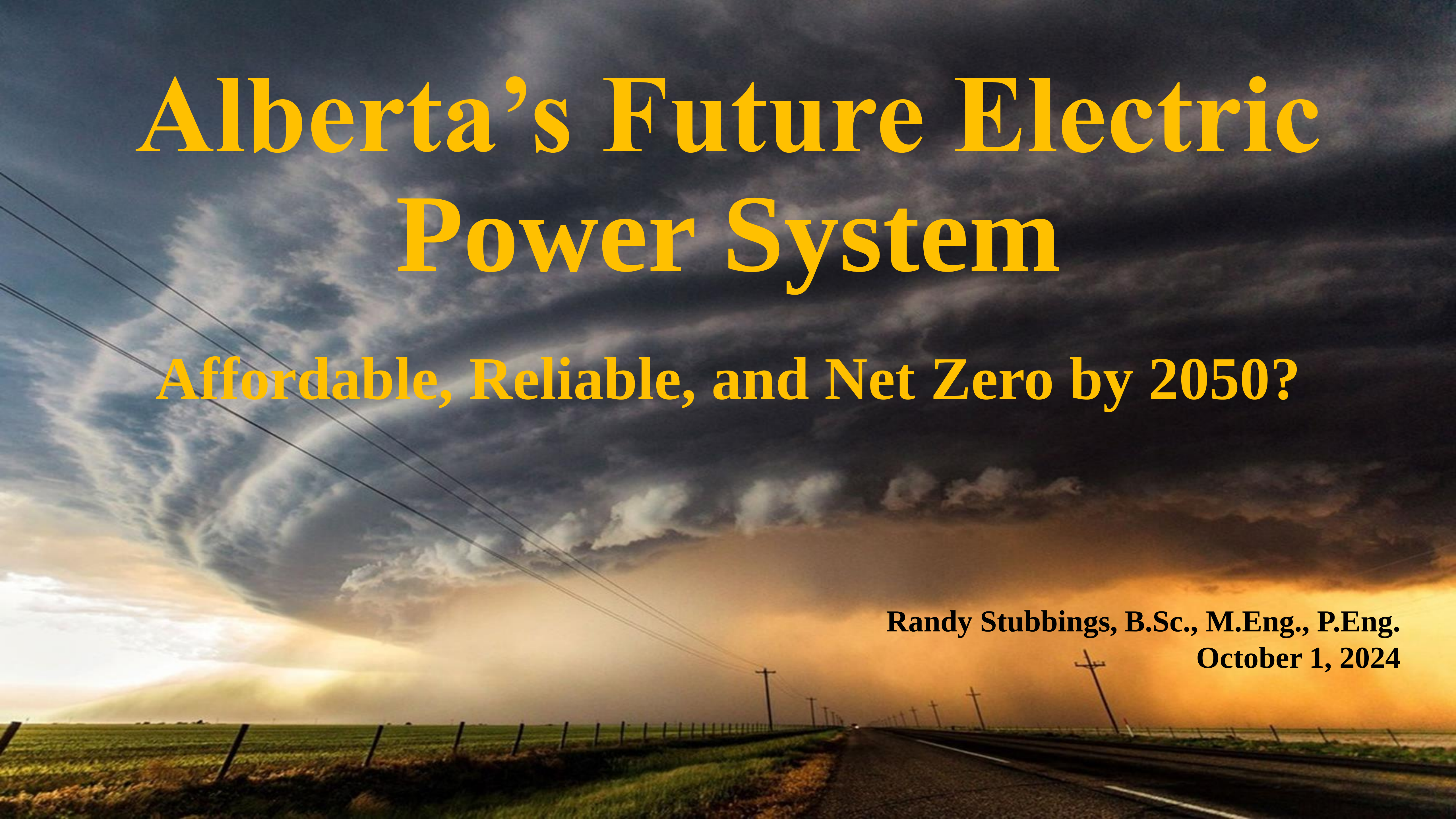
NET ZERO AND THE FUTURE POWER GRID

EXAMINING AFFORDABILITY, RELIABILITY AND ZERO EMISSIONS

OCTOBER 1, 2024 - 7PM
BEST WESTERN VILLAGE PARK INN
CALGARY, ALBERTA

PRESENTED BY RANDY STUBBINGS, P. ENG.



Alberta's Future Electric Power System

Affordable, Reliable, and Net Zero by 2050?

Randy Stubbings, B.Sc., M.Eng., P.Eng.

October 1, 2024

What does *net zero* mean?

- A *net zero* energy system is one that does not add to the total amount of greenhouse gases (GHGs) in the atmosphere
- *Net zero electricity* refers to the case in which electric energy is net zero but other energy systems, particularly transportation and building heating and cooling, have not reached net zero
- Carbon dioxide (CO_2) is a byproduct of the combustion of fossil fuels that is often referred to as “carbon pollution”

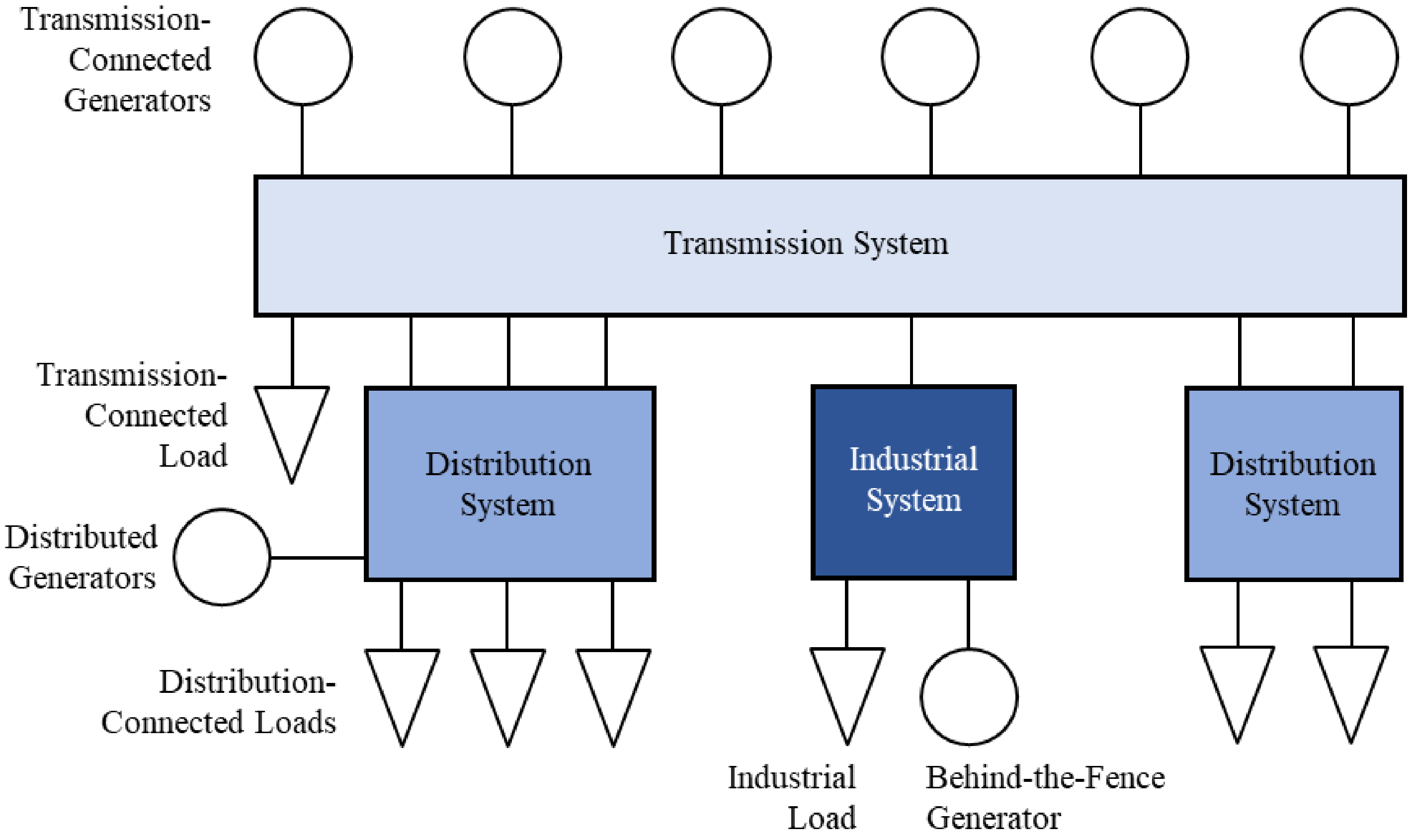
Electricity Supply and Demand

- Supply
  - domestic commercial (utility-scale) generators
  - distributed generators (e.g., rooftop solar)
  - imports (British Columbia, Saskatchewan, Montana)
- Demand
  - domestic consumers (residential, commercial, industrial, institutional, farm)
  - exports
  - transmission and distribution system losses
- Suppliers are connected to customers through transmission and/or distribution wires
  - on-site generators excepted

Major Challenges to Achieving Net Zero

- Maintaining electricity supply/demand balance given the increasing penetration of intermittent renewable generation
- Establishing the right economic conditions for dispatchable generators to stay in business
- Electrifying transportation and building energy systems
- Increasing the generation, transmission, and distribution infrastructure needed to achieve full electrification
- Getting everything designed, approved, and built in the time set by government
- **Doing all the above while keeping electricity affordable for Alberta families and businesses**

Alberta's Electric Power System

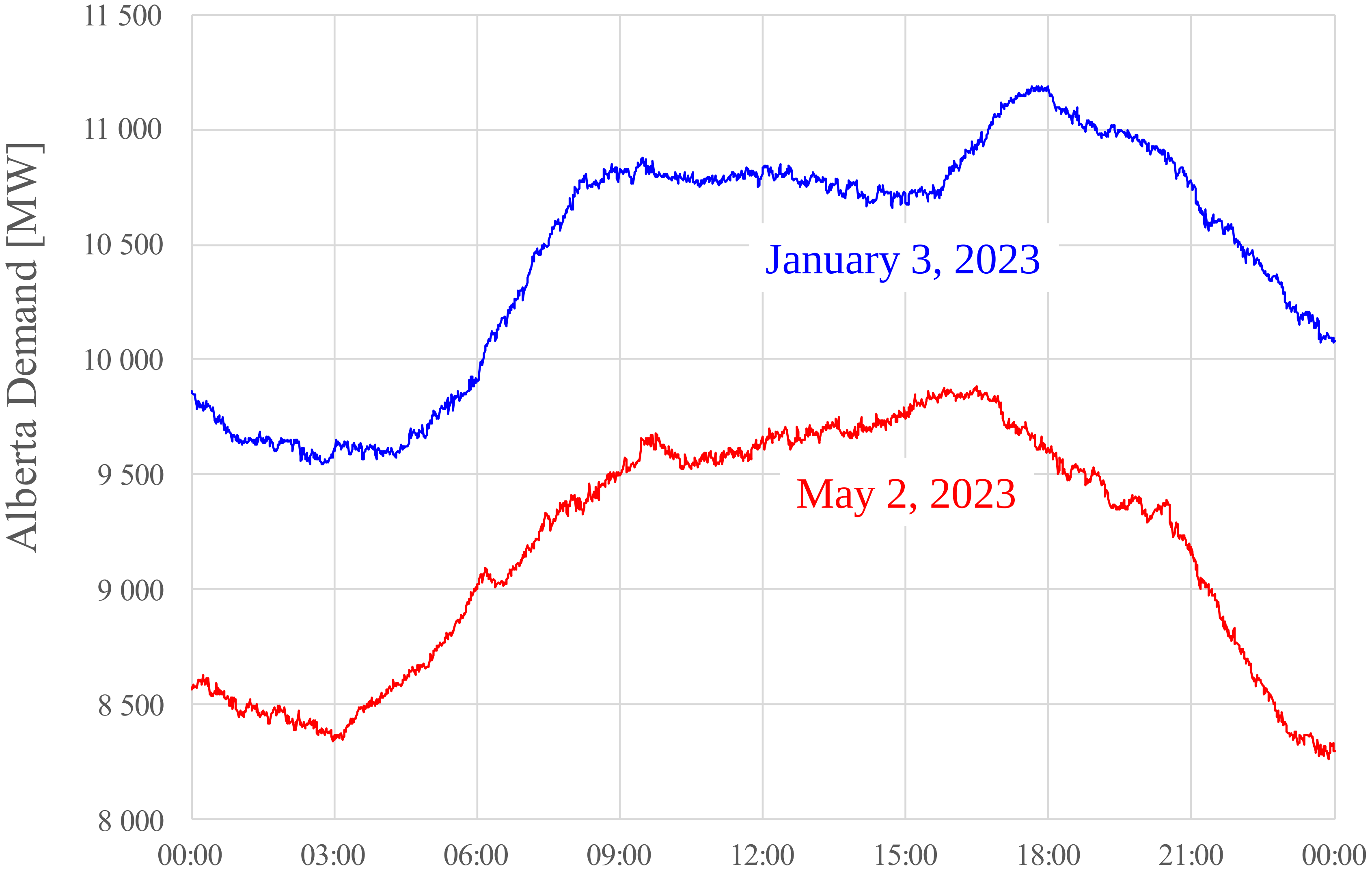


Two Critical Facts about Power Systems

- **Supply and demand must be kept in near-perfect balance at all times**
  - Imbalances can lead to blackouts and equipment damage in less than a second
  - The larger the imbalance, the more quickly problems can arise
  - Significant human resources and automated protection & control systems are dedicated to maintaining that balance
- **Power systems are planned to handle extremes, not averages**
  - "Extreme" conditions can occur over the entire system or in local areas
  - They do not always coincide with peak demand or extreme weather
  - Understanding daily, weekly, and seasonal variation is critical

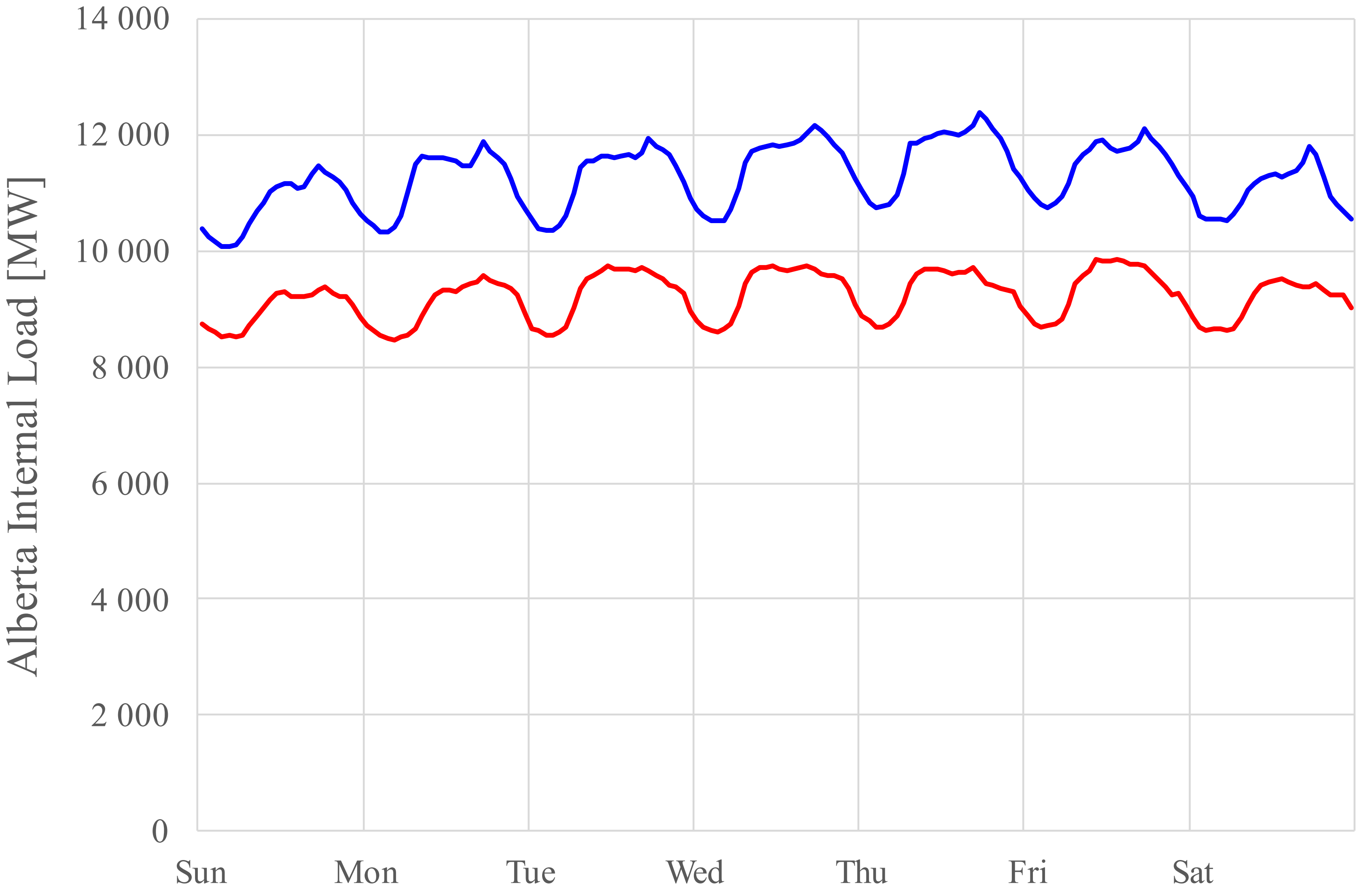
Typical Daily Demand

- Demand varies over all time scales from seconds to seasons
- Winter demand is typically higher and has a more pronounced peak at around 6 p.m.



