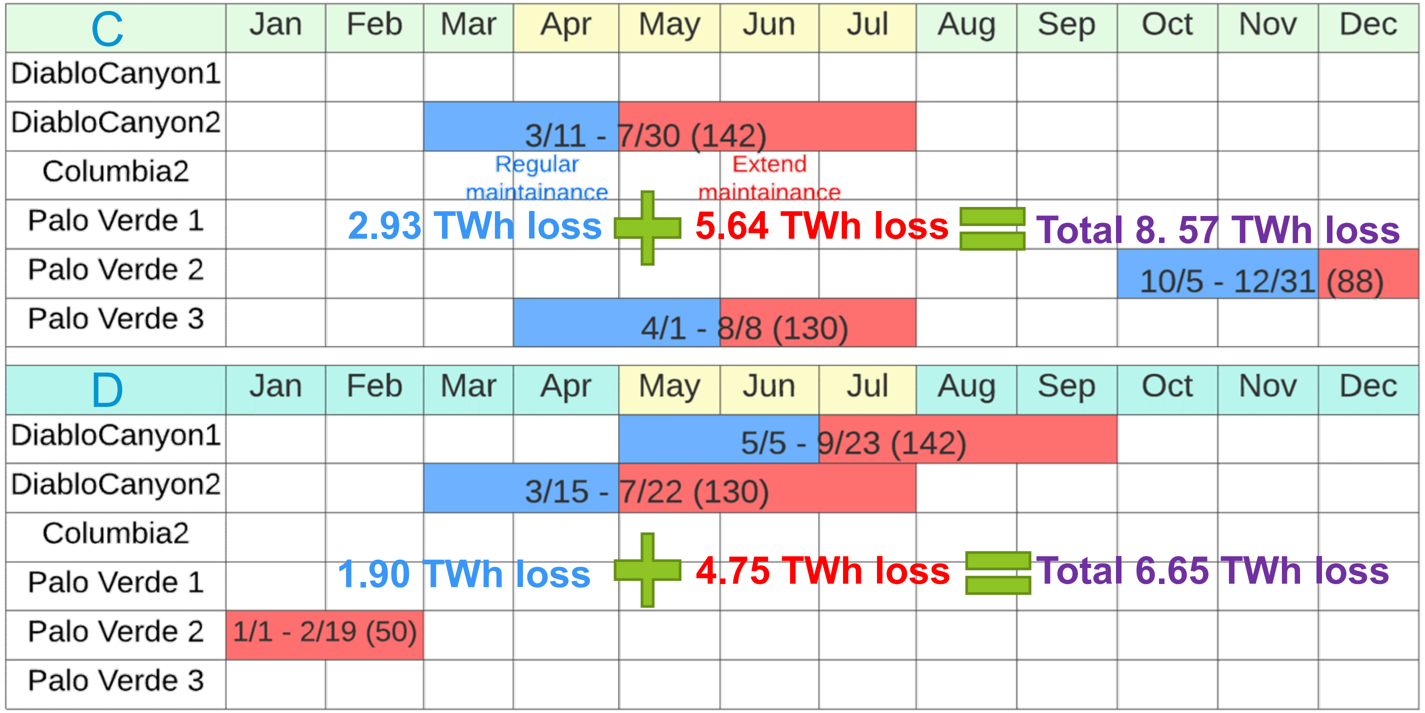


https://www.wecc.org/Pages/home.aspx

Nuclear Maintenance Schedules in WI

Maintenance Schedule Cases

i. A: all units are on
ii. B: all units are off (creating 64.79 TWh generation loss)
iii. C: extended schedule 2024 (8.57 TWh generation loss)
iv. D: extended schedule 2025 (6.65 TWh generation loss)



Nuclear Resources				Schedule C 2024			Schedule D 2025		
BA	Generator	Plant code	Capacity (MW)	Start	End	Days out	Start	End	Days out
CISO	DCPP 1	6099	1200				5/5	9/23	142
CISO	DCPP 2	6099	1200	3/11	7/30	142			
BPAT	Columbia 2	371	1185				3/15	7/22	130
SRP	Palo Verde 1	6008	1333						
SRP	Palo Verde 2	6008	1336	10/5	12/31	88			
SRP	Palo Verde 3	6008	1334	4/1	8/8	130	1/1	2/19	50

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Nuclear Outage Scenarios for PCM Simulations Comparison Overview

- The comparison overview:
  - Six scenario, including base case (Scenario 1), derated hydro (Scenario 2), two heatwave (Scenarios 3 - 4) and combined (Scenarios 5 - 6)

Scenario	Event	Nuclear Outage	WECC ADS Case	Load	Wind	Solar	Hydro
1	Extended Nuclear Maintenance Outage	Case 1A: Base Case* (Business as usual) Case 1B: Total Nuclear Retirement Case 1C Nuclear Maintenance Schedule A Case 1D: Nuclear Maintenance Schedule B	2030 WECC ADS (NTP case 1)	2030 WECC ADS	2030 WECC ADS	2030 WECC ADS	--
2	Drought (2001 hydro weekly dispatch)	Case 2A: Base Case (Business as usual) Case 2B: Total Nuclear Retirement Case 2C Nuclear Maintenance Schedule A Case 2D: Nuclear Maintenance Schedule B	2030 WECC ADS (NTP case 1)	2030 WECC ADS	2030 WECC ADS	2030 WECC ADS	DerateHydro PNNL 2001
3	Heatwave 1 (2015 NW heatwave)	Case 3A: Base Case (Business as usual) Case 3B: Total Nuclear Retirement Case 3C Nuclear Maintenance Schedule A Case 3D: Nuclear Maintenance Schedule B	2030 WECC ADS	2030 WECC using 2015 weather profile	2030 WECC ADS	2030 WECC ADS	--
4	Heatwave 2 (2018 CA heatwave)	Case 4A: Base Case (Business as usual) Case 4B: Total Nuclear Retirement Case 4C Nuclear Maintenance Schedule A Case 4D: Nuclear Maintenance Schedule B	2030 WECC ADS	2030 WECC using 2018 weather profile	2030 WECC ADS	2030 WECC ADS	--
5	Drought + Heatwave 1	Case 5A: Base Case (Business as usual) Case 5B: Total Nuclear Retirement Case 5C Nuclear Maintenance Schedule A Case 5D: Nuclear Maintenance Schedule B	2030 WECC ADS	2030 WECC using 2015 weather profile	2030 WECC ADS	2030 WECC ADS	DerateHydro PNNL 2001
6	Drought + Heatwave 2	Case 6A: Base Case (Business as usual) Case 6B: Total Nuclear Retirement Case 6C Nuclear Maintenance Schedule A Case 6D: Nuclear Maintenance Schedule B	2030 WECC ADS	2030 WECC using 2018 weather profile	2030 WECC ADS	2030 WECC ADS	DerateHydro PNNL 2001

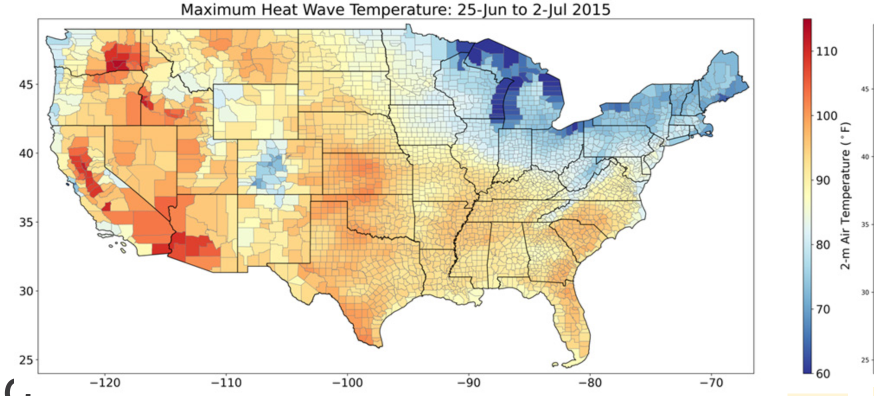
*Nuclear Maintenance Schedules A: using expected BAU schedule in year 2024, plus additional 90 days as extended maintenance outage
*Nuclear Maintenance Schedules B: using expected BAU schedule in year 2025, plus additional 90 days as extended maintenance outage