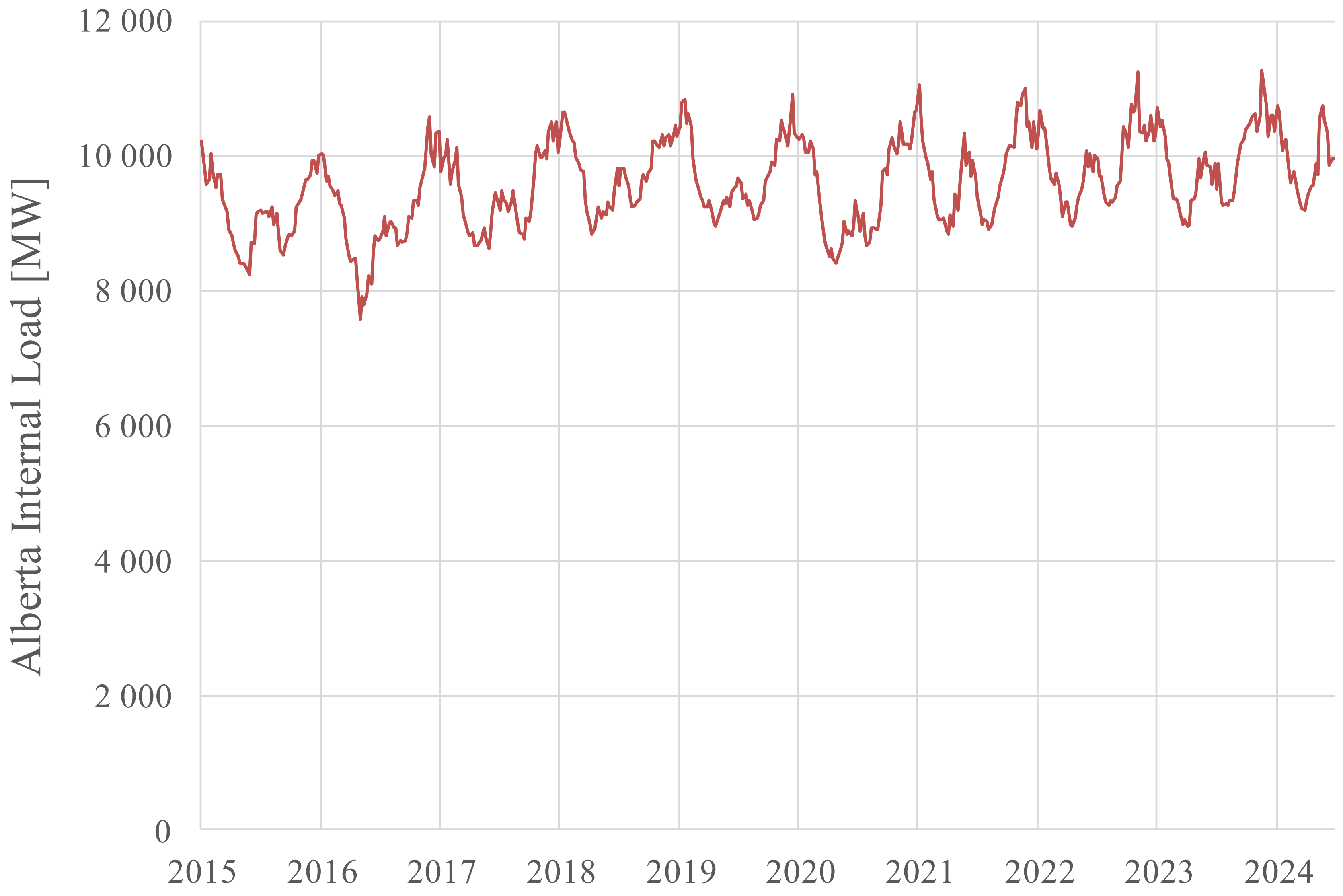
Typical Weekly Demand

- Demand is usually slightly lower on weekends
- The daily pattern is quite consistent, and therefore reasonably predictable
    - Note the "on peak" and "off peak" periods (their days are numbered)

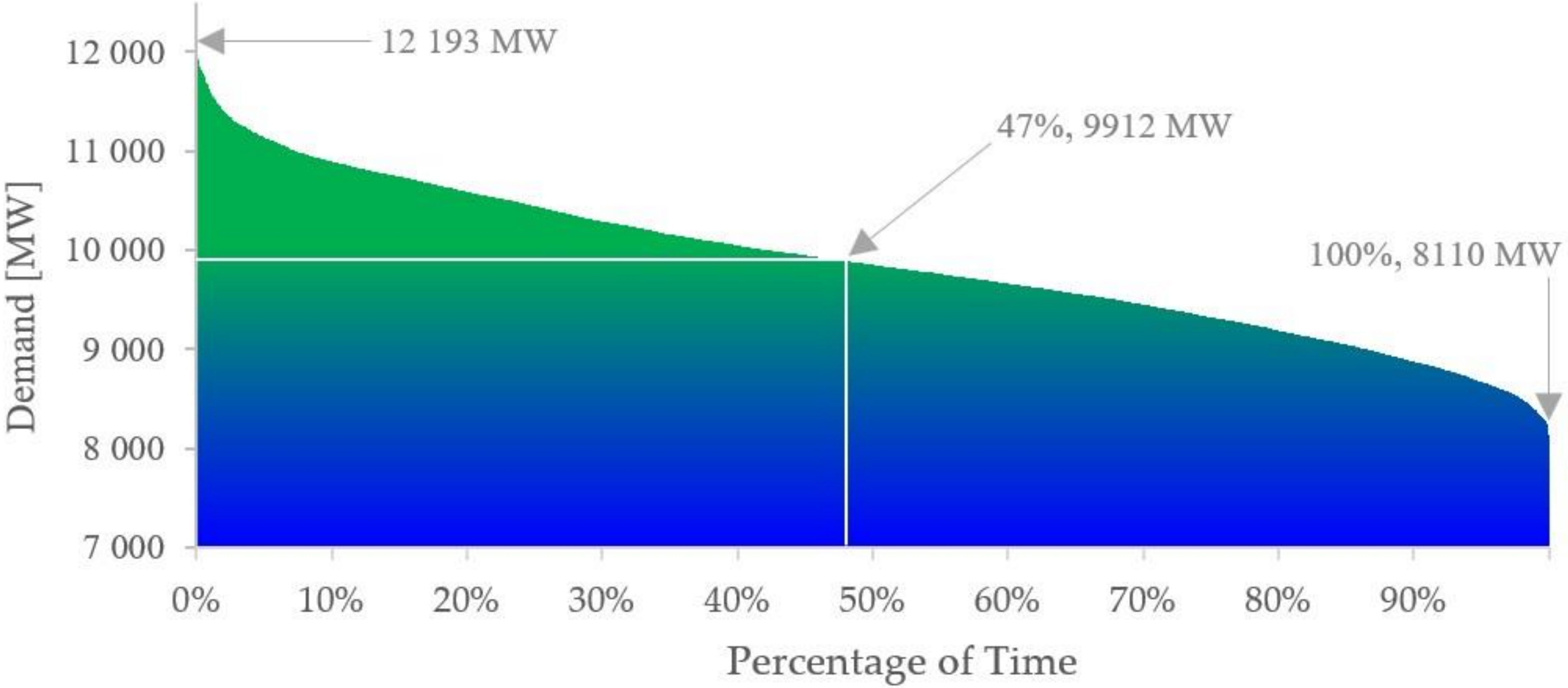


Average Weekly Demand, 2015-2024

- The pattern of high winter demand, lower spring and fall demand, and medium summer demand is also quite consistent



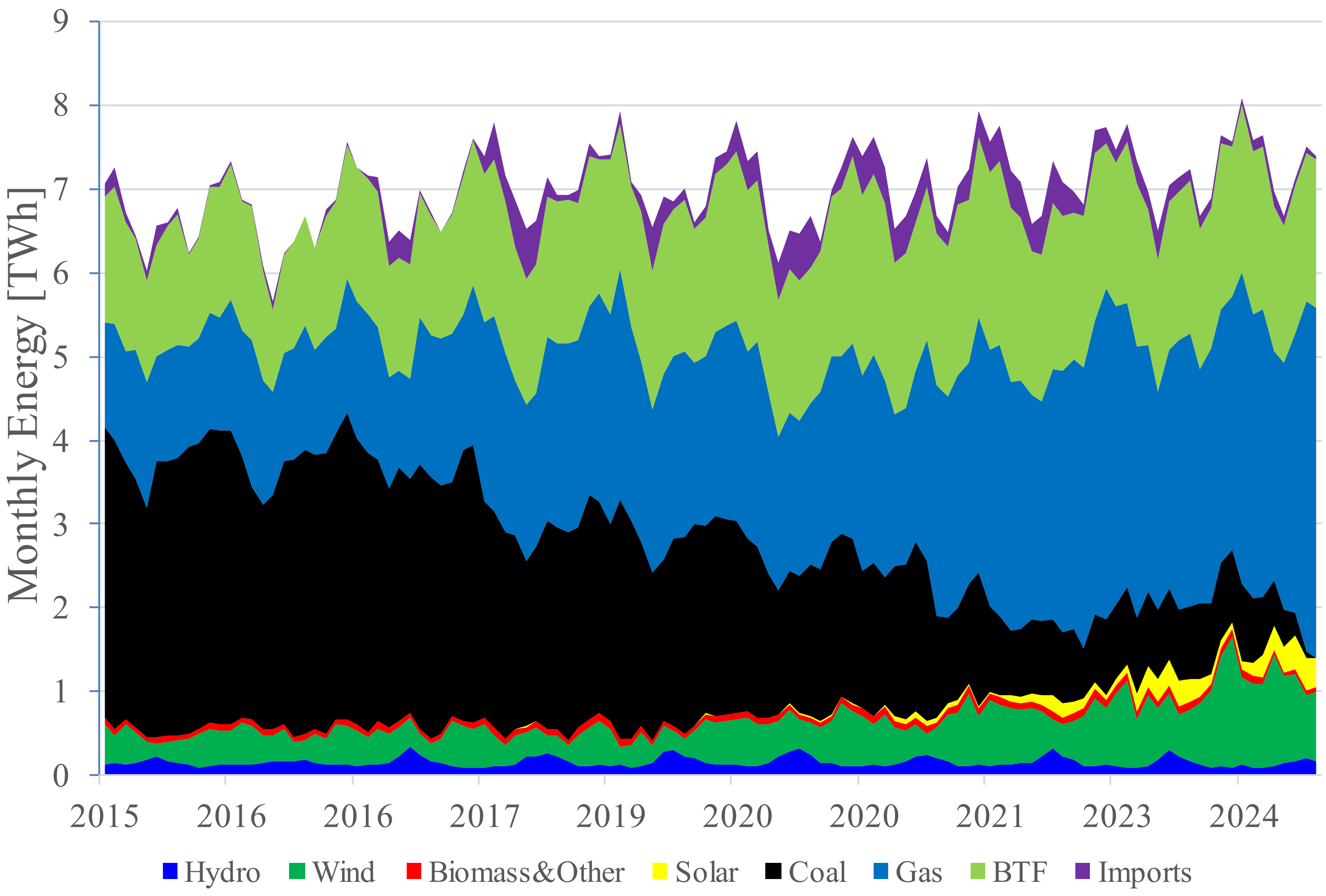
Alberta Load Duration Curve, 2023



A duration curve shows the amount of time (hours, days, percent, etc.) that a quantity was at or above some value. The white lines show that, 47% of the time, Alberta demand is at or above 9912 MW

Alberta Electric Energy Sources, 2015-2024

- Some of Alberta's coal units have been converted to burn natural gas
- The last coal unit was retired in June 2024
- Alberta has a large amount of "behind-the-fence" generation serving its large industrial load



Alberta Electric Energy Sources, 2015-2024

Fuel	Jan 1, 2015	Sep 29, 2024
Natural gas	7 143	13 218
Hydro	894	894
Energy storage*	0	190
Biomass and other	409	444
Coal and dual fuel	6 271	0
Dispatchable capacity	*14 717*	*14 746*
Wind	1 434	5 340
Solar	0	1 663
Nondispatchable capacity	*1 434*	*7 003*
Total	**16 151**	**21 749**

* Battery energy storage systems can act like generators when charged but cannot sustain their outputs indefinitely and are net energy sinks (not sources) over time. With batteries, it is important to know their *energy* capacity (MWh), not just their *power* capacity (MW).

Country	Megawatts
China	1 147 230
India	239 650
US	196 220
Japan	54 750
Indonesia	52 320
World	2 300 000

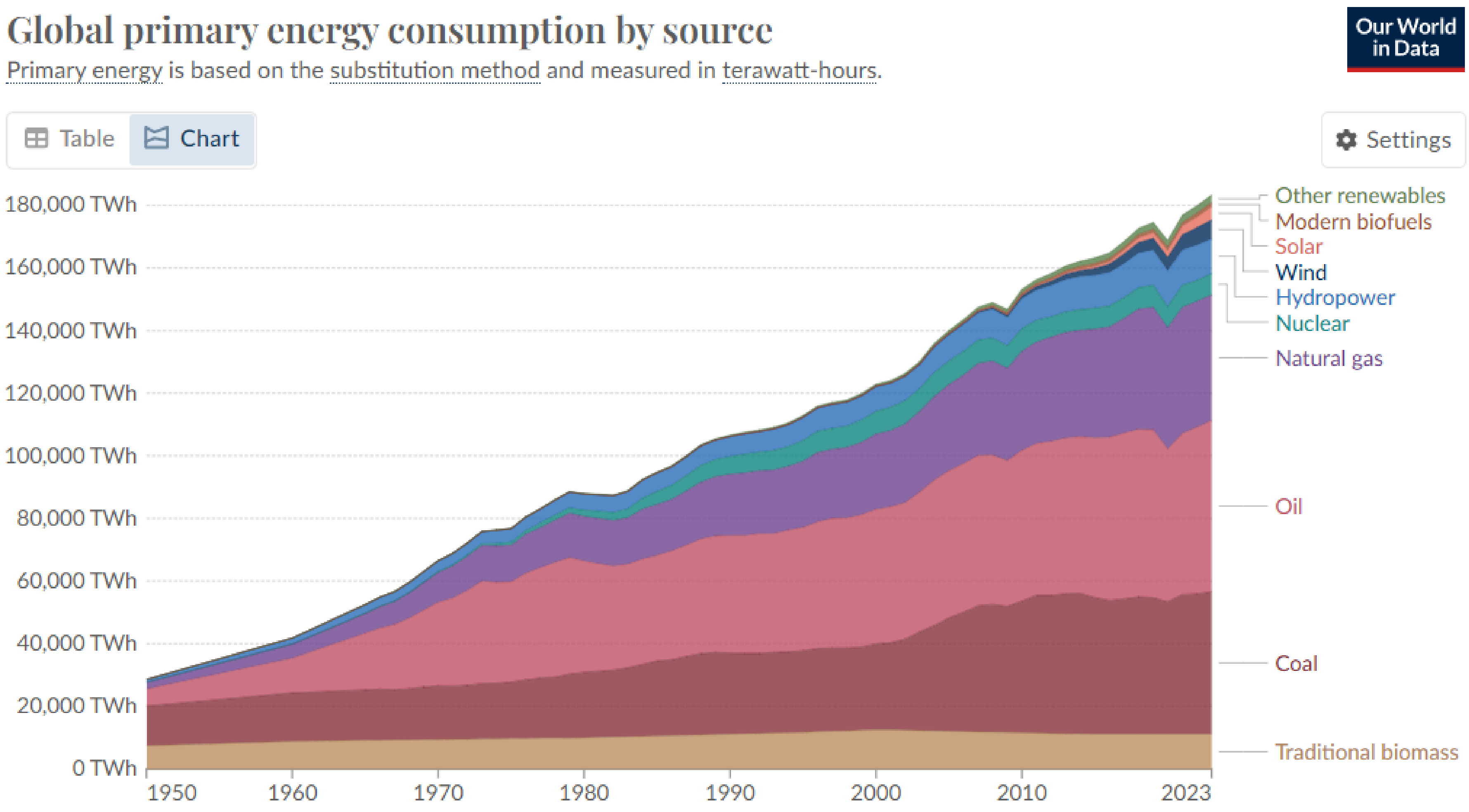
Global coal power capacity by major country 2024 | Statista

From 2015 through 2024, 627 875 MW of coal-fired power were added, 316 957 MW were retired

https://globalenergymonitor.org/projects/global-coal-plant-tracker/

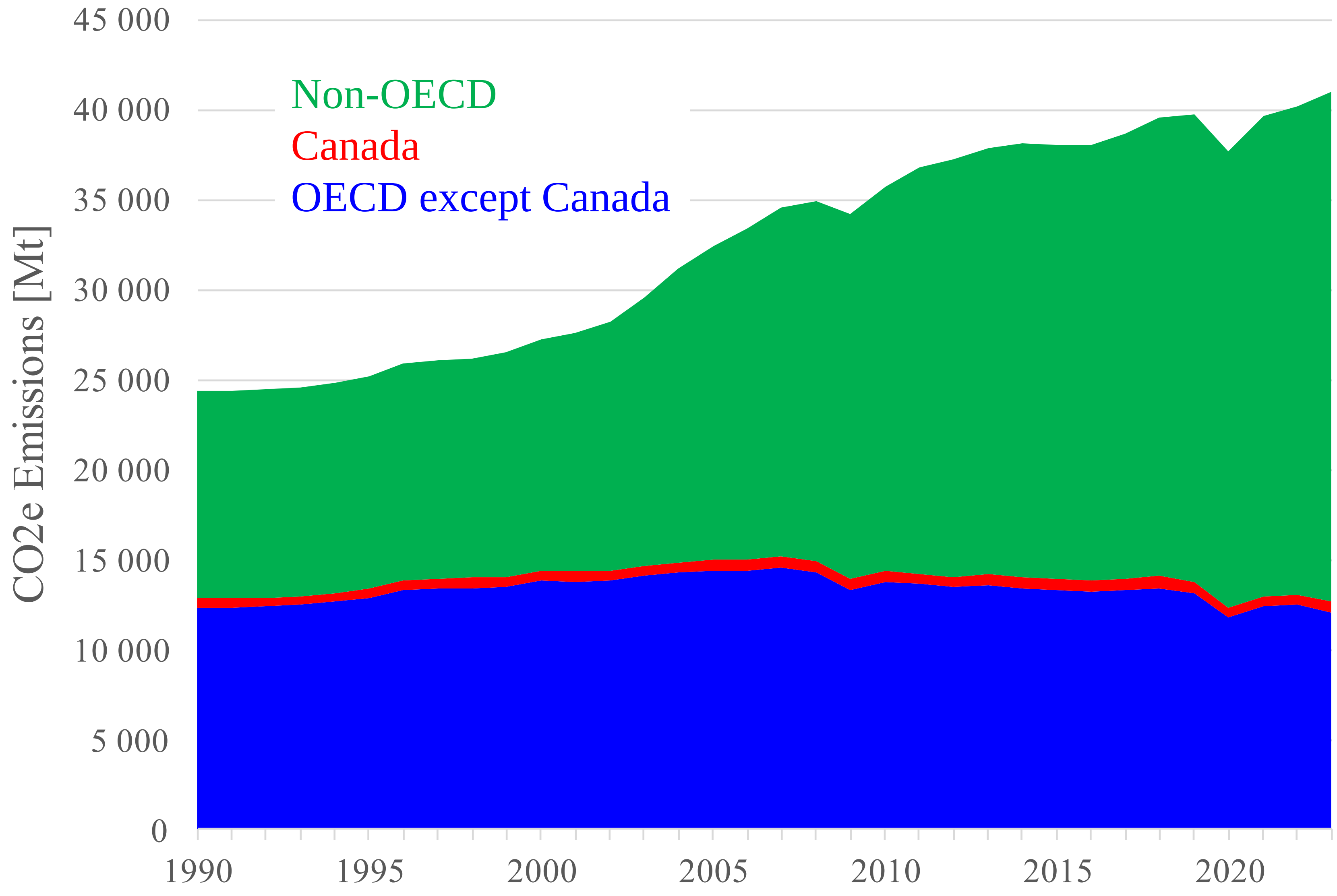
World Primary Energy Consumption by Fuel Type

- Fossil fuels (coal, oil, gas) provided 76.5% of world primary energy in 2023
- It was 78.5% in 1983 and peaked at 81.3% in 1973



CO_2e Emissions

- Canada's share of world CO_2e emissions is 1.48% and falling
- Emissions by OECD countries are also falling



https://www.energyinst.org/statistical-review/resources-and-data-downloads

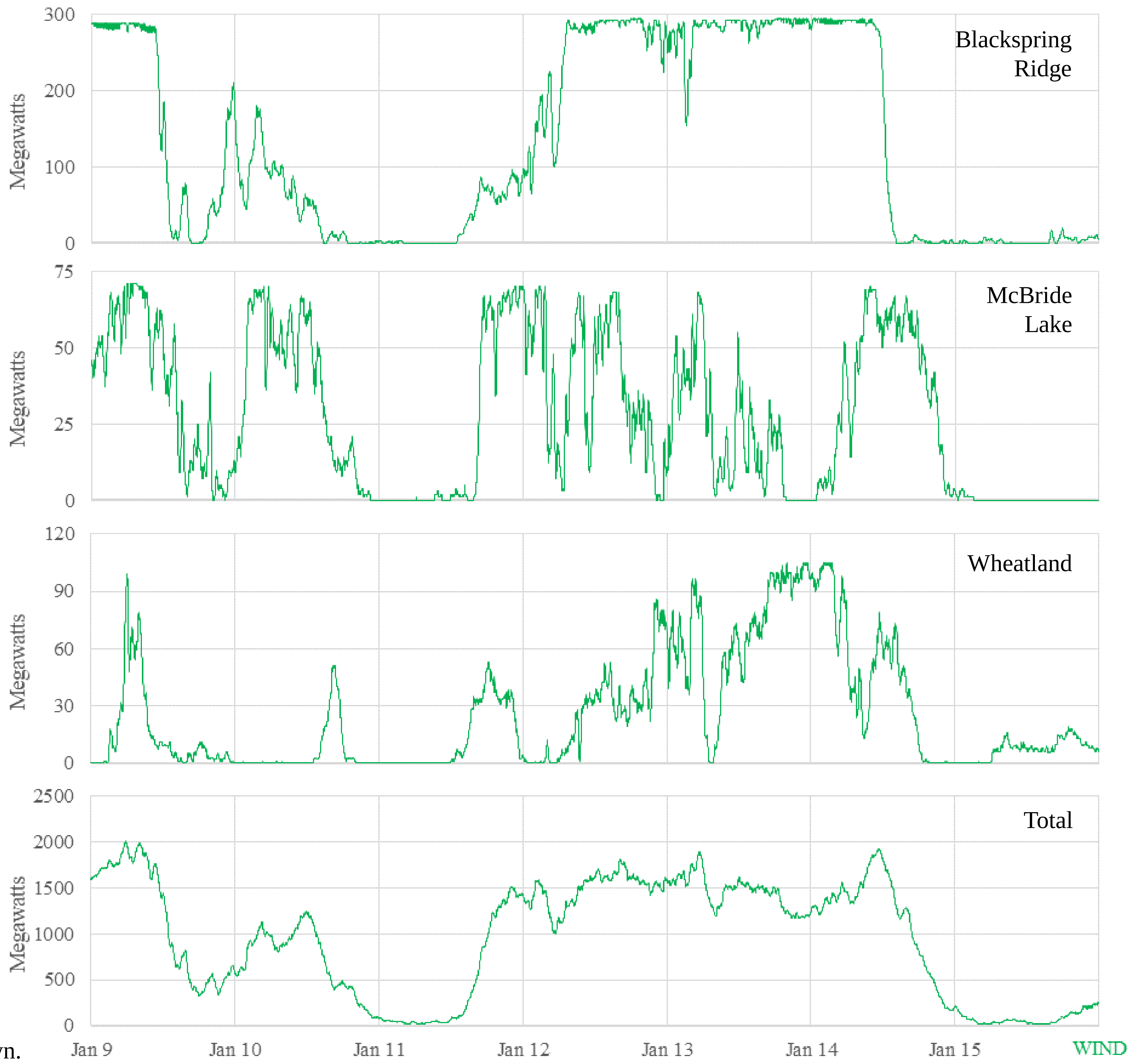
Wind Generation

- Near-zero variable cost
- No CO_2 emissions at source
- Weather-dependent
- Often located far from loads
- *Non-dispatchable*
    - No control of output beyond what wind conditions allow

Castle River Windfarm (44 MW)
https://transalta.com/about-us/our-operations/facilities/castle-river/

Wind Generation

- Individual units can exhibit large and fast up- and down-ramps, along with significant periods of high or low output
- The wind fleet in aggregate can also exhibit periods of high or low output

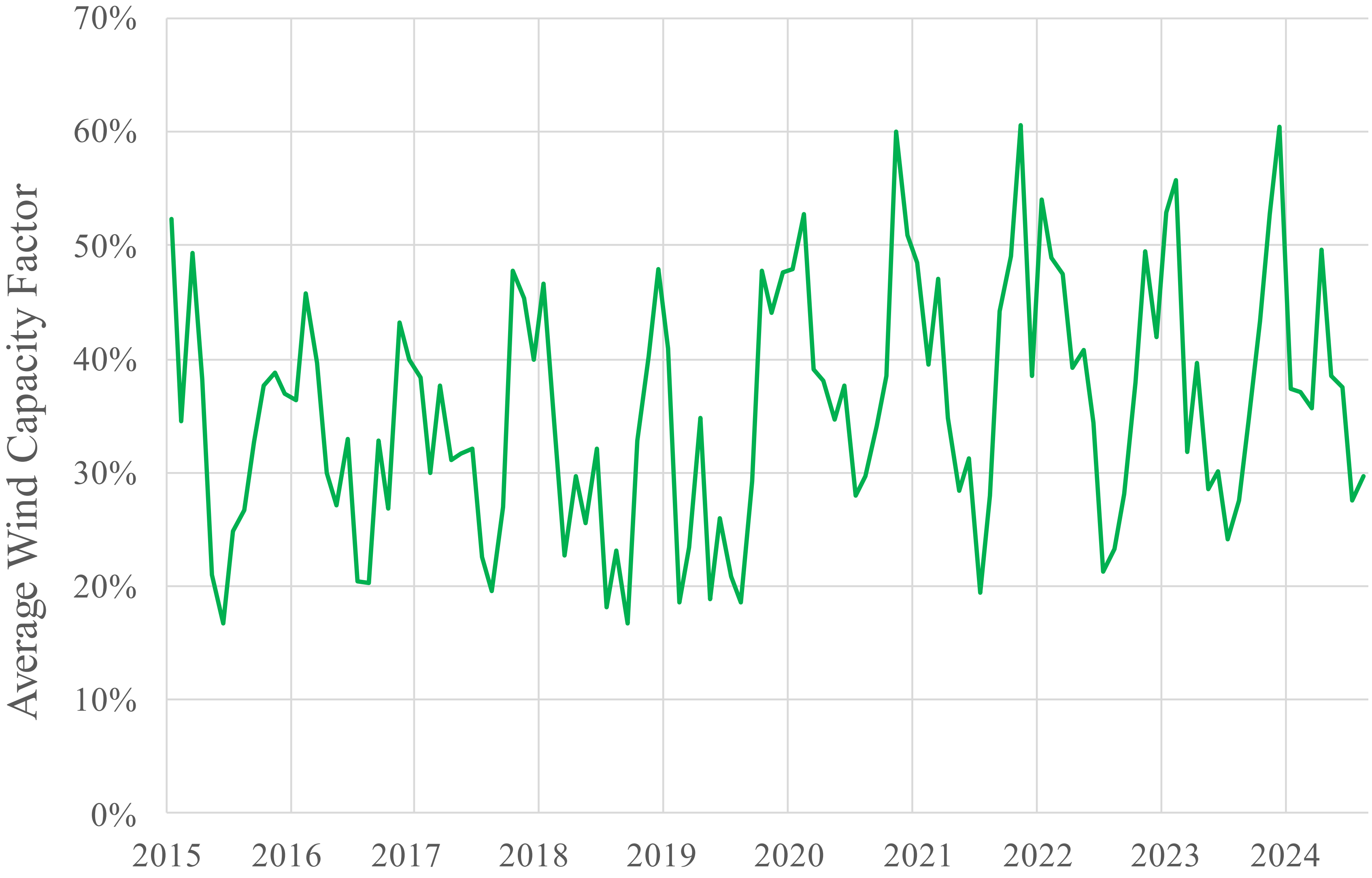


* The bottom chart shows total Alberta wind generation, not the total of the three windfarms shown.