Evaluate Nuclear Power Plants Role During Extreme Weather Events

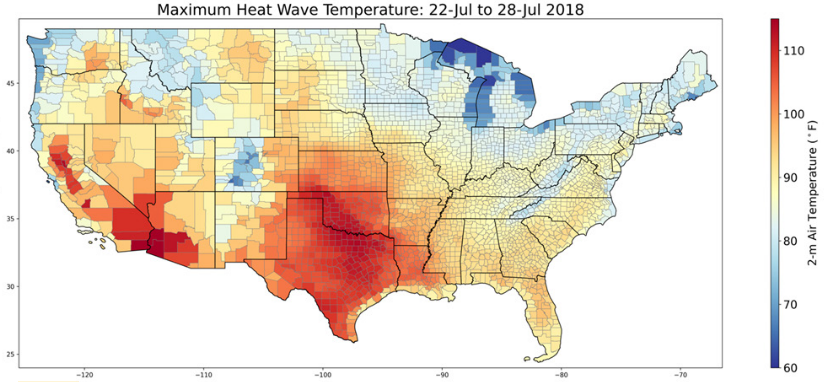
Load Models

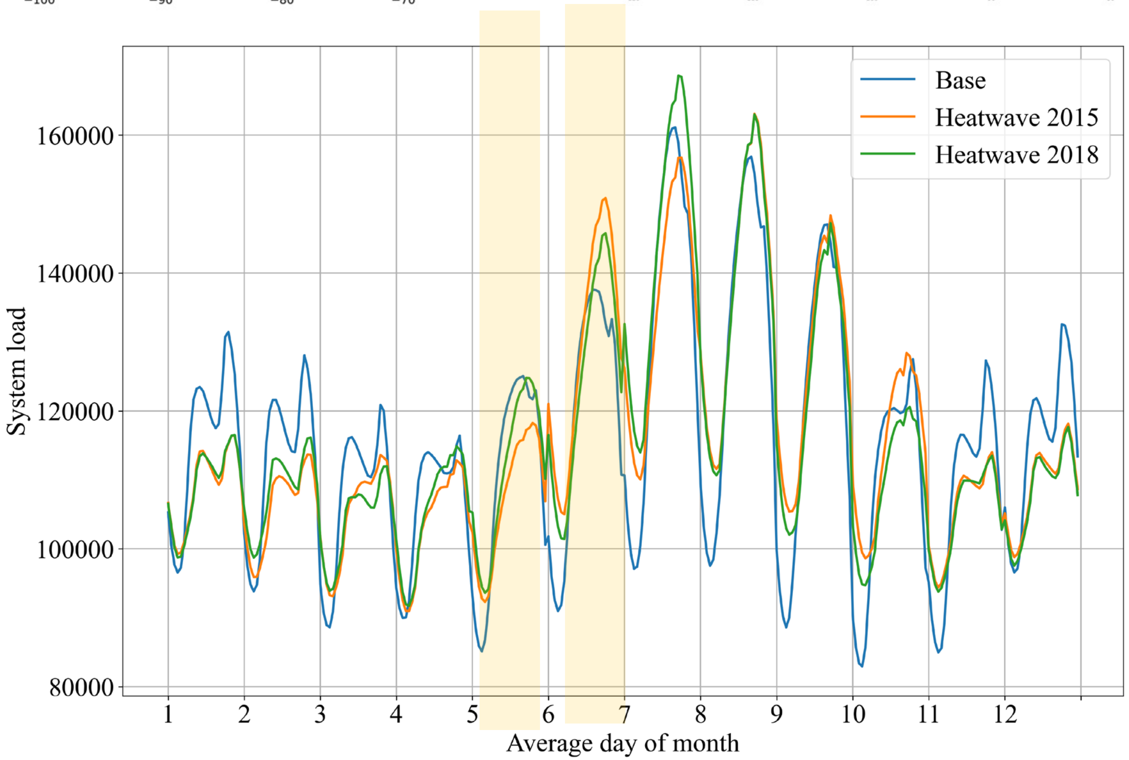
- Load
  - Base
    - 2030 WECC
  - 2015 heatwave using Total Electricity Loads Model (TELL)
    - 2030 WECC load shaped by a 2015 heatwave weather profile
  - 2018 heatwave
    - 2030 WECC load shaped by 2018 heatwave weather profile
- Average day of month

2015 Heatwave in Pacific Northwest



2018 Heatwave in California & Desert Southwest

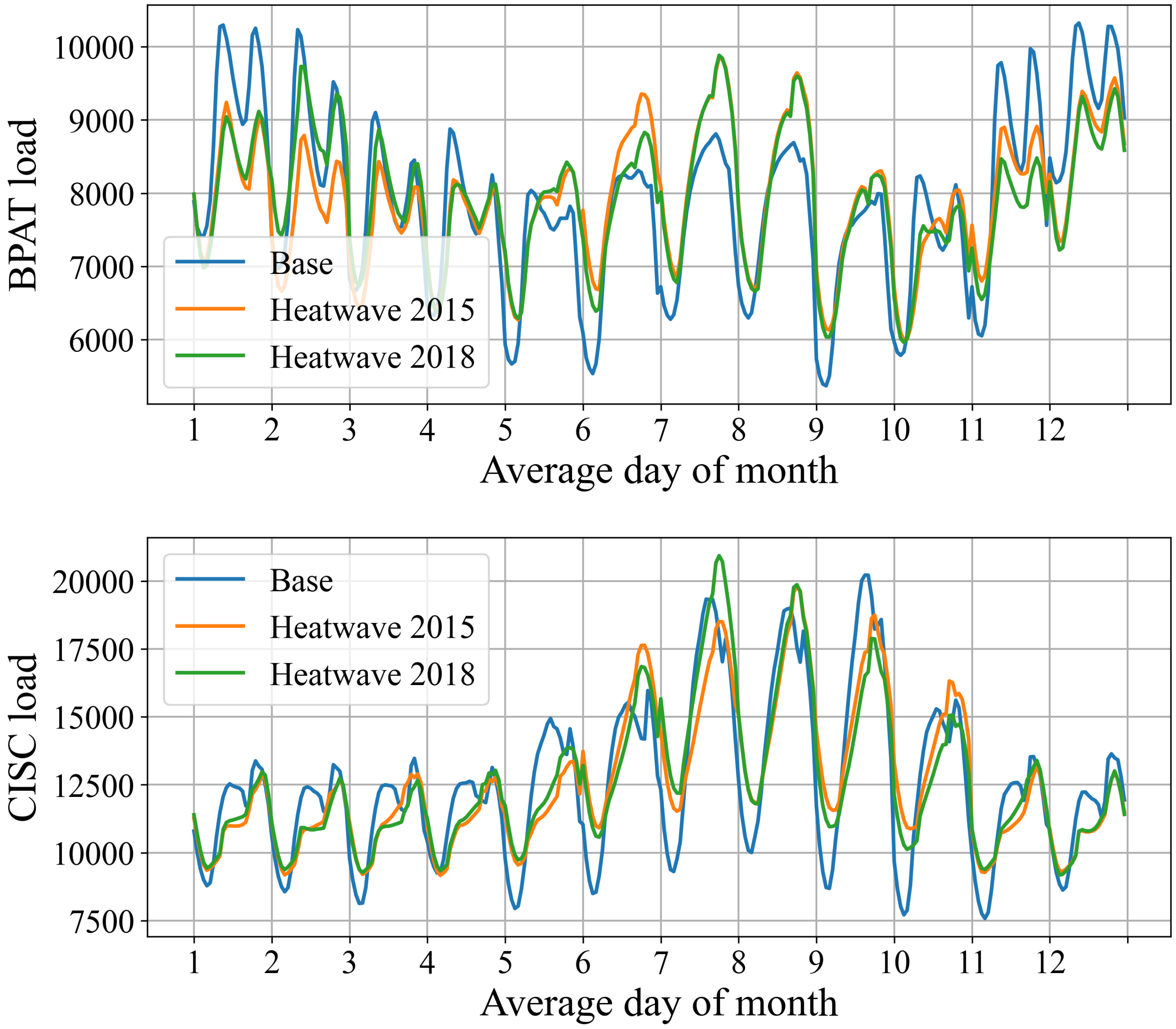




Load in CISC and BPAT

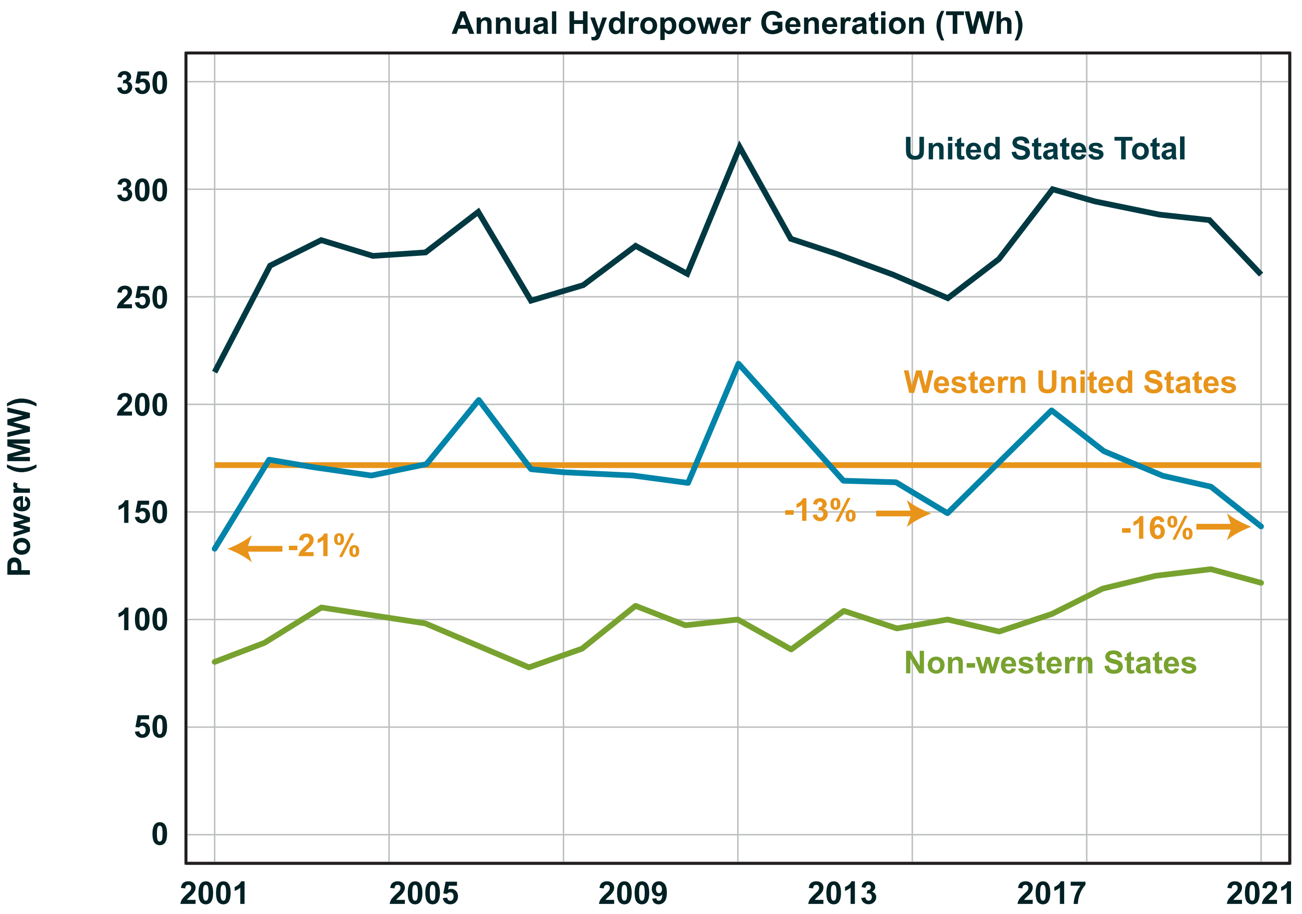
- Heatwave 2015 has a higher impact in NW region
- Heatwave 2018 has a higher impact in CA region

- Heatwave load example:
  - BPAT
    - Bonneville Power Administration
  - CISC
    - Southern California Edison



Derated Hydro 2001

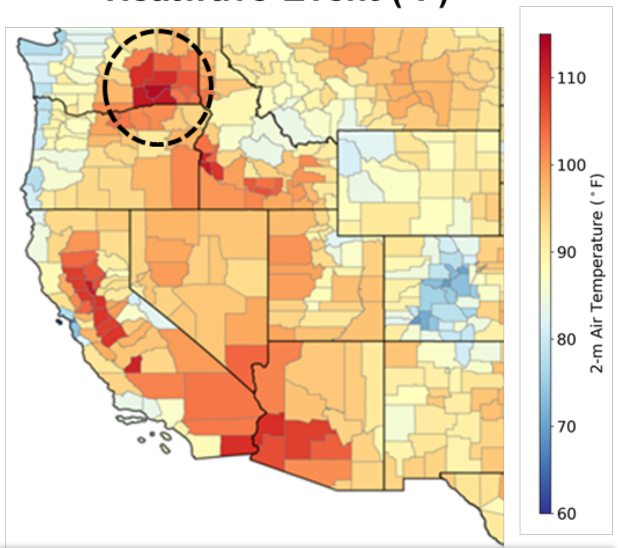
- The year 2001 shows the most severe drought, with a hydropower reduction of 21%.
  - The 2001 drought began with exceptionally low precipitation and snow accumulation in the fall and winter of 2000, leading to near record low springtime flows in the Columbia River, which is home to approximately two-thirds of western hydropower generating capacity

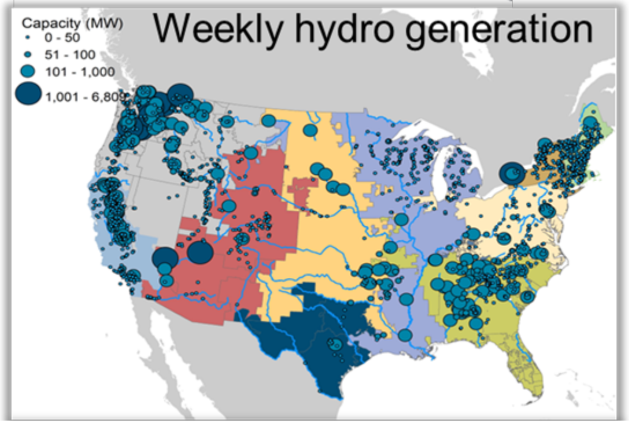


Evaluate Nuclear Power Plants Role During Extreme Weather Events

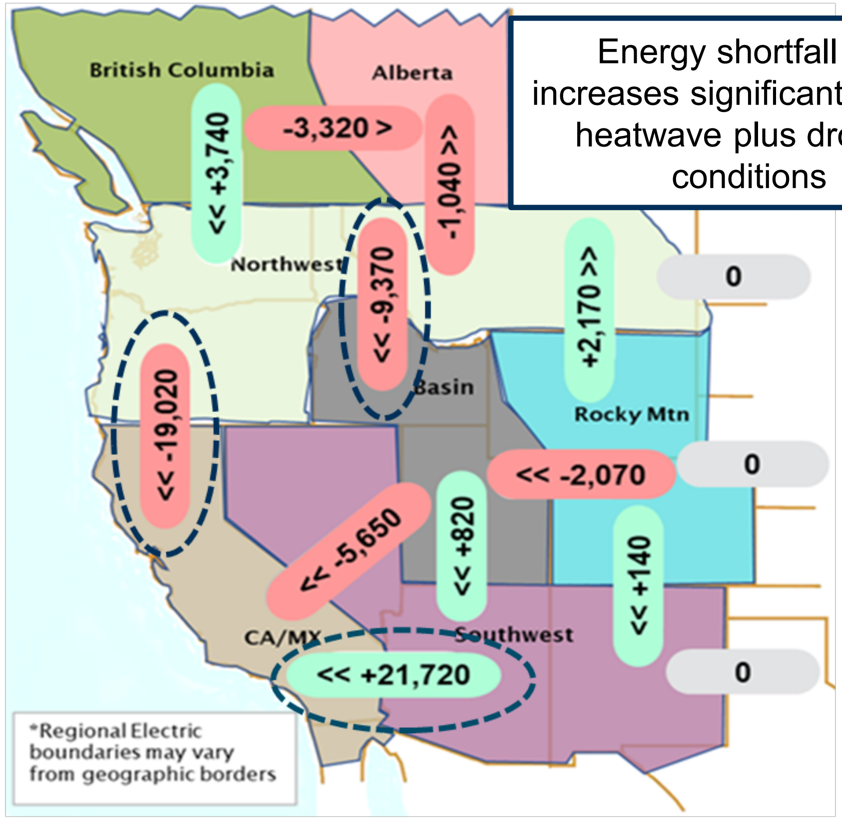
PCM Study Example: Impact of drought and heatwave on Power System Reliability

Heatwave Event (°F)



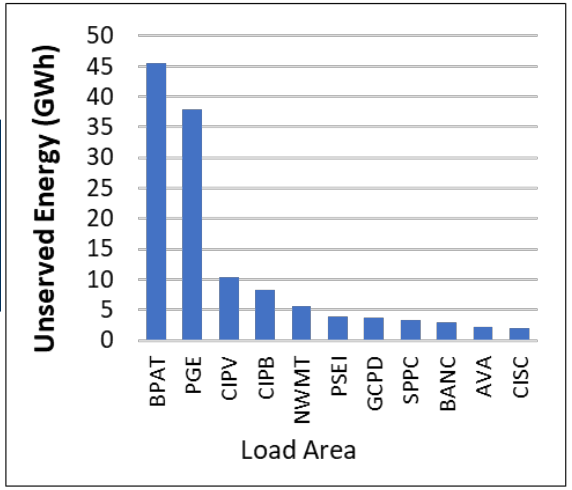


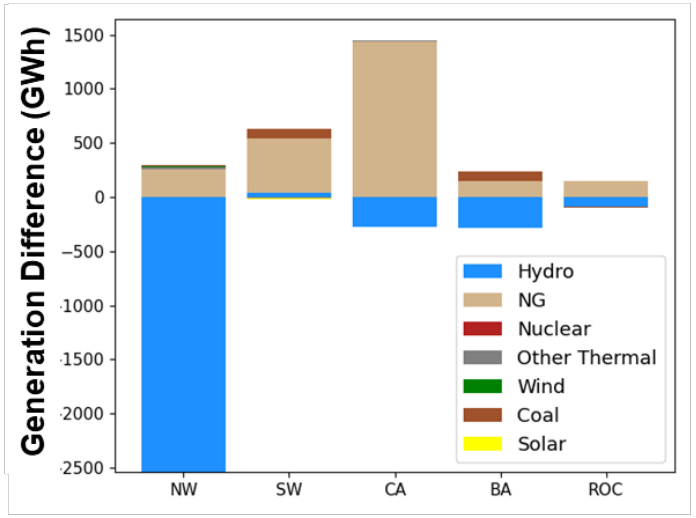
Net Regional Power Transfers Difference (GW): With Drought – Without Drought



Energy shortfall risk increases significantly under heatwave plus drought conditions

Source:
EERE-WPTO HydroWIRES project: Hydropower's Contribution to Grid Resiliency under Compounding Set of Extreme Events





Unserved Load: BAU maintenance A

- **Scenario**
  - S1: base
  - S2: Drought 2001
  - S3: Heatwave 2015
  - S4: Heatwave 2018
  - S5: S2+S3
  - S6: S2+S4
- **Nuclear maintenance**
  - A: base case

Avail.	Region	Scenario					
		Base	2001 Drought	3	4	5	6
A	Basin	–	–	–	5	1,045	7,577
	California	–	953	243	4,361	31,999	147,520
	Northwest	–	361	–	690	2,085	46,144
	Rocky Mtn	–	5	138	2,349	10,237	29,042
	Southwest	–	57	704	10,120	13,755	56,571
A	Total	–	**1,376**	**1,085**	**17,524**	**59,121**	**286,855**
	N. homes	–	**131**	**103**	**1,669**	**5,631**	**27,320**

- The system is capable of supplying its load under normal conditions Scenario 1.
- The scenarios considering drought, heat wave, and heat wave with drought are unable to supply its complete load.
- Drought + heatwave + nuclear outage could cause up to 27k households lose power: the estimation of number of homes is computed by dividing the total unserved load by 10.5, the yearly electricity consumption

Unserved Load:

- **Scenario**
  - S2: Drought 2001
  - S3: Heatwave 2015
  - S4: Heatwave 2018
  - S5: S2+S3
  - S6: S2+S4
- **Nuclear maintenance**
  - B: total nuclear retirement (64.79 TWh generation loss)
  - C: extended schedule 2024 (8.57 TWh generation loss)
  - D: extended schedule 2025 (6.65 TWh generation loss)

Avail.	Region	Scenario					
		1	2	3	4	5	6
B	Basin	4	607	2,226	4,429	11,993	32,281
B	California	3,431	39,789	49,808	87,218	246,356	370,296
B	Northwest	1,845	4,617	4,245	11,452	61,521	211,792
B	Rocky Mtn	5	2,486	8,586	20,409	33,435	62,960
B	Southwest	625	13,306	23,536	53,494	87,981	177,966
B	Total	5,910	60,806	88,401	177,001	441,286	**855,295**
B	N. homes	563	5,791	8,419	16,857	42,027	**81,457**
C	Basin	–	–	–	388	1,200	4,368
C	California	–	-121	-208	7,452	16,763	64,171
C	Northwest	–	–	–	70	5,292	33,766
C	Rocky Mtn	–	–	453	1,836	2,472	6,906
C	Southwest	–	0	310	5,238	5,101	29,650
C	Total	–	-121	555	14,985	30,827	138,861
C	N. homes	–	-12	53	1,427	2,936	13,225
D	Basin	–	–	–	336	1,454	2,852
D	California	–	805	2	6,372	20,281	57,344
D	Northwest	–	120	–	408	7,276	27,563
D	Rocky Mtn	-	81	924	2,658	3,147	6,286
D	Southwest	-	60	877	1,893	7,621	16,679
D	Total	–	1,066	1,803	11,666	39,779	110,724
D	N. homes	–	102	172	1,111	3,788	10,545

- The values have been subtracted from the nuclear availability Schedule A to present the values dependent on the nuclear availability

- The scenarios considering drought, heat wave, and heat wave with drought are unable to supply its complete load.
- Unserved load decreased even though nuclear availability was lower in schedule C due to co-optimization.