Wind Generation

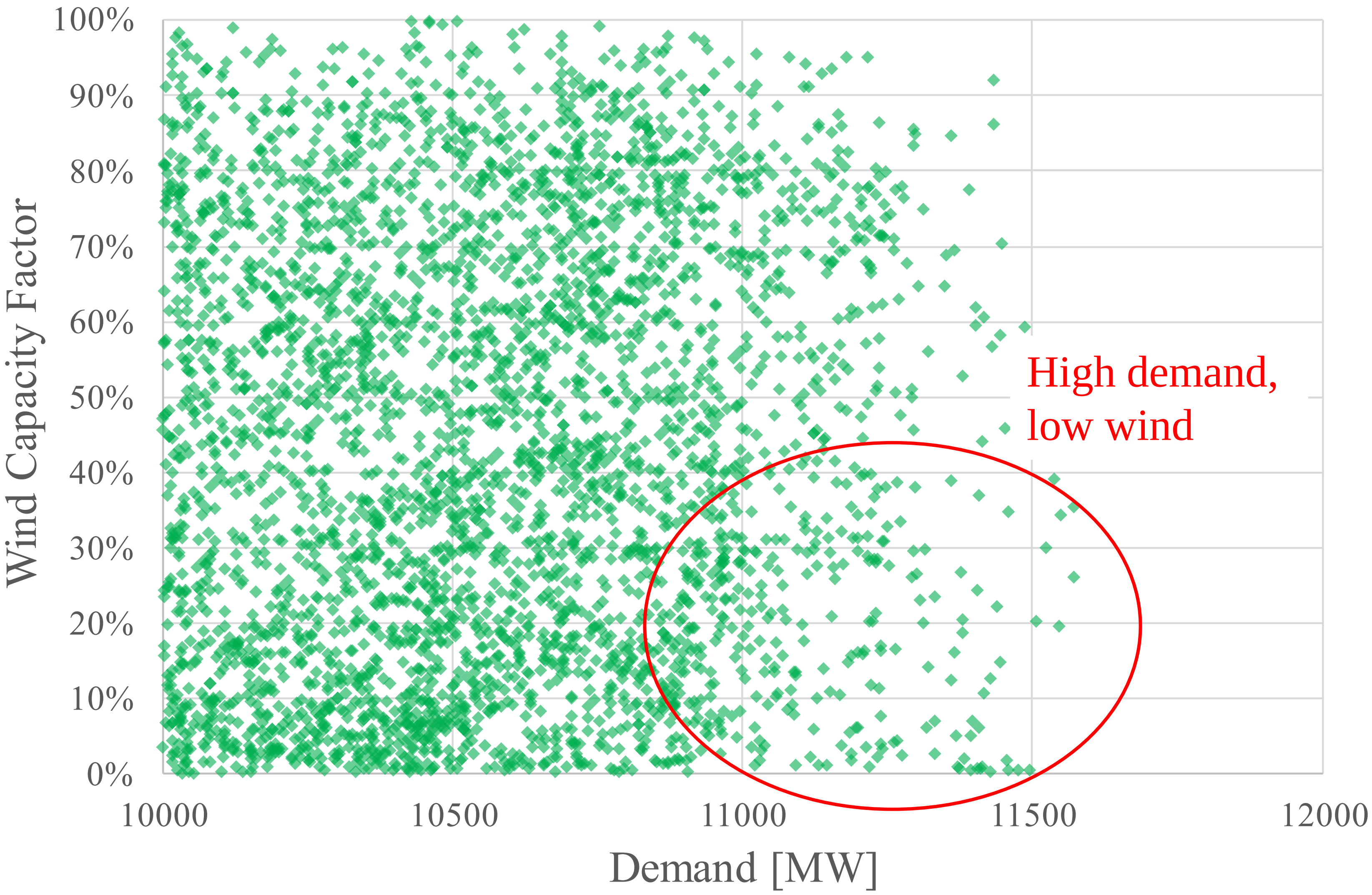
$$capacity\ factor = \frac{amount\ of\ energy\ produced\ in\ a\ given\ period}{maximum\ possible\ energy\ production\ in\ that\ period}$$

- Wind output exhibits significant seasonal variations
- Output is higher in the winter, but periods of low output still occur



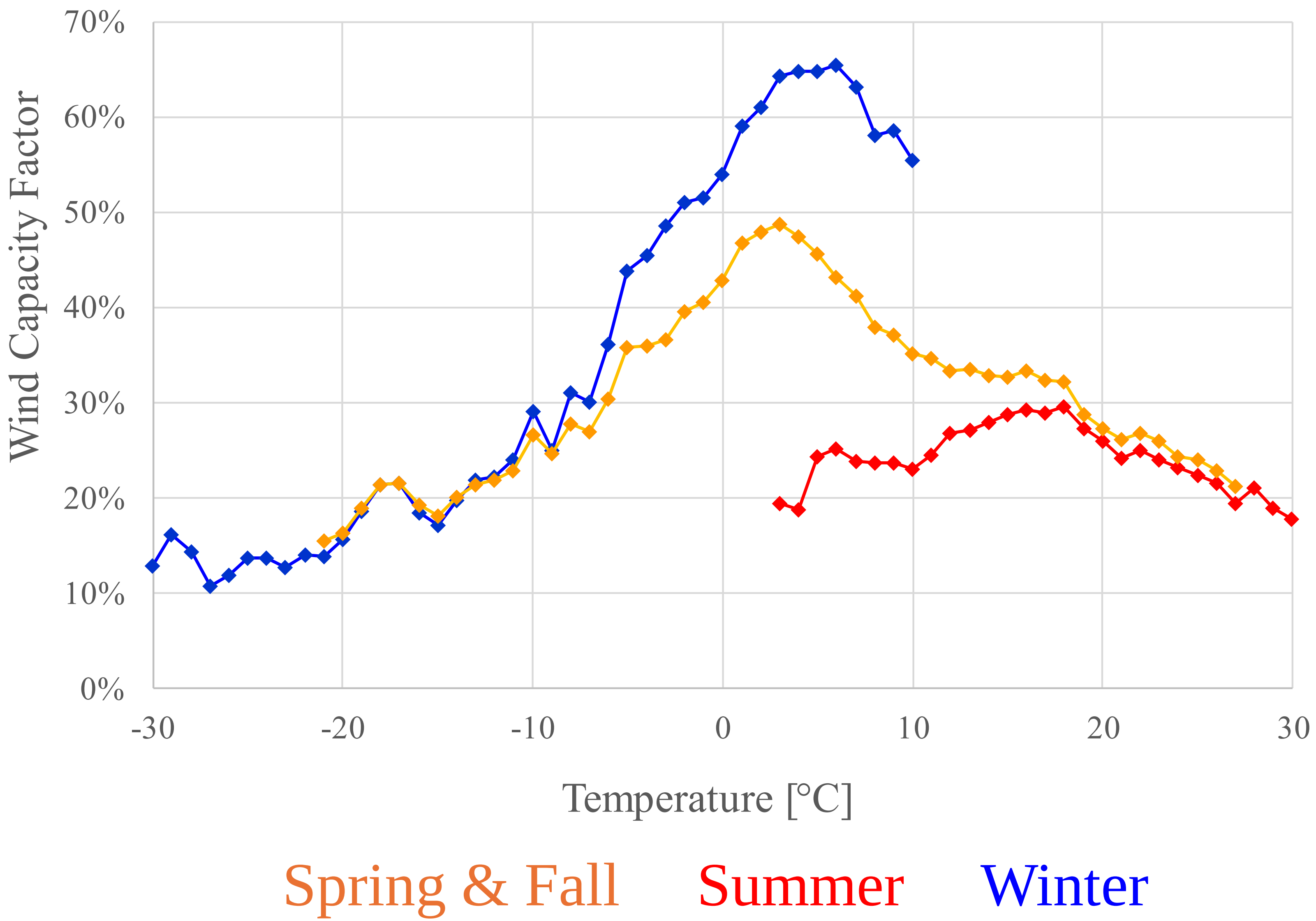
Wind Generation

- The lack of correlation with demand means that wind cannot be relied on to produce power when it's needed most
- As such, wind generation does not reduce the need for dispatchable generation



Wind Generation

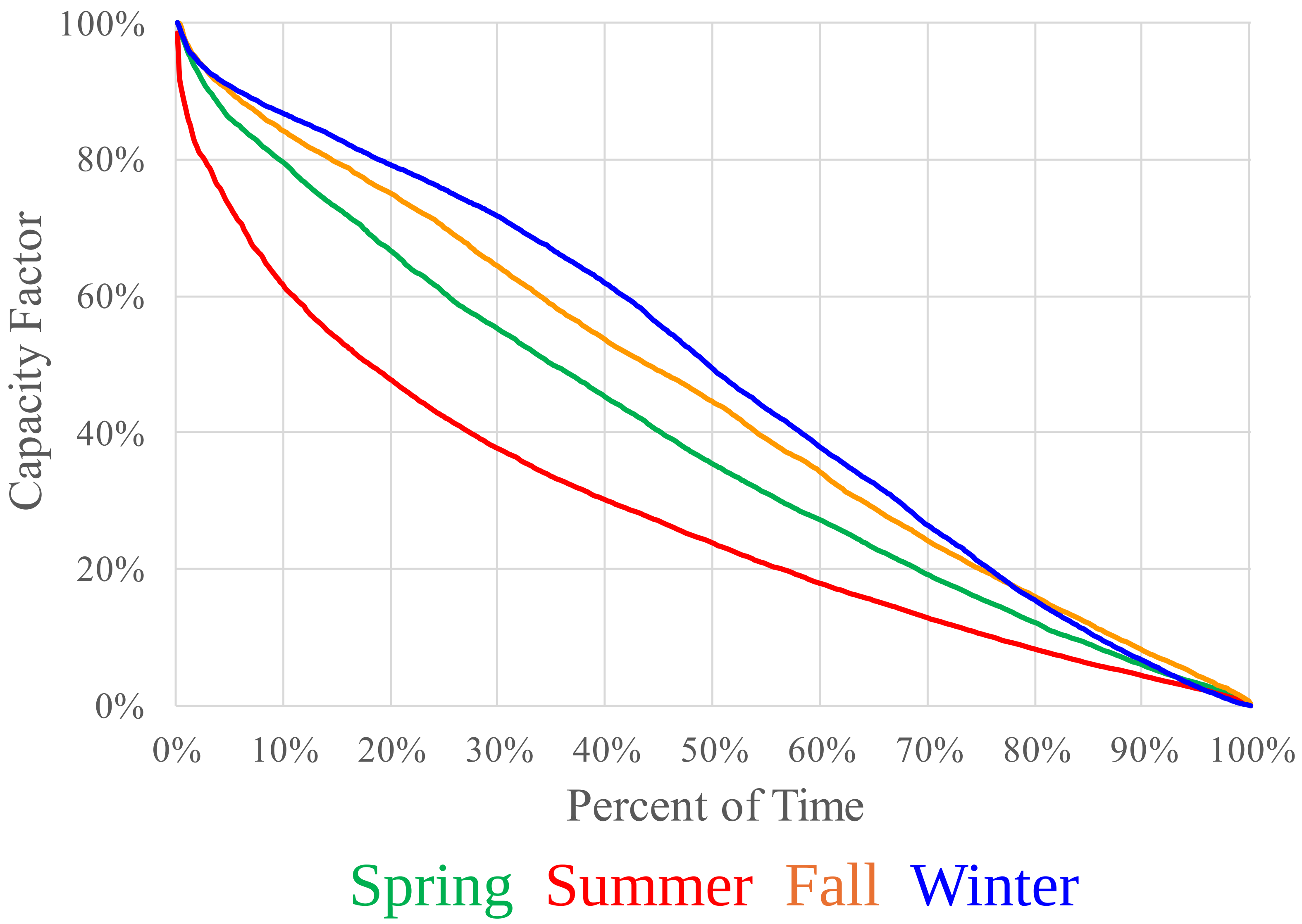
- Output tends to falls at very high and very low temperatures
- The winter pattern is well-known to Albertans



Wind Generation*

* Slides whose titles contain an asterisk were skipped during the live presentation.

- Duration curves emphasize wind generators' higher winter and lower summer output
  - In the summer, output is below 20% of installed capacity almost half the time



Solar Generation*

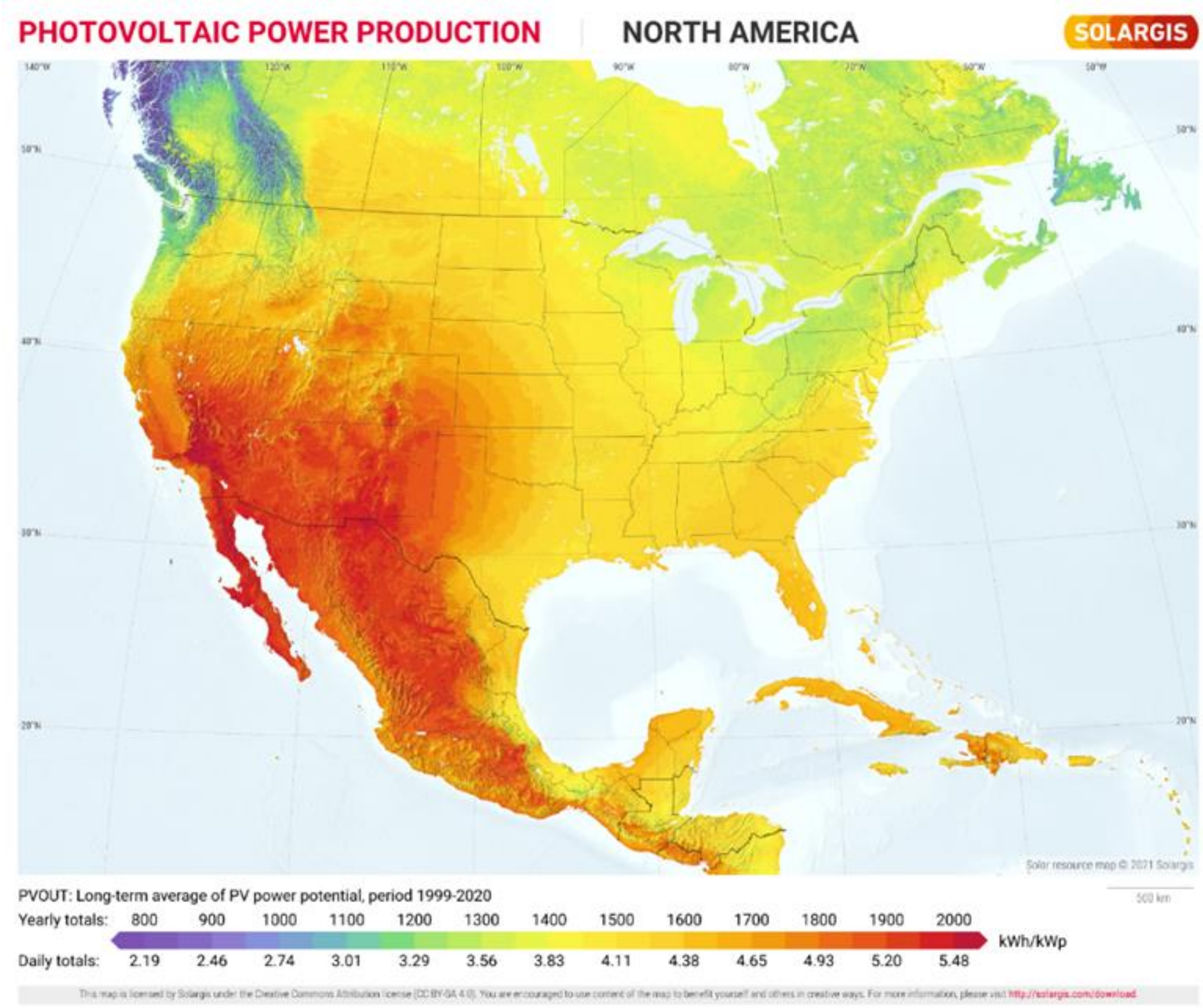
- Southern Alberta is one of the best places in Canada for solar energy
- Suitable for local energy production (homes, shopping centres, etc.)
- No CO_2 emissions at source

Claresholm Solar (132 MW)