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Reserves: Unmet regulation up

- Unmet reserve is measured by the difference between the reserve requirements and actual deployments, a higher reserve shortage value indicates a more stressed grid condition
- The smallest percentual increase is from Scenario 1 nuclear availability Schedule C of 5% and the maximum percentual increase is from Scenario 1 nuclear availability Schedule B of 355%.

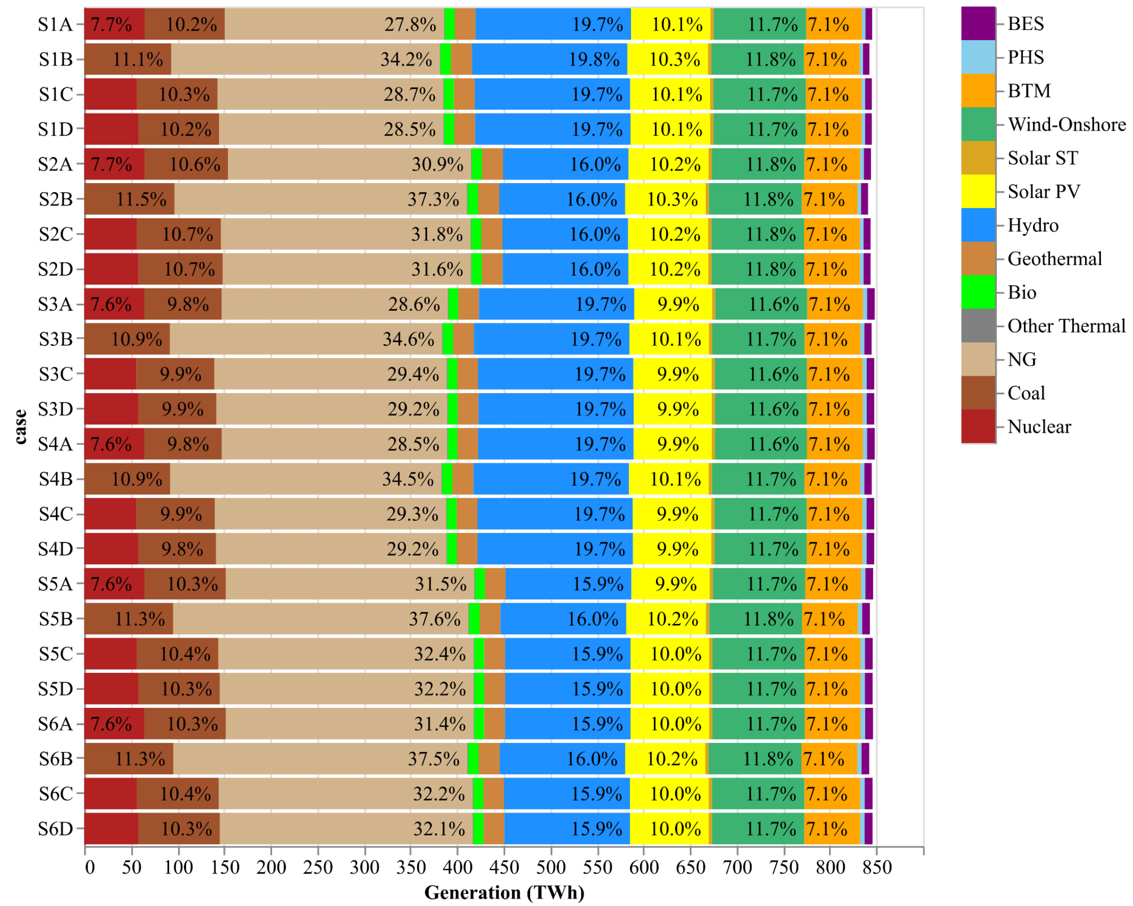
- The largest increase on unmet *regulation up* is Scenario 5 nuclear availability Schedule B of 213 GW

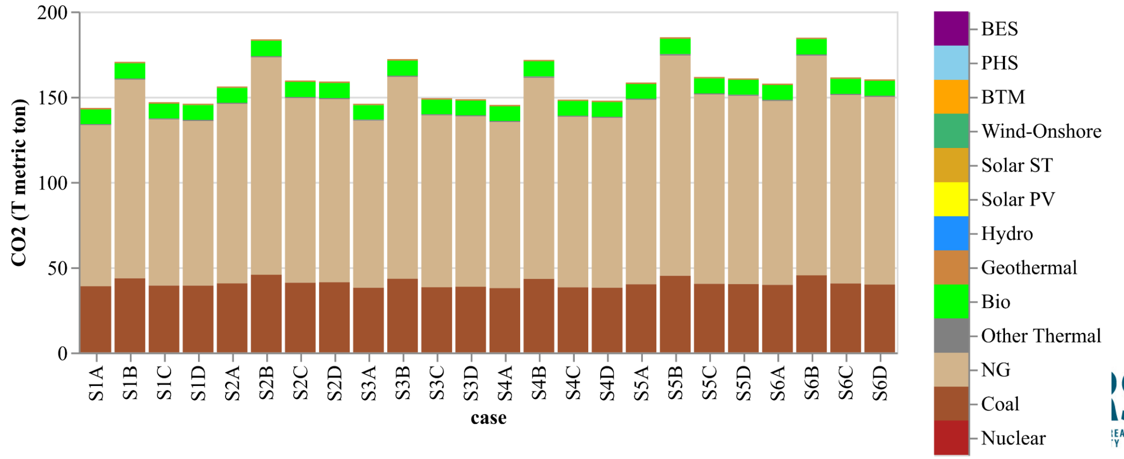
Nuclear Availability	Region	Scenario					
		1	2	3	4	5	6
B	Basin	4.65	15.30	18.47	18.01	35.49	30.89
	California	0.20	3.01	1.63	2.12	10.66	9.13
	Northwest	1.30	6.73	6.12	7.84	18.60	13.31
	Rocky Mtn	11.39	22.43	35.26	31.16	53.37	50.57
	Southwest	15.69	48.53	43.63	51.64	94.87	89.04
B	Total	33.24	96.00	105.11	110.78	**212.98**	192.94
	Increase	355%	185%	189%	136%	119%	87%
C	Basin	0.06	2.20	1.43	1.33	4.07	5.14
	California	0.03	0.11	0.12	0.33	1.31	1.88
	Northwest	0.03	0.50	0.23	1.10	2.10	2.91
	Rocky Mtn	0.53	5.31	4.90	6.40	11.88	10.33
	Southwest	-0.19	9.60	2.26	7.80	14.44	18.59
C	Total	0.45	17.71	8.95	16.95	33.79	38.85
	Increase	5%	34%	16%	21%	19%	17%
D	Basin	0.17	2.89	2.48	2.15	6.42	6.02
	California	0.03	0.13	0.21	0.30	1.27	1.50
	Northwest	0.04	0.74	0.77	1.62	2.60	2.68
	Rocky Mtn	0.62	4.34	2.95	4.07	8.72	8.13
	Southwest	0.35	8.13	3.89	7.38	12.80	15.65
D	Total	1.20	16.23	10.30	15.52	31.81	33.98
	Increase	13%	31%	18%	19%	18%	15%

Nuclear Availability	Region	Scenario					
		1	2	3	4	5	6
A	Basin	0.92	7.05	7.91	11.71	29.98	35.61
	California	0.02	0.71	0.29	0.67	3.79	9.01
	Northwest	3.77	12.69	5.62	6.77	23.91	25.42
	Rocky Mtn	2.25	11.58	23.07	28.54	48.35	57.52
	Southwest	2.41	19.92	18.80	33.82	73.65	95.02

Generation Mix of the entire year

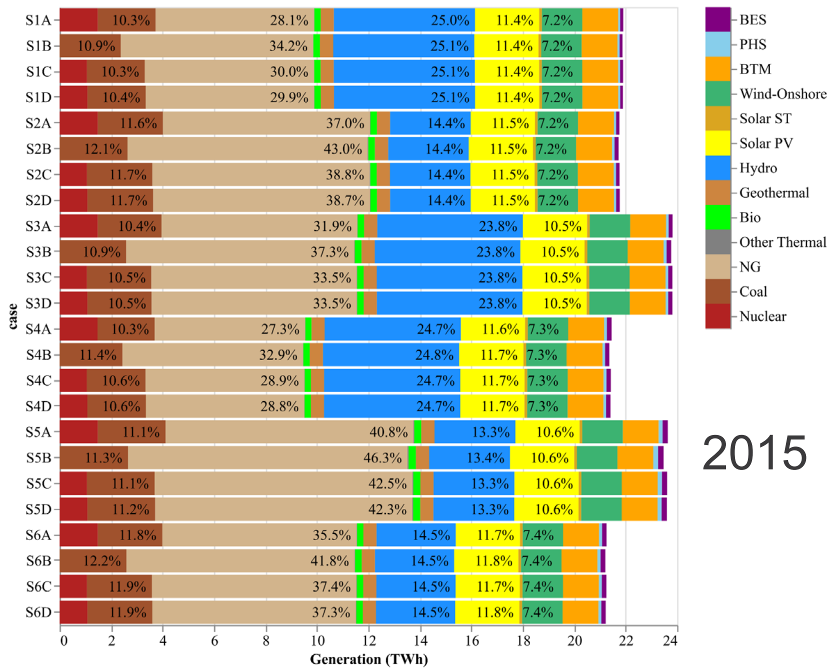
- Nuclear and nuclear are mostly replaced with NG, causing more green gas emissions
- The curtailment of solar and wind generation slightly decreases when nuclear and hydro power availability is reduced.