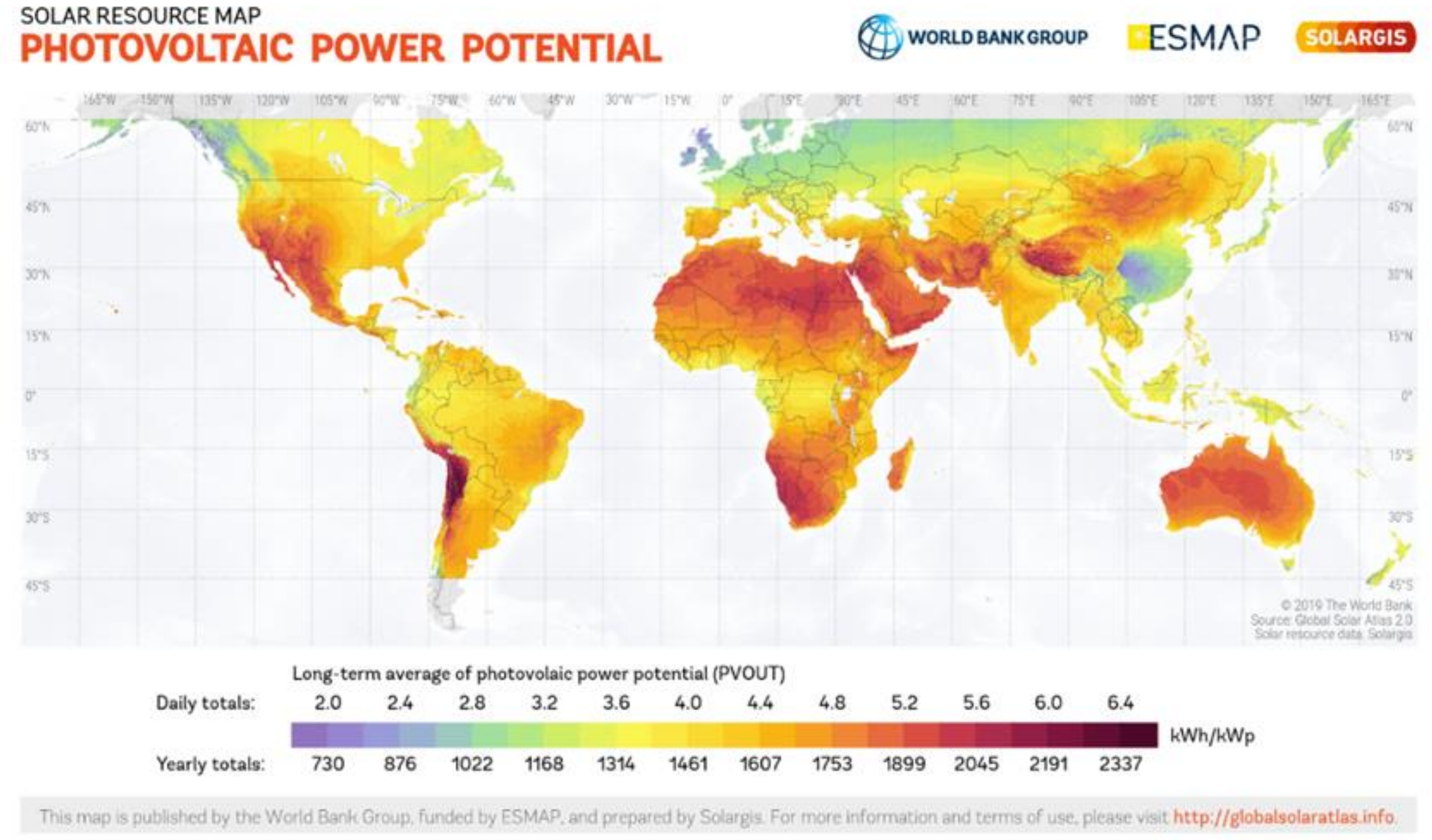
Canada’s Largest Solar Energy Facility Now Operational in Alberta - ReNew Canada

Solar Generation

- The amount of solar energy available each year in southern Alberta is quite high for this latitude but in about the middle of the pack across North America
  - Alberta is not California or Arizona
- Globally, it's a bit below average (next slide)

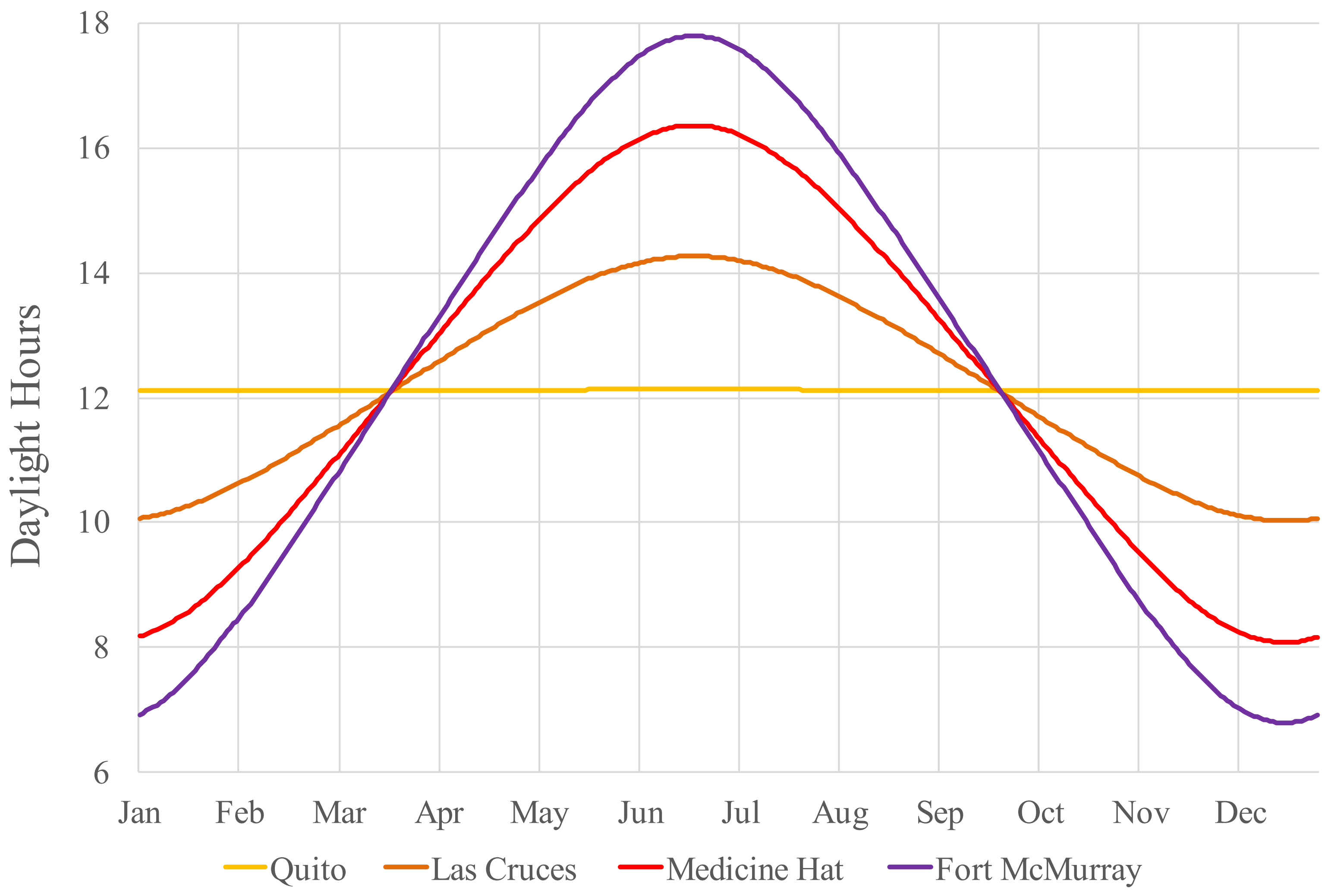


Solar Generation



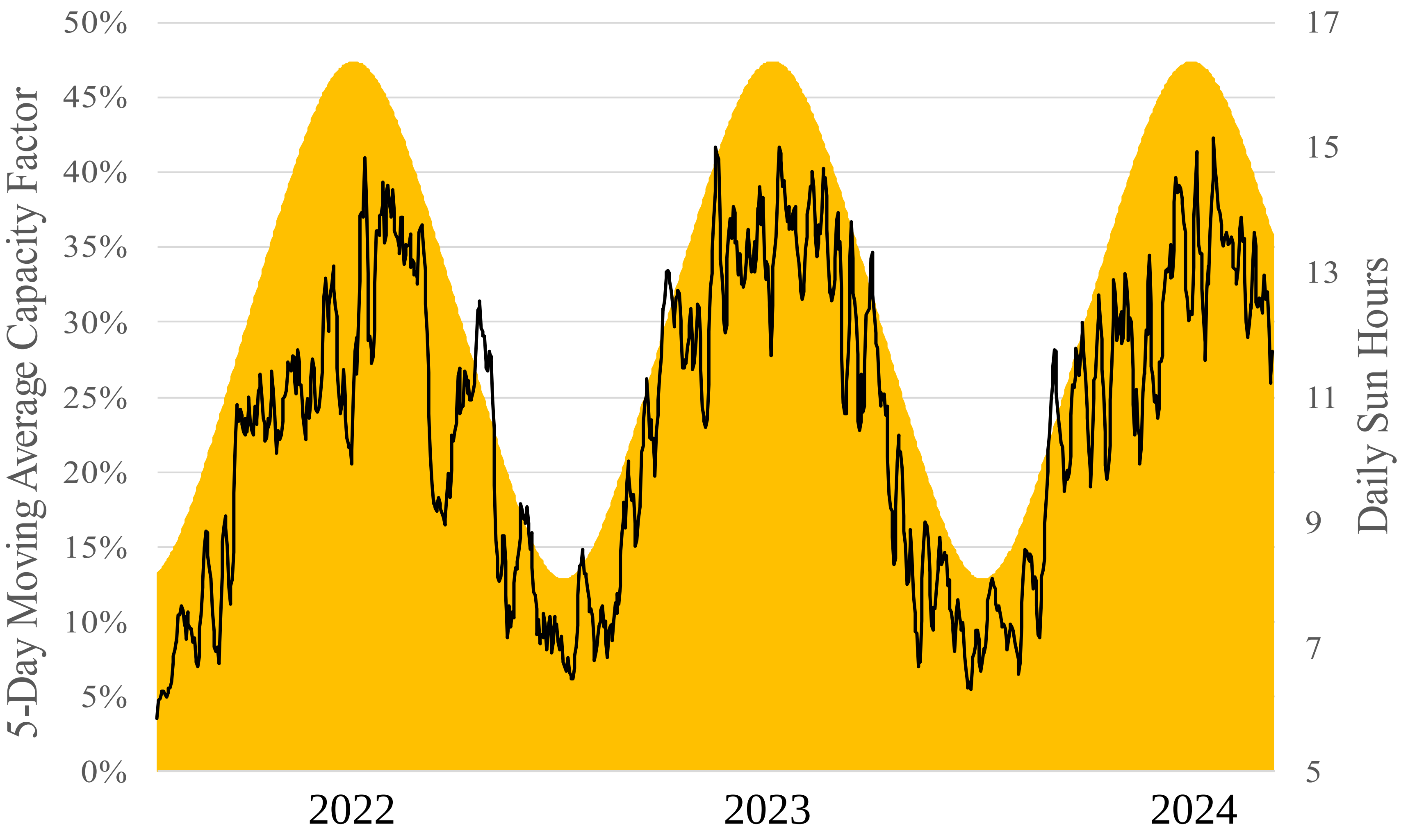
Solar Generation

- Seasonal variation in daylight hours grows as we move away from the equator
- Latitudes:
  - Quito, Ecuador –0.2°
  - Las Cruces, NM, 32.3°
  - Medicine Hat, AB, 50.0°
  - Fort McMurray, AB, 56.7°



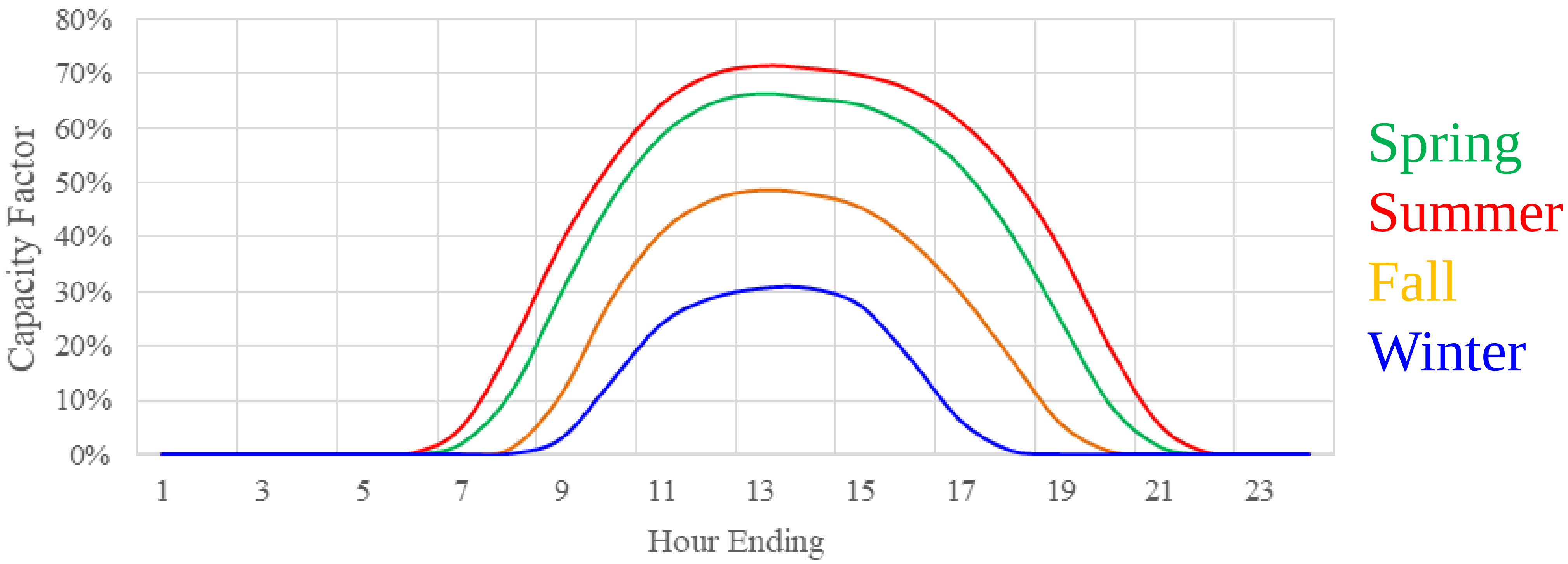
Solar Generation

- Seasonal variation in daylight hours directly affects solar energy production
- Significant variation within seasons



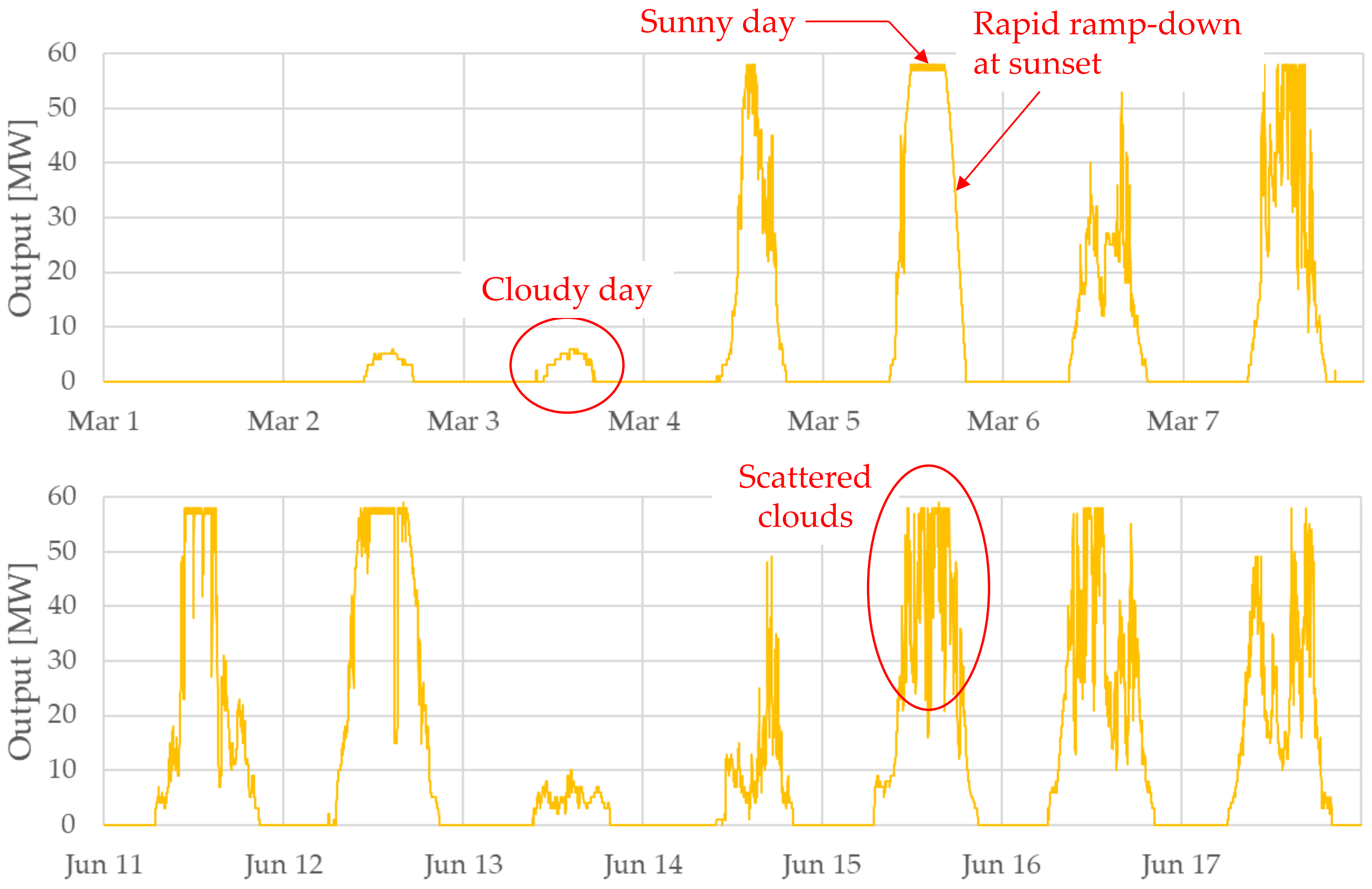
Solar Generation

- Seasonal variations in the path of the sun across the sky affect energy production
- Large commercial installations may use tracking systems that move the panels so they face the sun as it crosses the sky



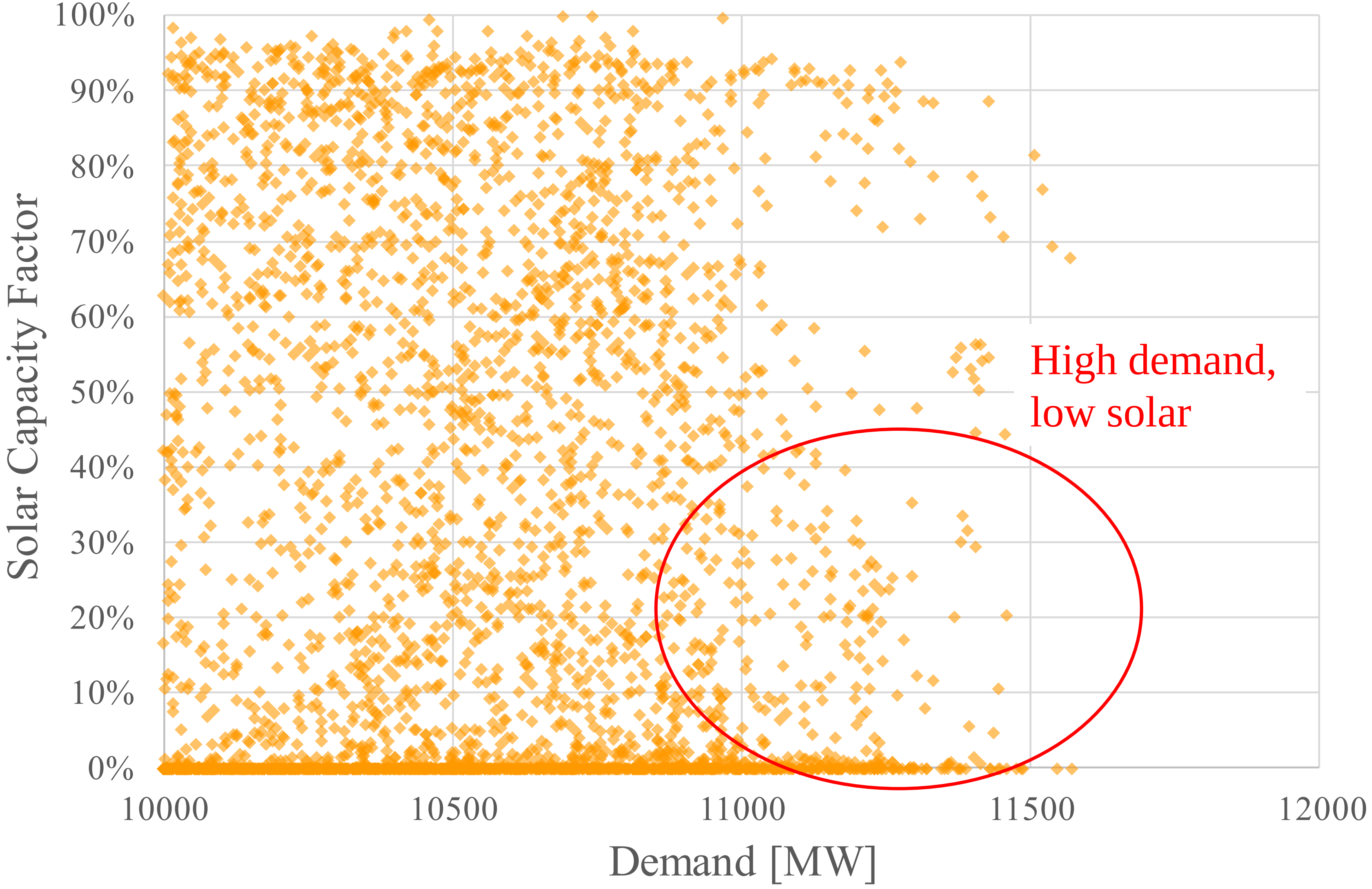
Solar Generation

- Daily variations in sky conditions affect energy production
  - Clouds, fog, fire smoke



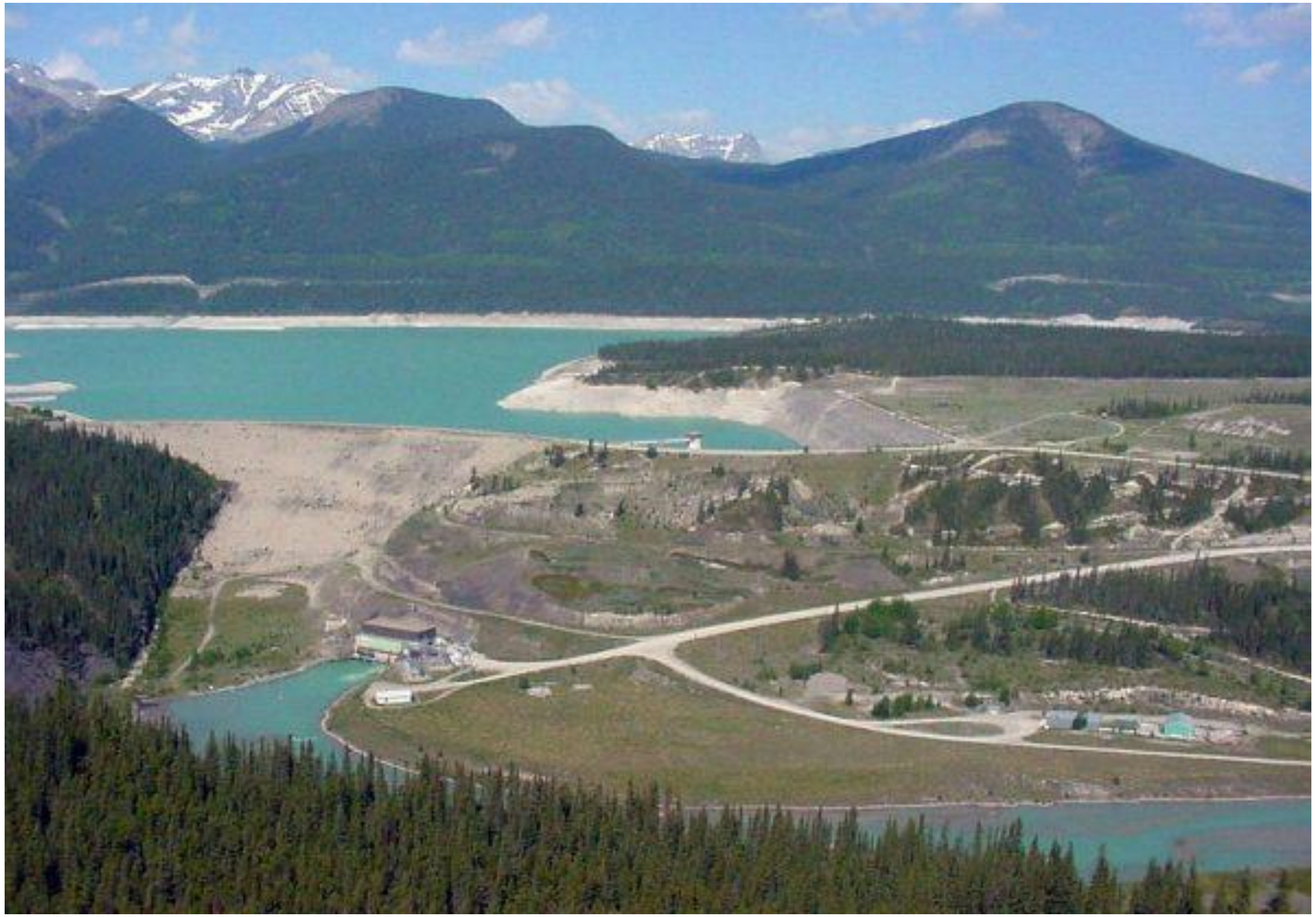
Solar Generation

- The lack of correlation with demand means that solar cannot be relied on to produce power when it's needed most
- Winter peaks occur after sunset
- As such, solar generation does not reduce the need for dispatchable generation



Hydro Generation

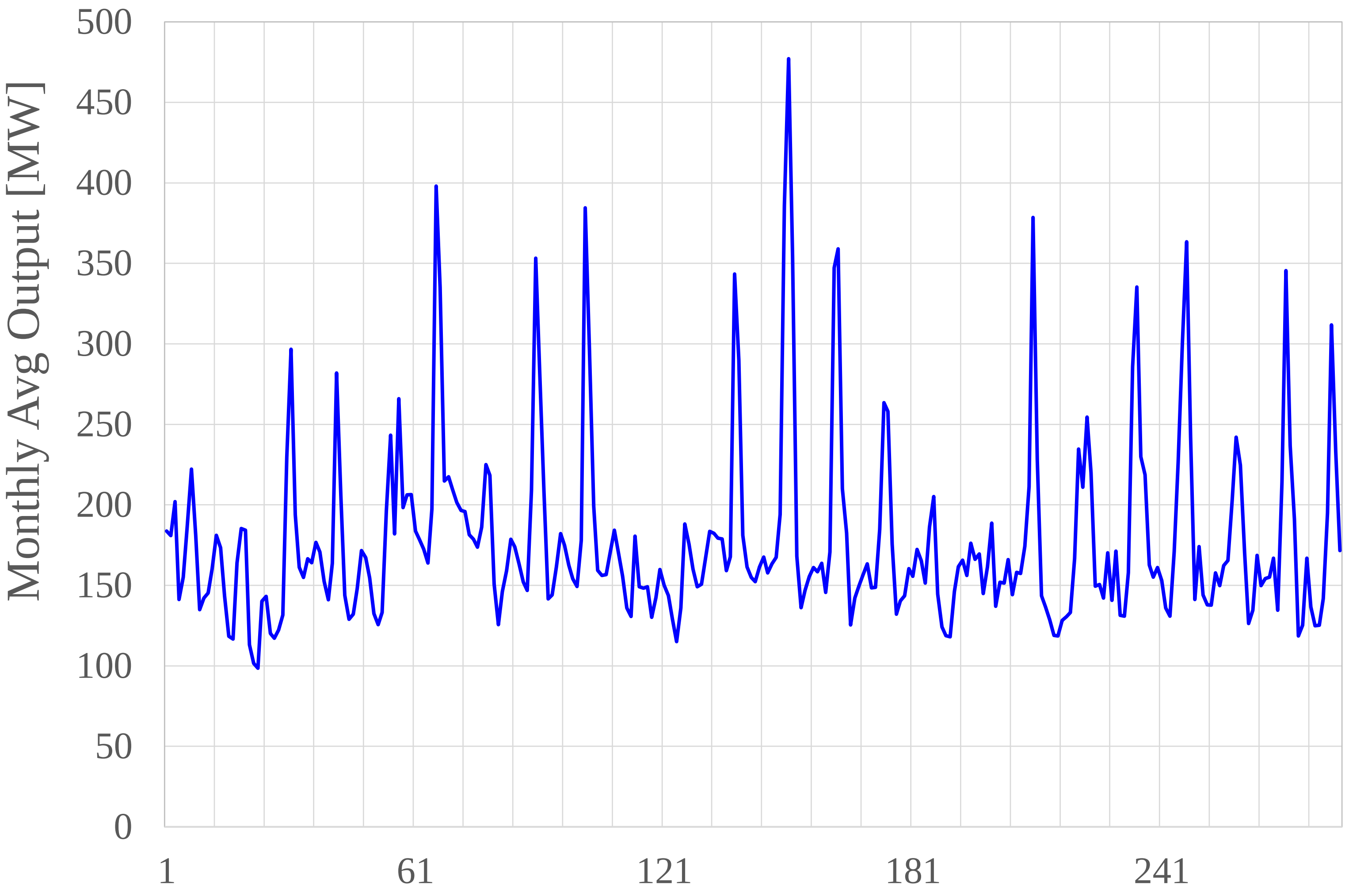
- Hydro with water storage is among the best sources of electricity
- Extremely reliable, long-lived, fast response
- High capital cost (usually), low “fuel” cost
- Large areas of land may be affected



Bighorn Hydro and Lake Abraham
https://transalta.com/about-us/our-operations/facilities/bighorn/

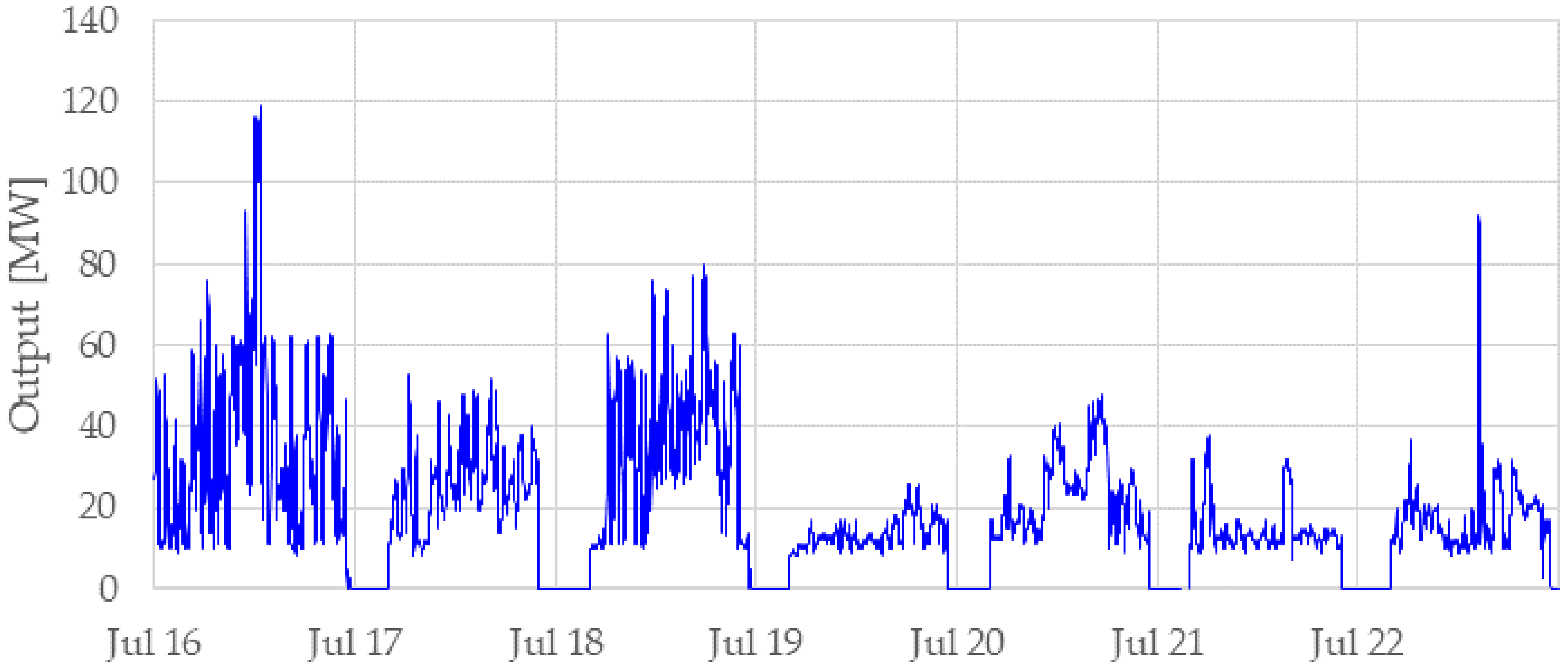
Hydro Generation

- Alberta hydro reservoirs are relatively small
  - Churchill Falls, NL: 5428 MW, 35 000 GWh/year
  - Alberta: 894 MW, 1800 GWh/year
- Hydro output exhibits significant seasonality
- Year-to-year changes can also be significant