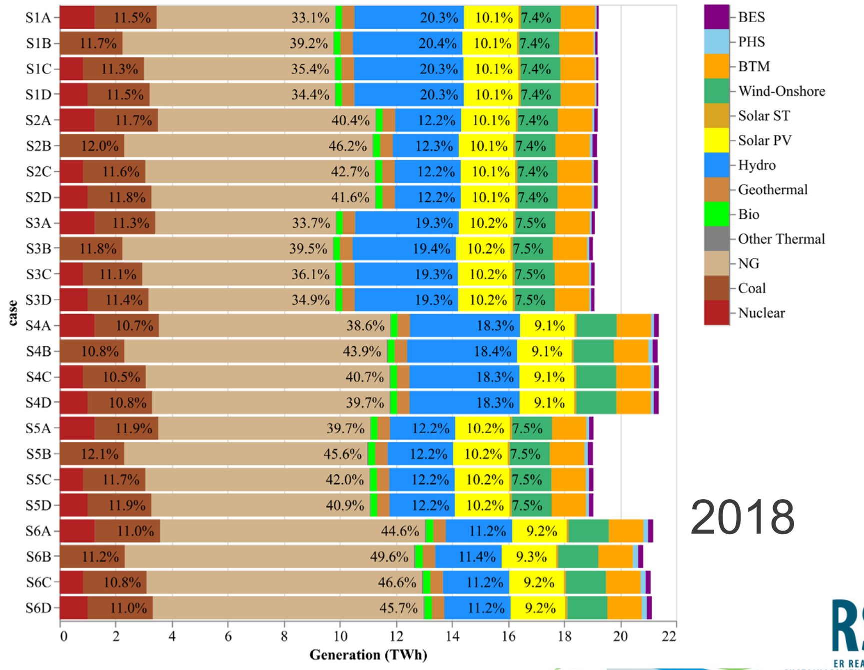


One week generation Mix during heatwave

- The 2015 heat wave effect is expected during the period from 2030-06-25 to 2030-07-02
- The 2018 heat wave effect is expected during the period from 2030-07-22 to 2030-07-28
- Nuclear is mostly replaced with NG, and Scenarios 5 and 6 exhibit a larger dependency in NG due to loss of hydro
- The curtailment of solar and wind generation slightly decreases when nuclear and hydro power availability is reduced.

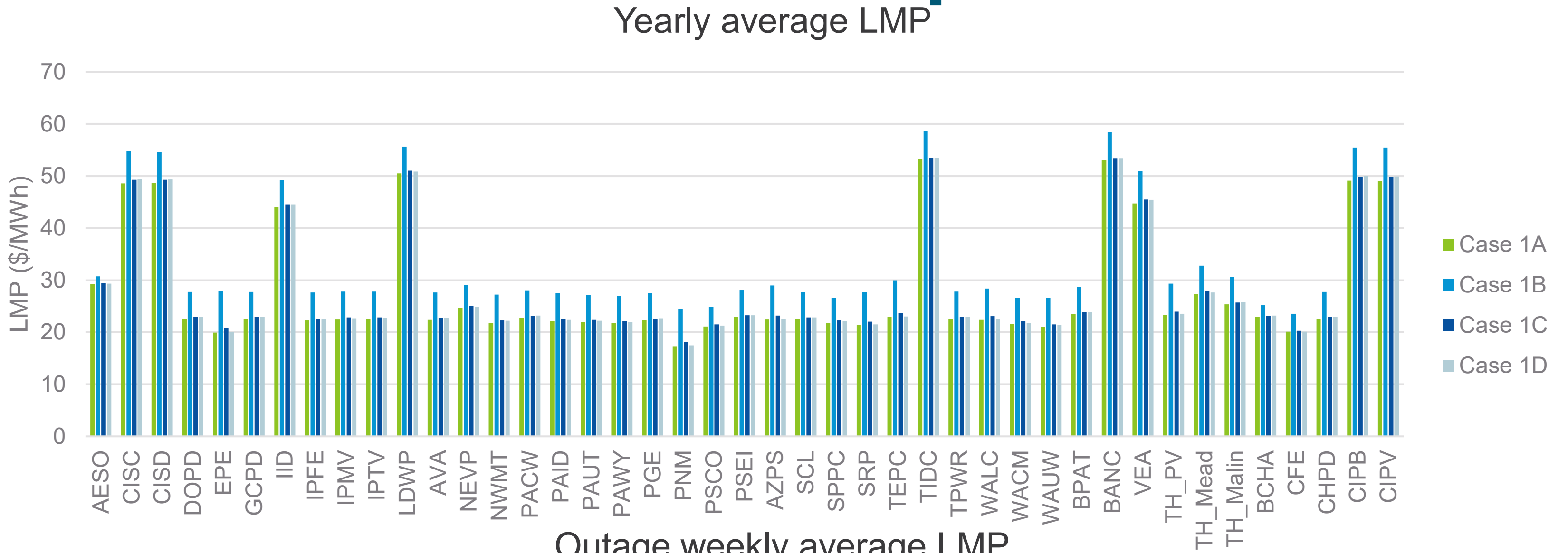


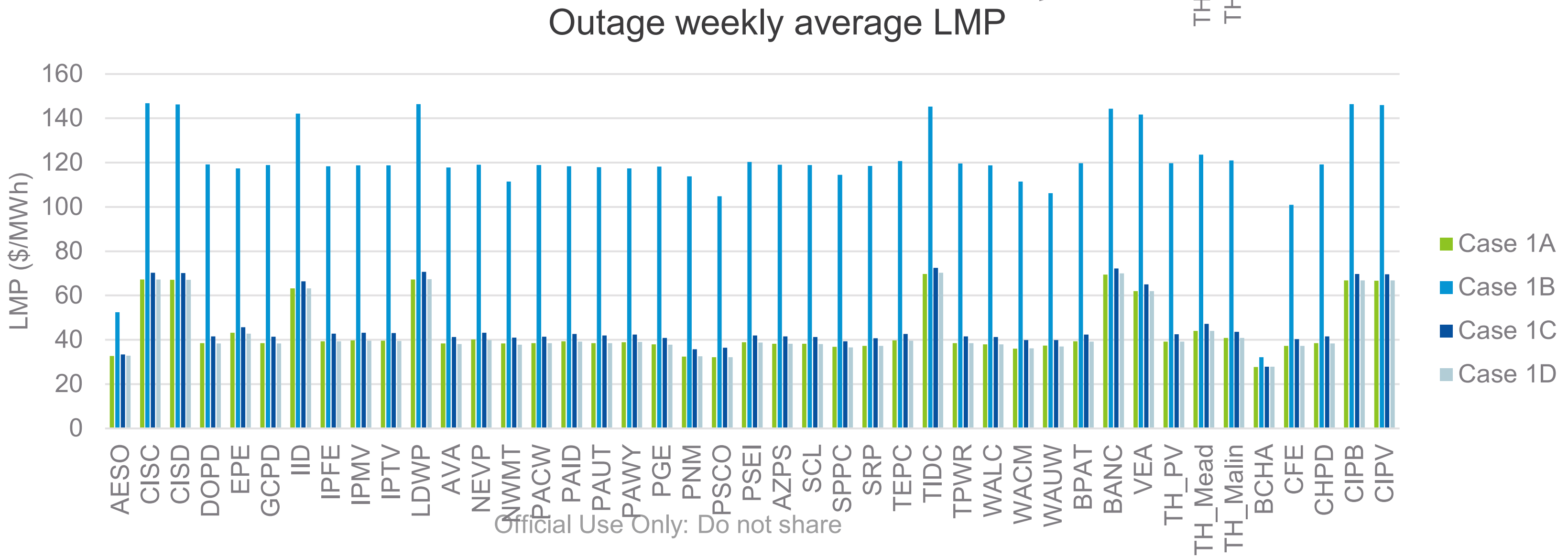
2015



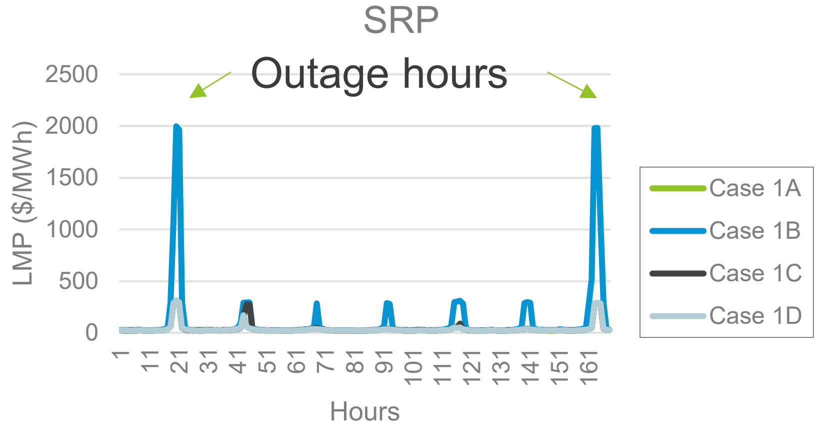
2018

Scenario 1 Cases Comparison: LMP





Weekly LMP during outage (8/29 – 9/4)



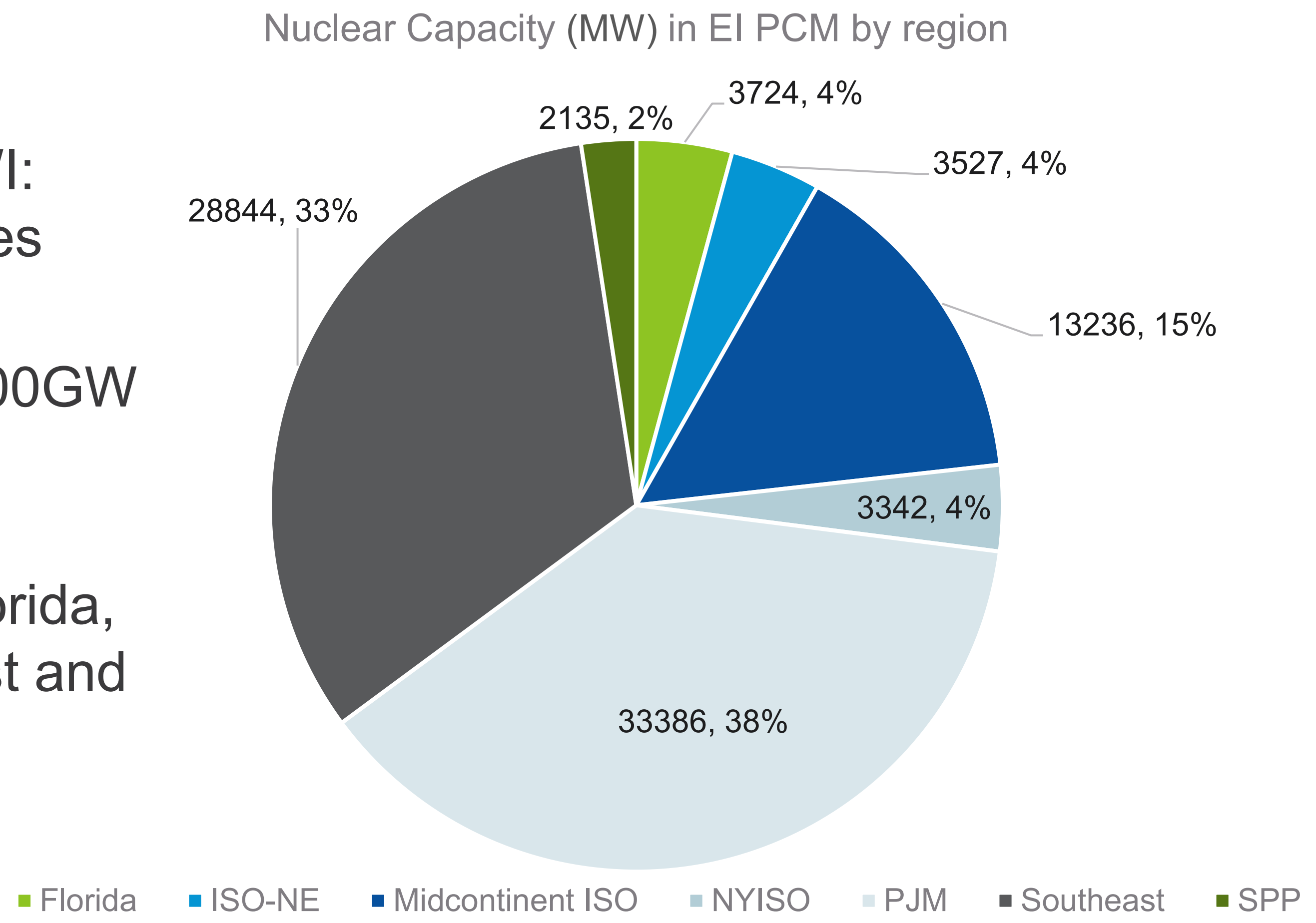
- Nuclear units shut down (Case 1B) leads to higher LMP, even reaches 2000 $/MWh in *SRP/CIPV/BPAT* during the outage hours
- Extended maintenance (Case 1C and 1D) doesn't increase unserved load but incur slightly higher LMP costs in most areas