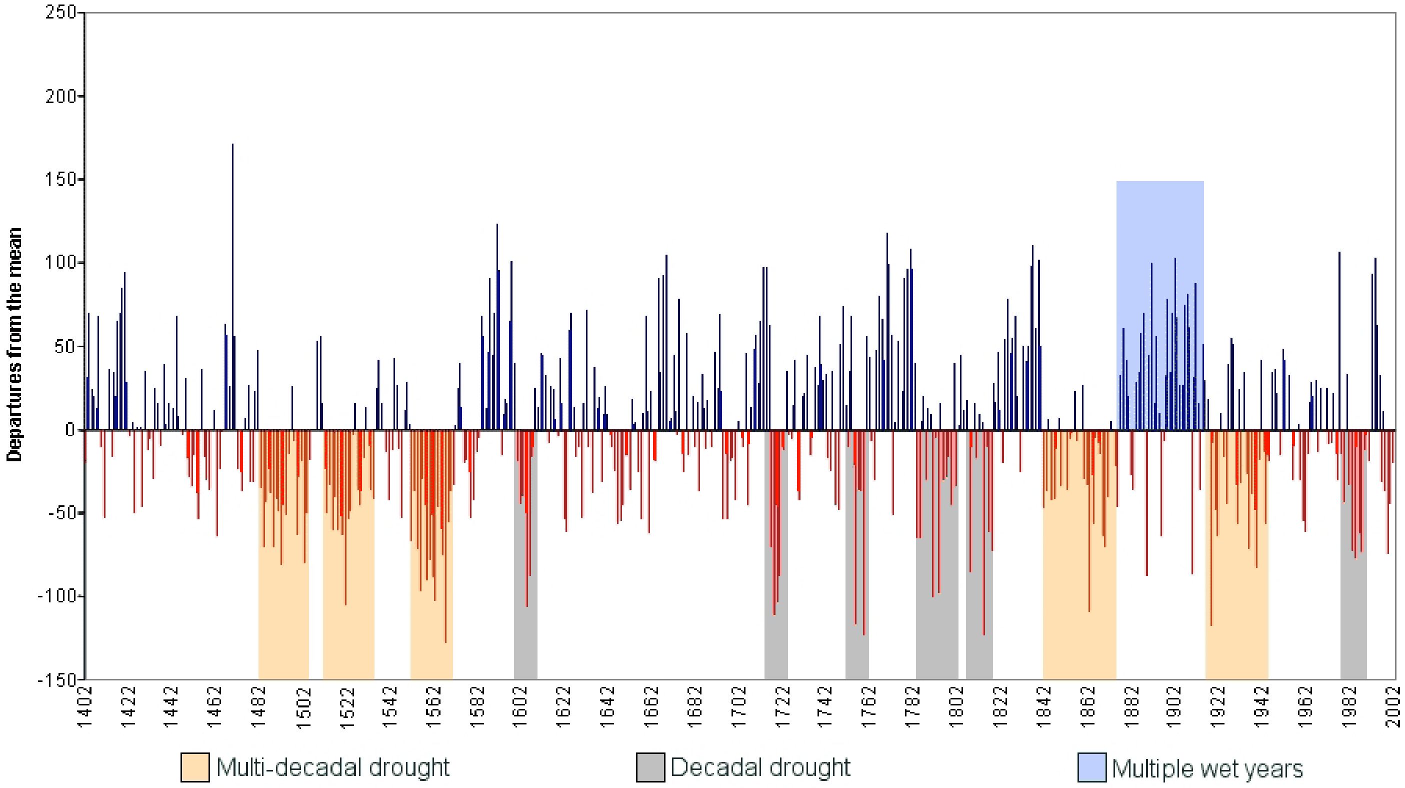
Hydro Generation*

- Inherent flexibility makes hydro a very good resource to follow changing system conditions



Hydro Generation

- Hydro generation can be significantly affected by drought
- Prairies have experienced frequent and much more severe droughts than even the 1930s
    - In the 1700s, the North Saskatchewan River at Fort Edmonton ran dry



Historical wet and dry periods on the Canadian Prairies

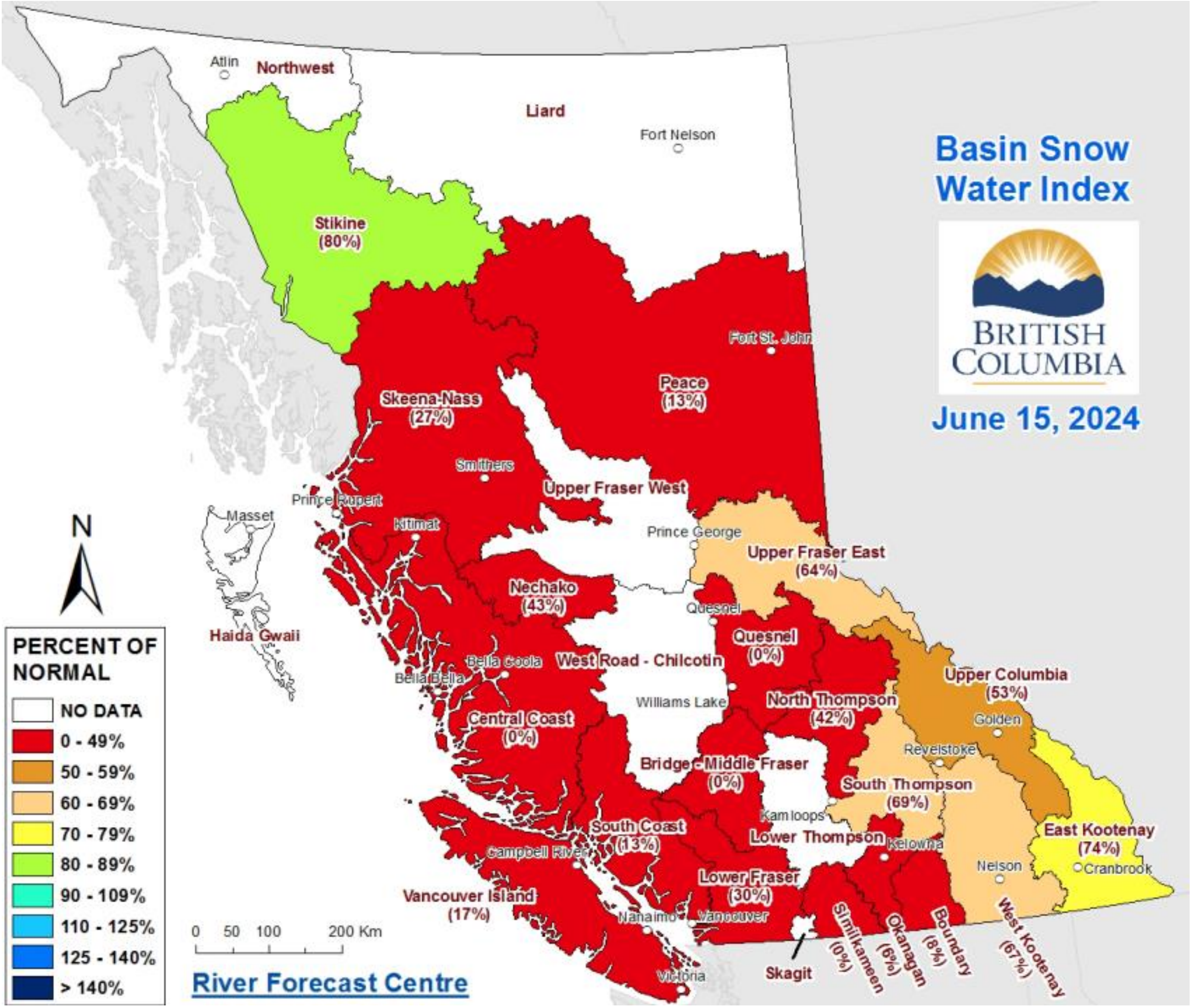
Water and Drought. https://www.parc.ca/saskadapt/adaptation-options/theme-assessments/water-drought.html

Hydro Generation

- BC Hydro has been a net exporter of electricity in only 8 of the past 15 years

Source: BC Hydro 2024/25 First Quarter Report for the Three Months Ended June 30, 2024

BC Hydro 2024/2025 First Quarter Report



Battery Energy Storage Systems

- BES systems are often proposed as solutions to wind & solar variability
- Extremely fast response to system changes (when charged)
- To match Alberta's peak daily generation in 2024 (so far), it would take 6200* of these… but that's not nearly enough…

Enfinite's eReserve3 facility, in the Hamlet of Clairmont in the County of Grande Prairie, is one of nine battery-storage facilities the company has connected to Alberta's electricity grid. Each facility has a 20 MW, 35MWh capacity. (Submitted by Enfinite)

- * The slide shown in the video presentation contained an incorrect value of 6800 due to a transcription error.

Battery Energy Storage Systems

- To replace 2022’s FF generation with wind, solar, and batteries alone, it would take it would take 24 000 × 50 MW, 200 MWh battery systems at $85 million each
  - that’s $2 trillion, or $100 million per day for 55 years
- No suggestion that this would be optimal!

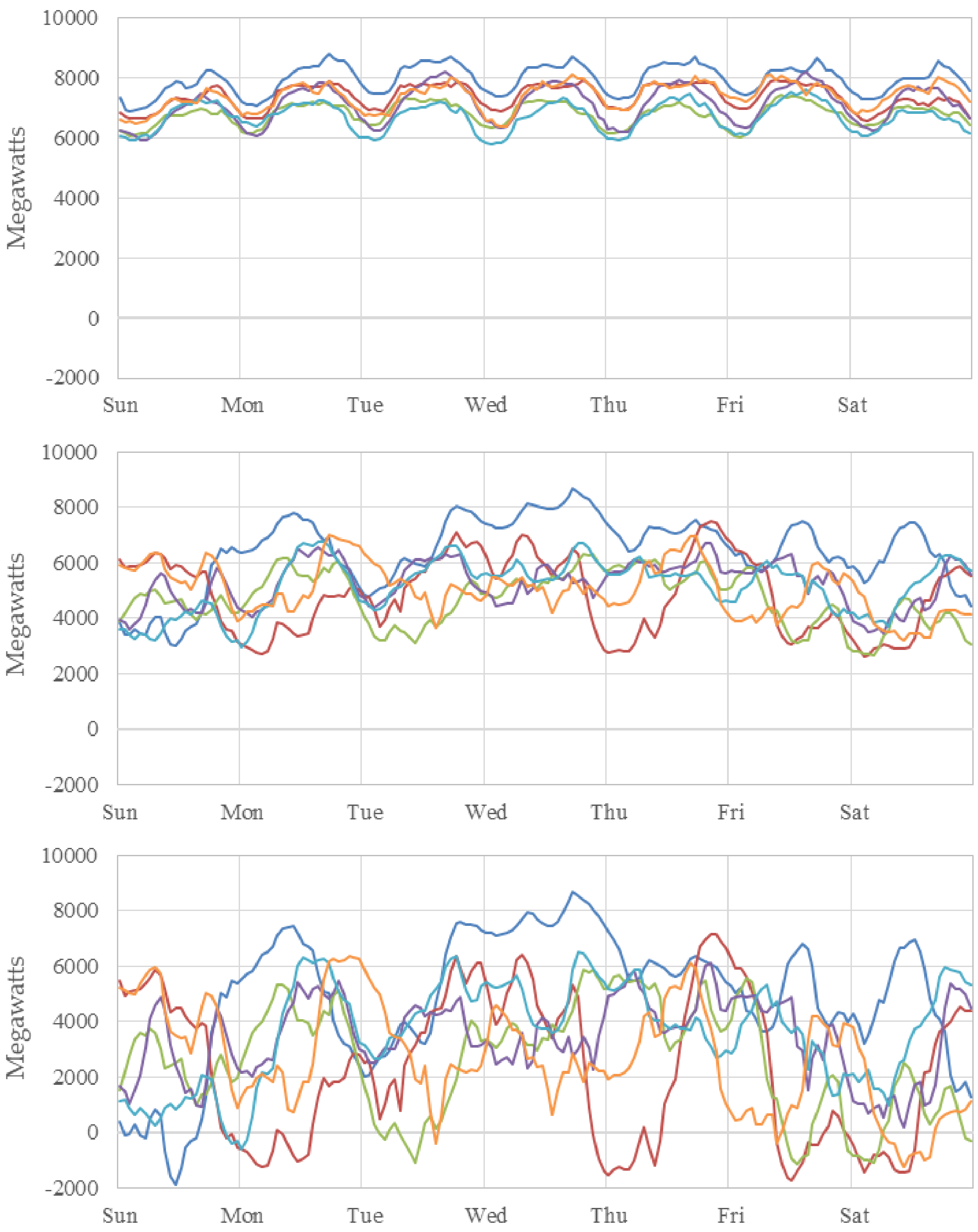
This graph shows the amount of stored energy in a hypothetical lossless battery energy storage system under the assumption that wind and solar are scaled up to provide the amount of energy that was provided by fossil fueled generators in 2022

Net Demand

- Net demand is the demand that remains after subtracting the output of non-dispatchable renewable generation
  - in Alberta, that’s almost entirely wind and solar
  - the province has a small amount of run-of-river / irrigation-canal hydro
- Net demand is a critical number because it is the demand that must be matched from moment to moment by dispatchable generation

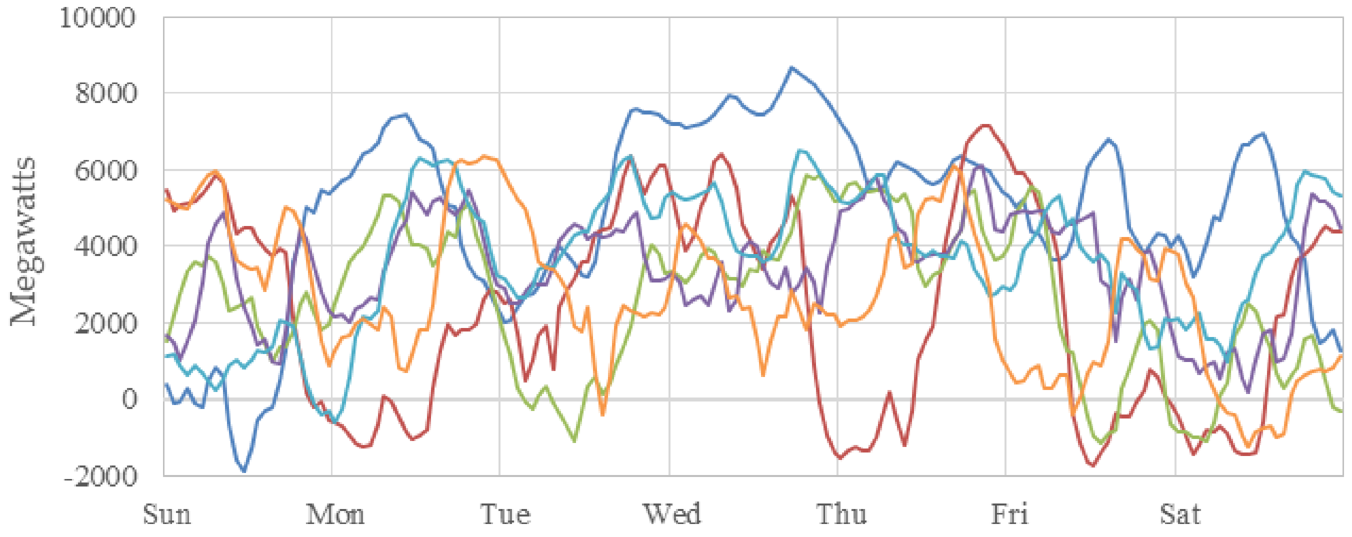
Net Demand

- Top: six different weeks of consumer demand (excluding demand served by behind-the-fence generation) in 2022
- Middle: demand net of dispatchable and nondispatchable renewable generation
- Bottom: net demand with wind scaled to 9000 MW and solar scaled to 3000 MW