Summary/Key takeaways on WI

- Historical NRC data shows that the majority of generation units in nuclear power plants are operating at full capacity as base load units, with bi-annual or 18-month cycles with several weeks of down time for maintenance/refueling
- PCM simulations shows that in the Western Interconnect, unplanned nuclear retirements would create:
  - unserved load during peak load summer days,
  - higher LMP in the retirement area as nuclear generation replaced by high marginal cost gas units,
  - overall higher generation cost compared to the business as usual case
  - shortage in reserves
  - Higher greenhouse gas emissions
- Extended nuclear maintenance leads to higher LMP, generation cost, and green house gas emissions without significantly increasing in unserved load and reserve shortage compared with base case due to relatively small% percentage of total generation capacity in WI is nuclear

2025 EI PCM

- Eastern Interconnection Area:
  - A much larger system compared with WI: ~95k nodes and ~119k transmission lines (~22k nodes and ~26k in WI)
  - The EI has 86 unclear units and over 100GW installed capacity including Canadian generators (6 units, 7.6 GW in WI)
  - Focus on 7 regions rather than BAs: Florida, ISO-NE, MISO, NYISO, PJM, Southeast and SPP
  - Scenario development similar to WECC



Installed capacity: WI vs EI

Type	WI ADS 2030		EI 2025	
	Capacity (MW)	Percentage (%)	Capacity (MW)	Percentage (%)
Coal	14,975	5.77	100,559	12.26
Nuclear	8,175	3.15	88,194	10.75
Gas	78,489	30.27	362,486	44.18
Other	37,412	14.43	93,915	11.45
Hydro	49,761	19.19	51,138	6.23
Wind	31,188	12.03	78,774	9.60
Solar	39,331	15.17	45,480	5.54
Peak load	152,850	-	575,520	-
Total	259,331	100.0	820,546	100.0
Total controllable resources	139,051	53.62	645,154	78.62
Over install	106,480	69.66	245,026	42.57
Over install controllable	(13,799)	(9.03)	69,634	12.10

EI has approximately 12% installed capacity of controllable units above its peak base load, while WI has about 9% below its peak base load.
Consequently, this leads to greater challenges for WI in flexibly adjusting its supply to meet reserve and energy demands

Nuclear Outage Scenarios for EI PCM Simulations

Base Case: EI 2025 PCM case modified from 2031 PNNL EI PCM					
Scenario	**Event**	**Nuclear Outage**	**EI Case**	**Load**	**Wind/Solar**
7	Extended Nuclear Maintenance Outage	Case 7A: Base Case* (Business as usual) Case 7C: Nuclear Maintenance Schedule A Case 7D: Nuclear Maintenance Schedule B	EI 2025 PCM	EI 2025 PCM	2025 EI PCM
8	Heatwave 1 (2015 heatwave)	Case 8A: Base Case (Business as usual) Case 8C: Nuclear Maintenance Schedule A Case 8D: Nuclear Maintenance Schedule B	EI 2025 PCM	EI 2025 PCM using TELL 2015 weather profile	2025 EI PCM
9	Heatwave 2 (2018 heatwave)	Case 9A: Base Case (Business as usual) Case 9C: Nuclear Maintenance Schedule A Case 9D: Nuclear Maintenance Schedule B	EI 2025 PCM	EI 2025 PCM using TELL 2018 weather profile	2025 EI PCM

*Cases 7B, 8B, and 9B (fully unavailability of nuclear) are not applicable in EI system
*Nuclear Maintenance Schedules A: using expected BAU schedule in year 2025, plus additional 90 days as extended maintenance outage
*Nuclear Maintenance Schedules B: using expected BAU schedule in year 2026, plus additional 90 days as extended maintenance outage

***Base Case: EI 2025 PCM leverages available databases to adjust transmission, load, and generation capacity to reflect 2025 system conditions.**

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Nuclear Maintenance Schedules in EI

Maintenance Schedule Cases

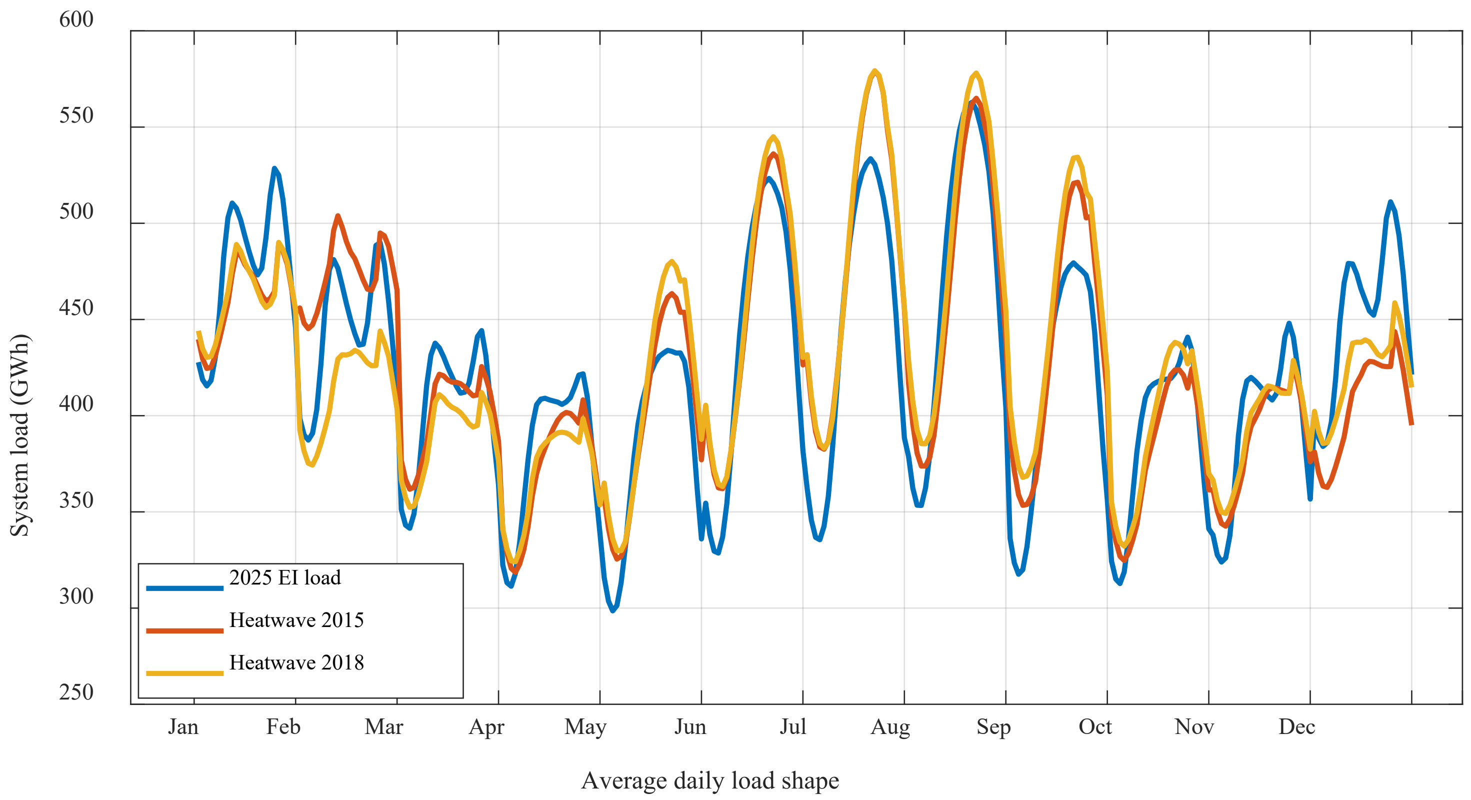
i. A: business as usual (44.7 TWh generation loss)
ii. C: extended schedule 2025 (124.8 TWh generation loss)
iii. D: extended schedule 2026 (146.5 TWh generation loss)

MISO, PJM, and Southeast have different generation loss in these two extended maintenance schedules since most nuclear units' maintenance cycles are from 18 to 24 months

Nuclear Resources in EI			Extended Schedule in 2025				Extended Schedule in 2026			
Region in EI PCM	Count of units	Capacity (MW)	Units scheduled in Spring	Units scheduled in Fall	Units w/o schedule	Energy generation loss (TWh)	Units scheduled in Spring	Units scheduled in Fall	Units w/o schedule	Energy generation loss (TWh)
Florida	4	3,724	1	2	1	5	1	1	2	7.8
ISO-NE	3	3,527	0	2	1	4.1	1	0	2	9.5
MISO	14	13,236	3	3	8	21	5	3	6	23
NYISO	4	3,342	1	2	1	1.8	1	0	3	7.6
PJM	31	33,386	12	7	12	52.2	10	8	13	48.3
Southeast	27	28,844	8	9	10	37.5	8	6	13	48.4
SPP	2	2,135	1	1	0	3.2	0	1	1	1.9
Total	85	88,194	26	26	33	124.8	26	19	40	146.5

Load in EI

- Heatwave 2015
- Heatwave 2018



Cases Comparison: Unserved Load

Unserved load

	Nuclear Availability	A			C			D		
	Scenario	7	8	9	7	8	9	7	8	9
Region	Florida	-	-	-	-	-	-	537	537	537
	ISO-NE	-	-	-	-	-	-	-	-	-
	MAPP (Non-MISO)	-	-	-	-	-	-	446	434	447
	MISO	-	-	-	-	-	-	53	202	168
	NYISO	-	-	-	-	-	-	-	-	-
	PJM	-	-	-	-	-	-	-	-	-
	SPP	-	-	-	-	-	-	34	42	36
	Southeast	-	-	-	-	-	-	-	-	-
System	Total	-	-	-	-	-	-	1,069	1,215	1,188
	N. homes year	-	-	-	-	-	-	102	116	113
	N. homes month	-	-	-	-	-	-	1,221	1,388	1,358

- The system can supply its load under BAU nuclear maintenance A and extended maintenance C nuclear normal weather conditions or heatwaves.
- The nuclear availability D has the largest amount of nuclear unavailability for the month of June and will cause unserved load up to 1300 homes.
- The heat wave scenario increases slightly the amount of unserved load

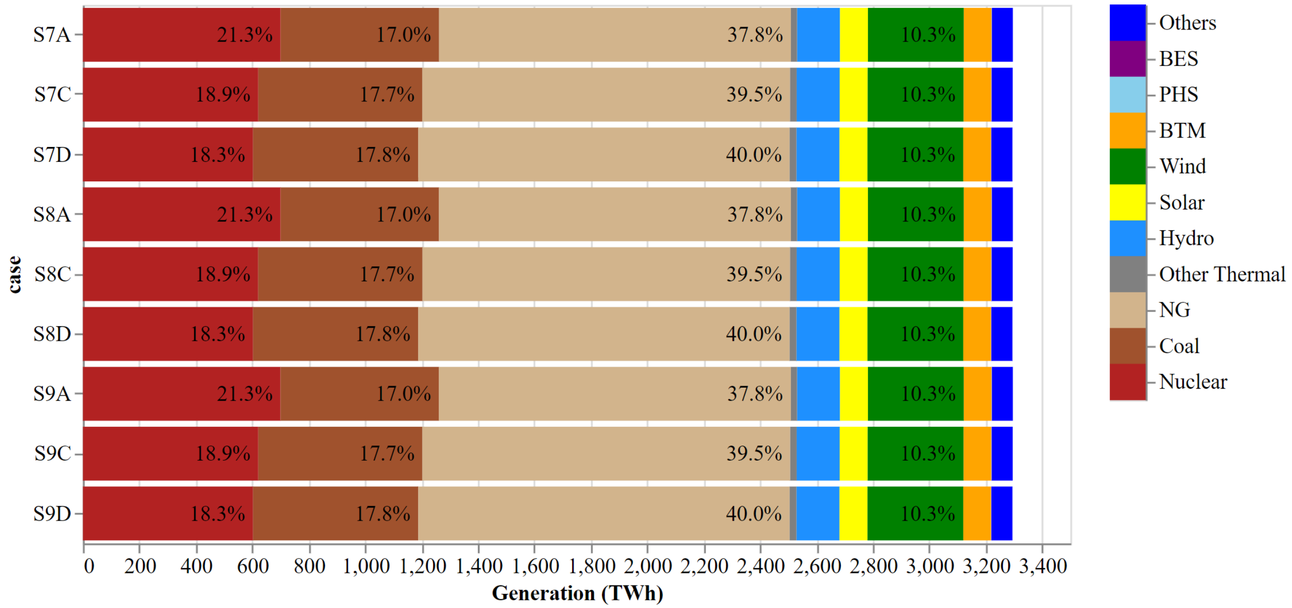
Cases Comparison: Unmet Reserves

Number of hours the unmet *spinning reserve* by violation severity levels (VSL).

Nuclear Availability	Scenario	SPP	Southeast	Florida	Midcontinent ISO	PJM	Total
A	7	3	1	0	0	0	4
	8	3	0	0	0	0	3
	9	0	0	0	0	0	0
C	7	20	17	13	16	0	66
	8	20	18	13	17	0	68
	9	20	18	13	17	0	68
D	7	31	28	24	26	8	117
	8	31	28	24	27	8	118
	9	31	28	24	27	8	118

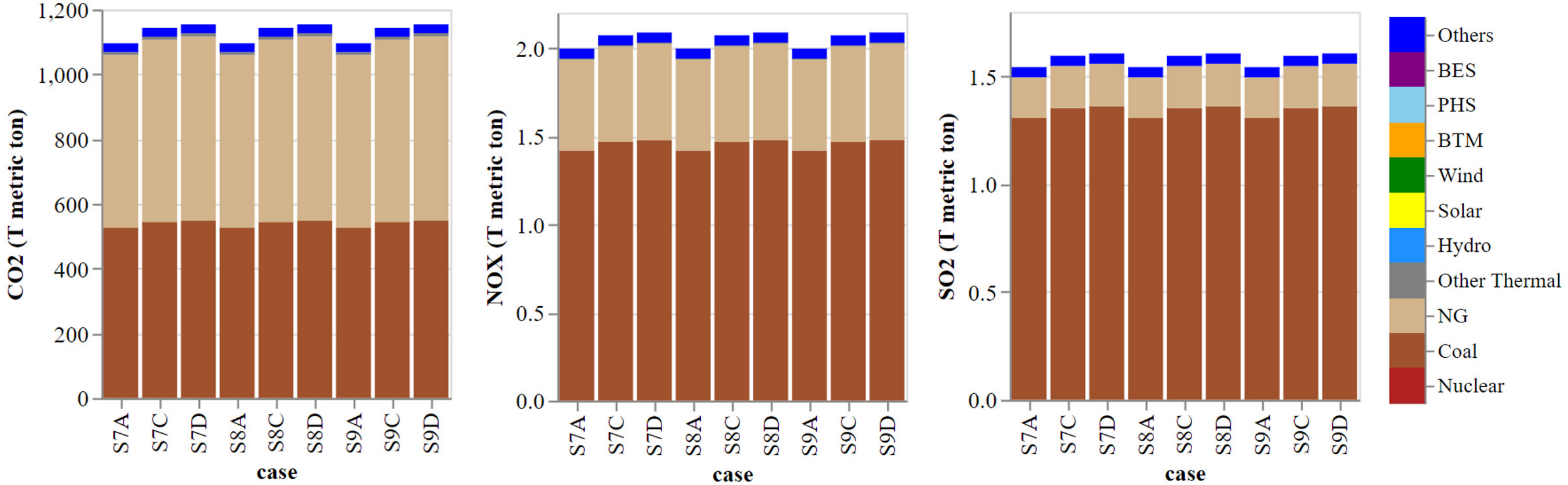
- The number of hours the unmet reserve are calculated by hours multiply violation severity levels (VSL)
- Different VSL levels of "Lower", "Moderate", "High", and "Severe" by considering the weight of 1, 2, 3, and 4
- The nuclear availability has a larger implication on the number of hours with unmet spinning reserve than the heat wave scenarios, and maintenance schedule D has a higher impact on the system compared with schedule C

Cases Comparison: Generation Mix and Emissions

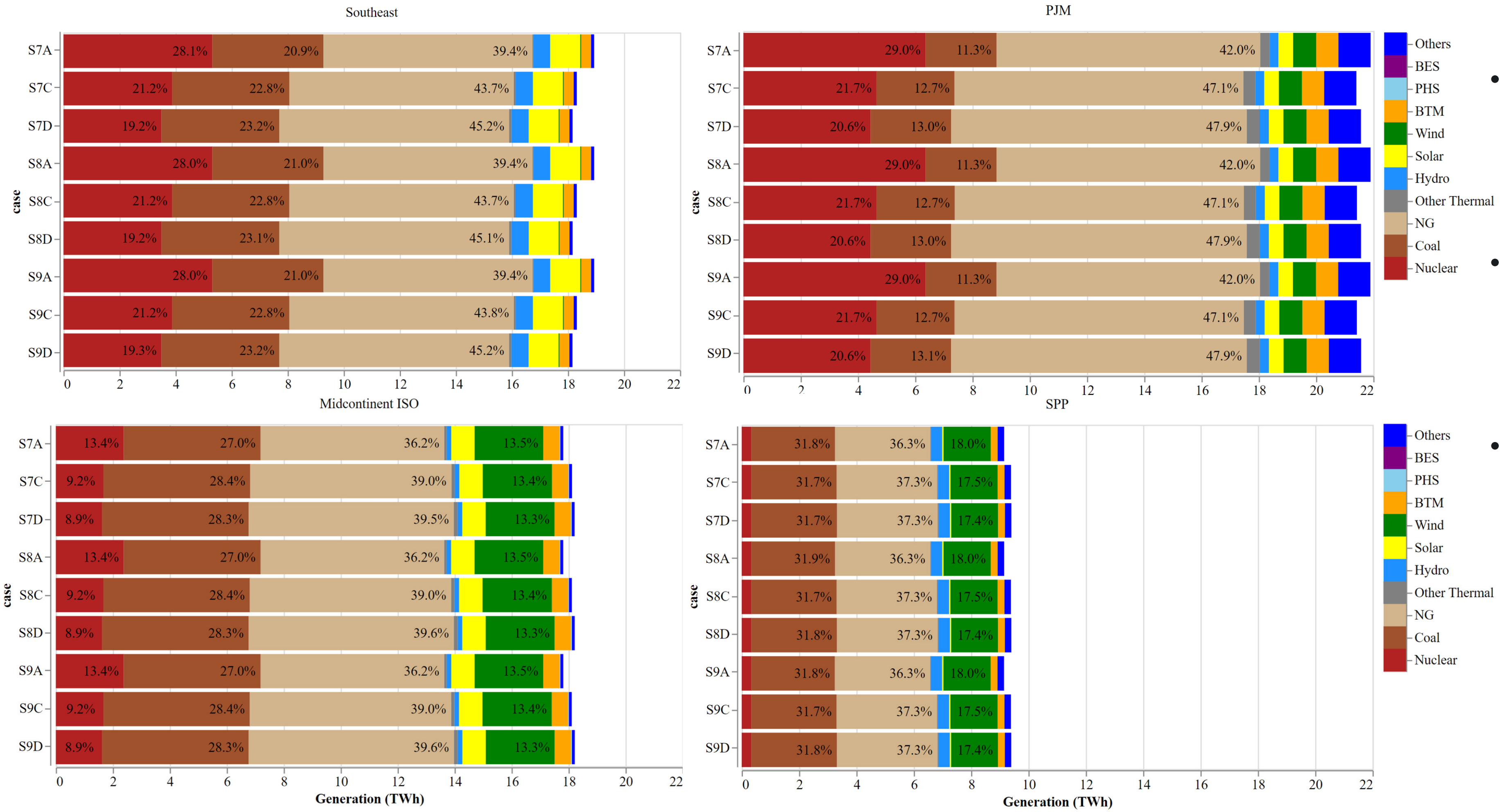


- The extended nuclear maintenance Scenarios C and D present as expected reduced nuclear generation, which is mostly replaced by thermal units, resulting in increased emissions

- The solar and wind generation remain the same despite the nuclear generation and load demand are changed



Cases Comparison: Generation Mix and Emissions of Southeast, PJM, MISO, and SPP



- Total generation of Southeast and PJM region decreases in Scenarios C and D, indicating extra energy import needed from other regions during extended maintenance event
- Total generation of Midcontinent ISO region increases in Scenarios C and D, indicating additional energy export to other regions during extended maintenance events.
- Other several regions, e.g., SPP, increase thermal generation to support other regions during extended maintenance event

Summary/Key takeaways on EI

The EI is a more robust system compared to WI due to a larger installed capacity of controllable units in relation to their peak base load. In the EI, the reduction of nuclear availability and heat wave conditions would create:

- Increased shortage in reserves
- Slightly increased unserved load during peak load summer days in several regions
- Higher generation cost compared to the BAU case as nuclear generation is replaced by high-marginal cost thermal units and more greenhouse gas emissions
- Changed generation mix and total energy generated on major regions in EI, indicating the nuclear availability's impact on interregional energy imports/exports.
- The extended nuclear availability schedule C/D demonstrated to be more impactful to stress the EI than the heat wave events.
- The EI during nuclear availability schedule D is the only type with unserved energy. The unmet reserves hours increase significantly with nuclear availability C/D.

What's next

- Hydrogen – Hight temperature electrolysis flexibility
- Consideration of reserve market and operational capability

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Sustaining National Nuclear Assets

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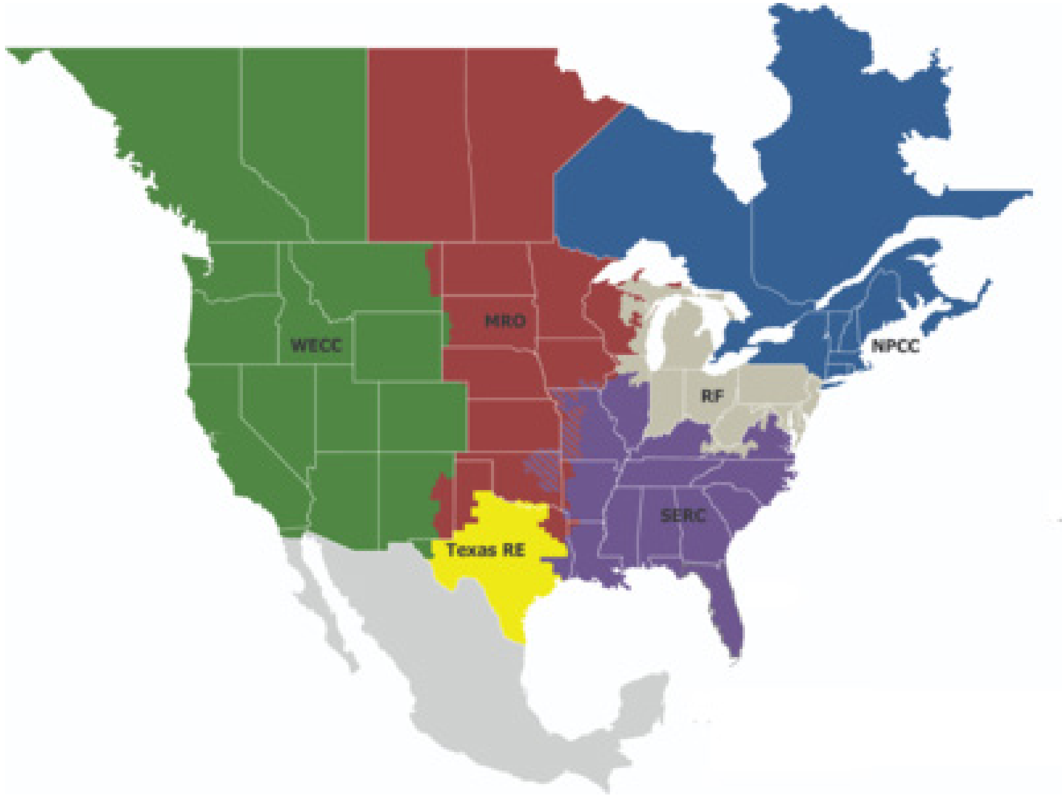
Total and Nuclear installed Capacity by NERC Region

NERC Region	Total Capacity GW	Nuclear (GW)	Nuclear %
RFC	249	35	14
NPCC*	82	10	12
SERC	370	42	11
MRO	142	5	3
Eastern Interconnect	850	91	11
TRE	113	5	5
WECC	234	8	3



* NPCC Not including Ontario or hydro-Quebec

NRC Nuclear Power Plants Outage/Maintenance Analysis

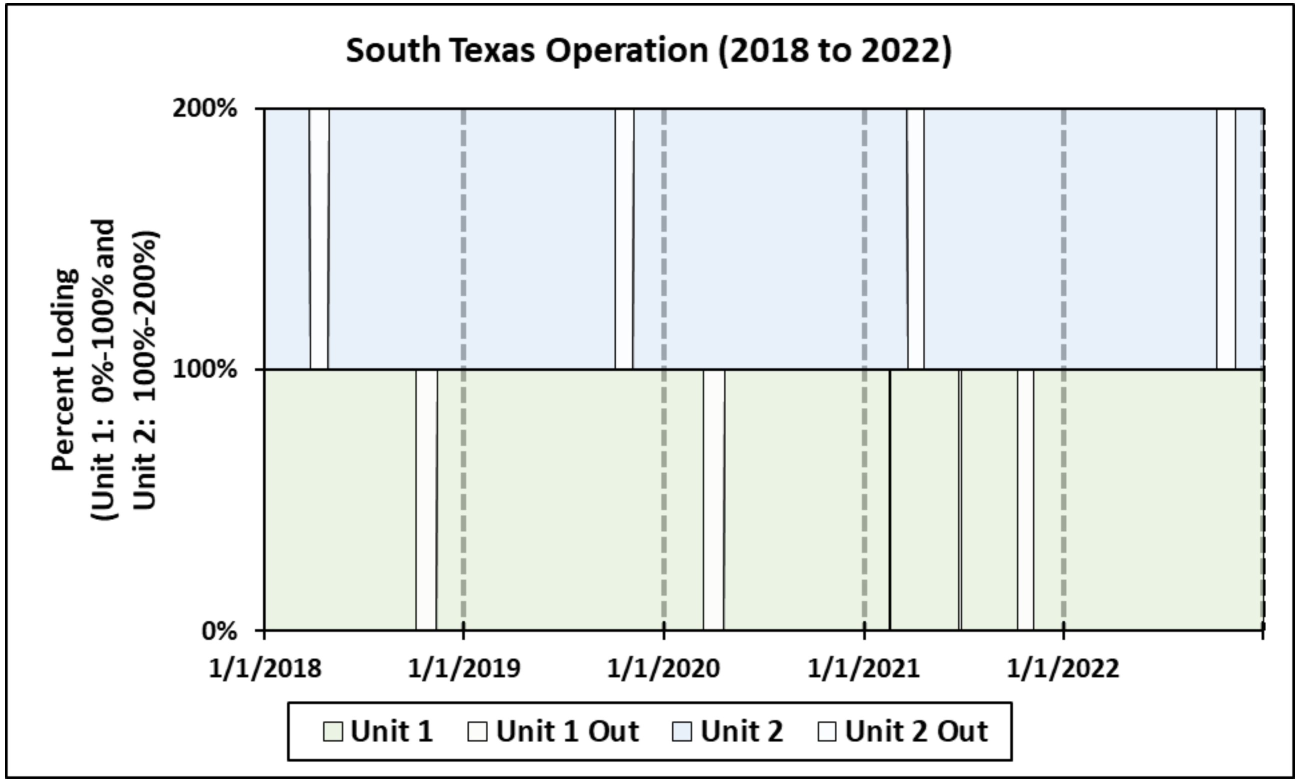
- Re-fueling drives nuclear maintenance. Nuclear maintenance pattern can be determined based on historic operation
- Historic daily operation is obtained from NRC “Power Reactor Status Report”. It show reactor loading.
  - https://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/index.html
- The NRC data was processed to determine the maintenance cycle:
  - Nuclear units re-fueling/maintenance cycles are typically on an eighteen-month or two-year cycle (Data from 2005 through 2022 was processed)
  - Maintenance event was identified as either spring, fall, or none for each year
- Nuclear maintenance cycle was extended from 2022 to 2027 (spring, fall, or none)
- The average start day of the year and duration was calculated for spring and fall events

Outage due to Maintenance Examples

- Re-fueling drives nuclear maintenance
- Nuclear re-fueling are typically on an eighteen month or two-year cycle
- South Texas is on an eighteen month

Maintenance Cycle			
	18 Month	2 Year	
Yr n	Spring	Spring	Fall
Yr n+1	Fall	None	None
Yr n+2	None	Spring	Fall
Yr n+3	Spring	None	None

South Texas Re-Fueling Cycle					
	2018	2019	2020	2021	2022
Unit 2	Spring	Fall	None	Spring	Fall
Unit 1	Fall	None	Spring	Fall	None



Data from NRC Reactor Daily Status Report

Note: Unit 1 had two forced outage events in 2021