Effects of Nondispatchable Renewables*

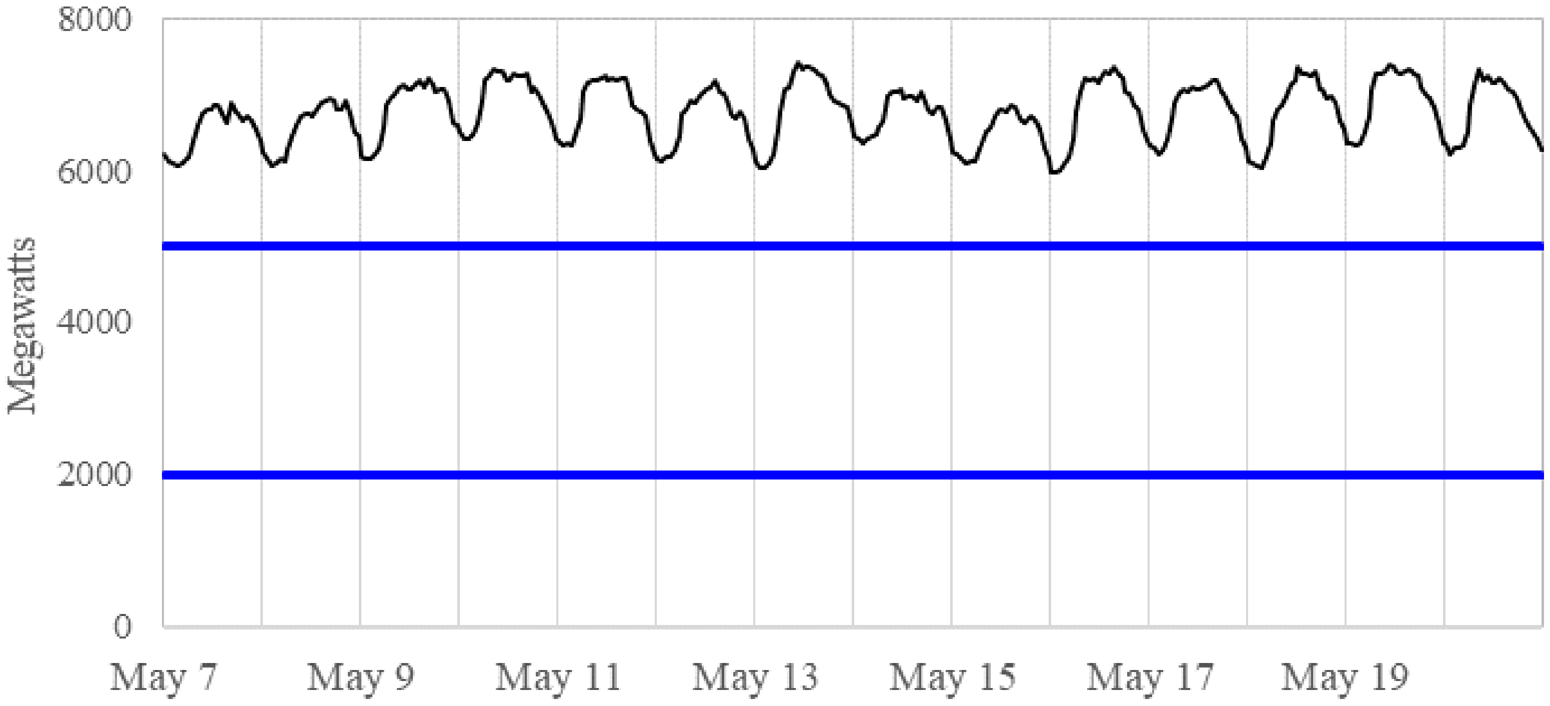
- No consistent daily pattern
- No such thing as "on peak" or "off peak" periods
- Electricity prices will not be consistently high during some hours of the day and consistently low during others
- The idea that we will be able to charge our EVs cheaply at night will not hold



Note: Negative net demand is not possible. Where it is negative, generator outputs must be curtailed.

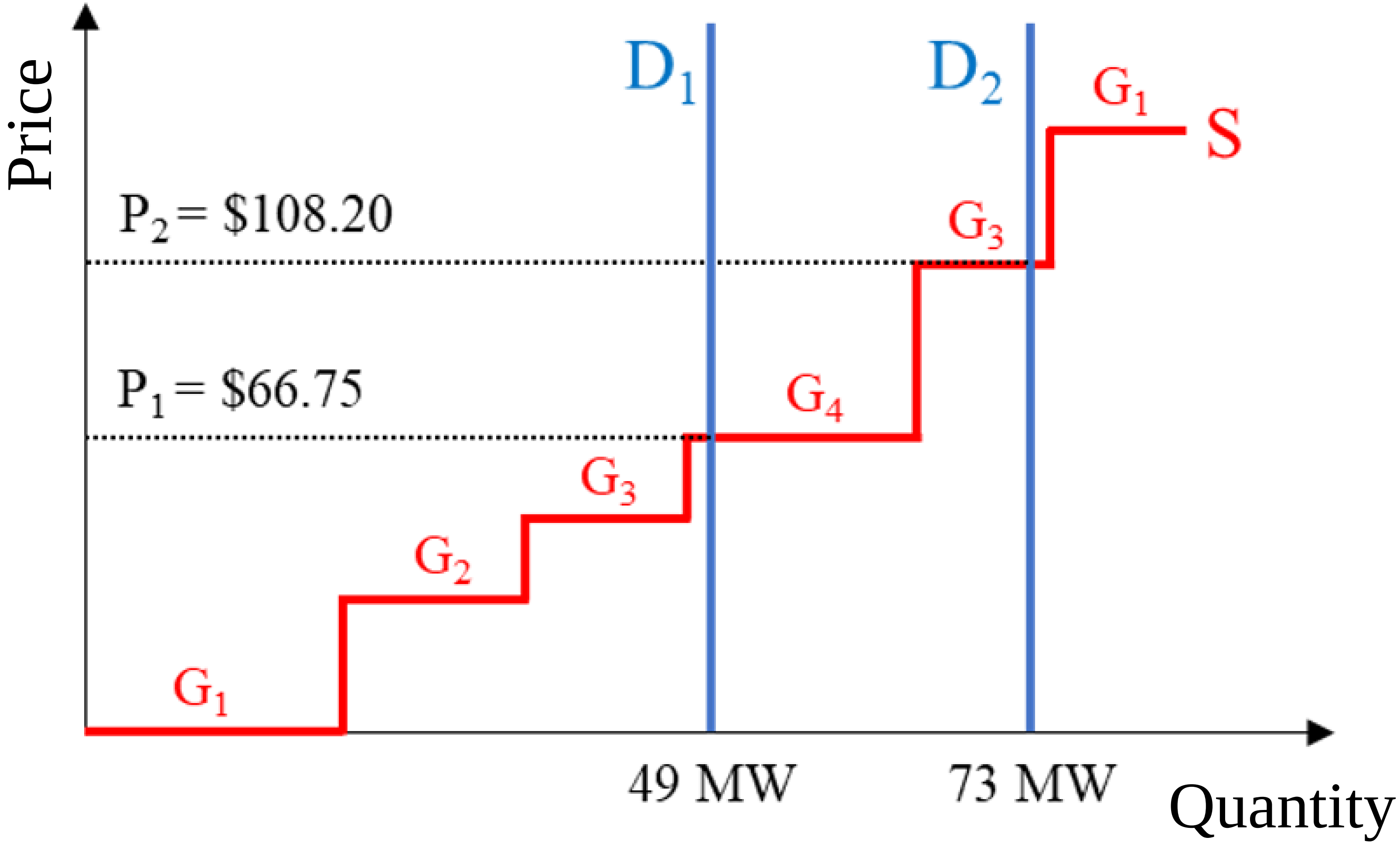
Effects of Nondispatchable Renewables*

- Black: demand (excluding industrials
- Blue: on-states of 2000th and 5000th megawatts in the supply stack
  - Assume they're supplied by generators G2 and G5
- Here, G2 and G5 are needed in all hours



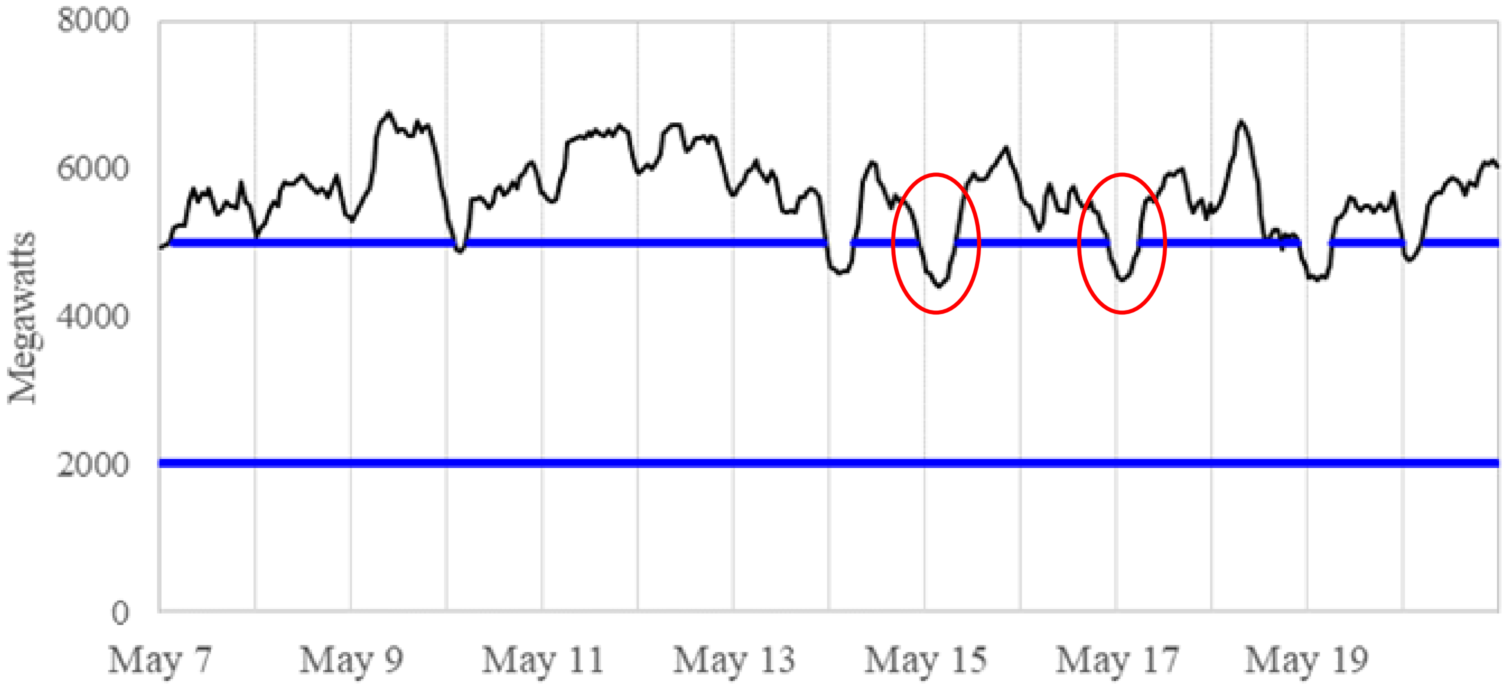
* This example is conceptual only, so it does not precisely mirror reality. Nevertheless, it is realistic enough that the conclusions hold.

Energy Market Merit Order*



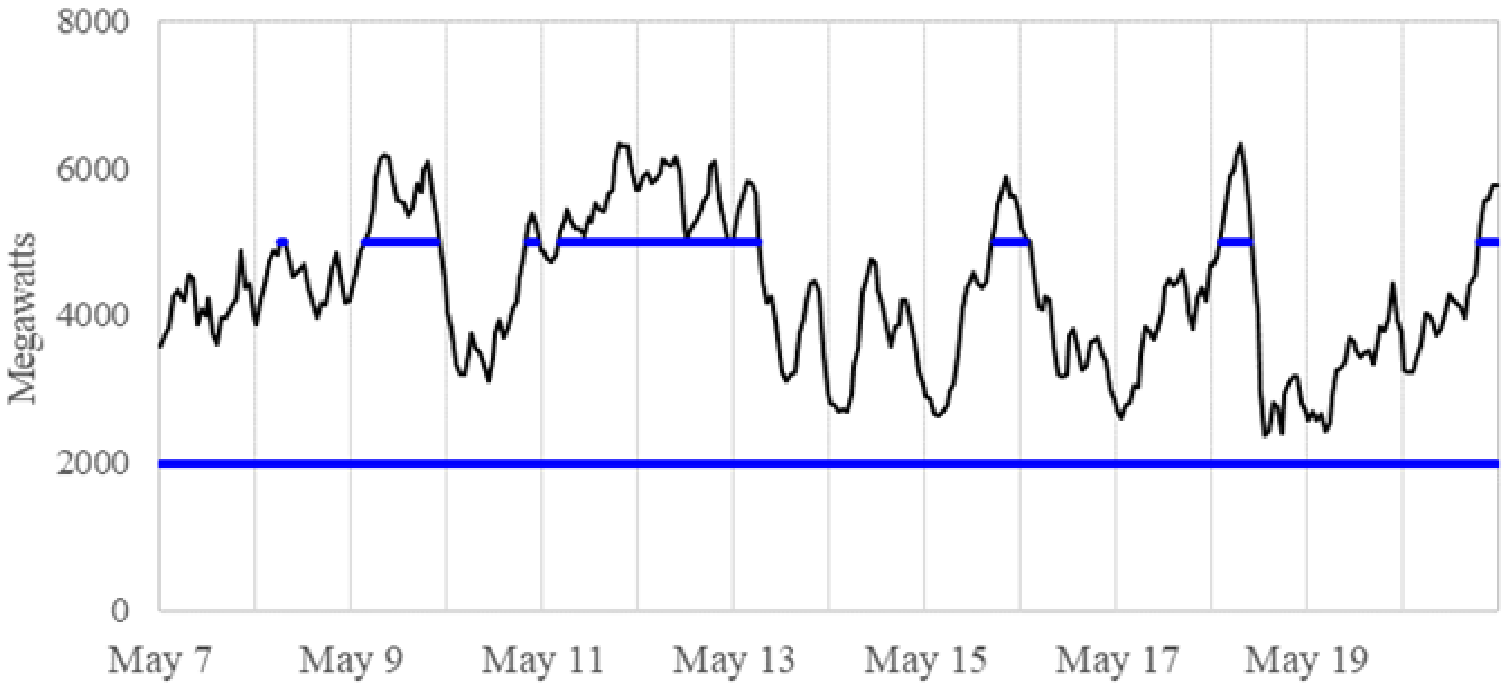
Effects of Nondispatchable Renewables

- Gaps in the blue lines show where net demand is below a generator’s place in the supply stack
  - In the case of G5, this happens when net demand is less than 5000 MW
- Since the unit’s power is not needed, it must either shut down or continue running in a no-load state



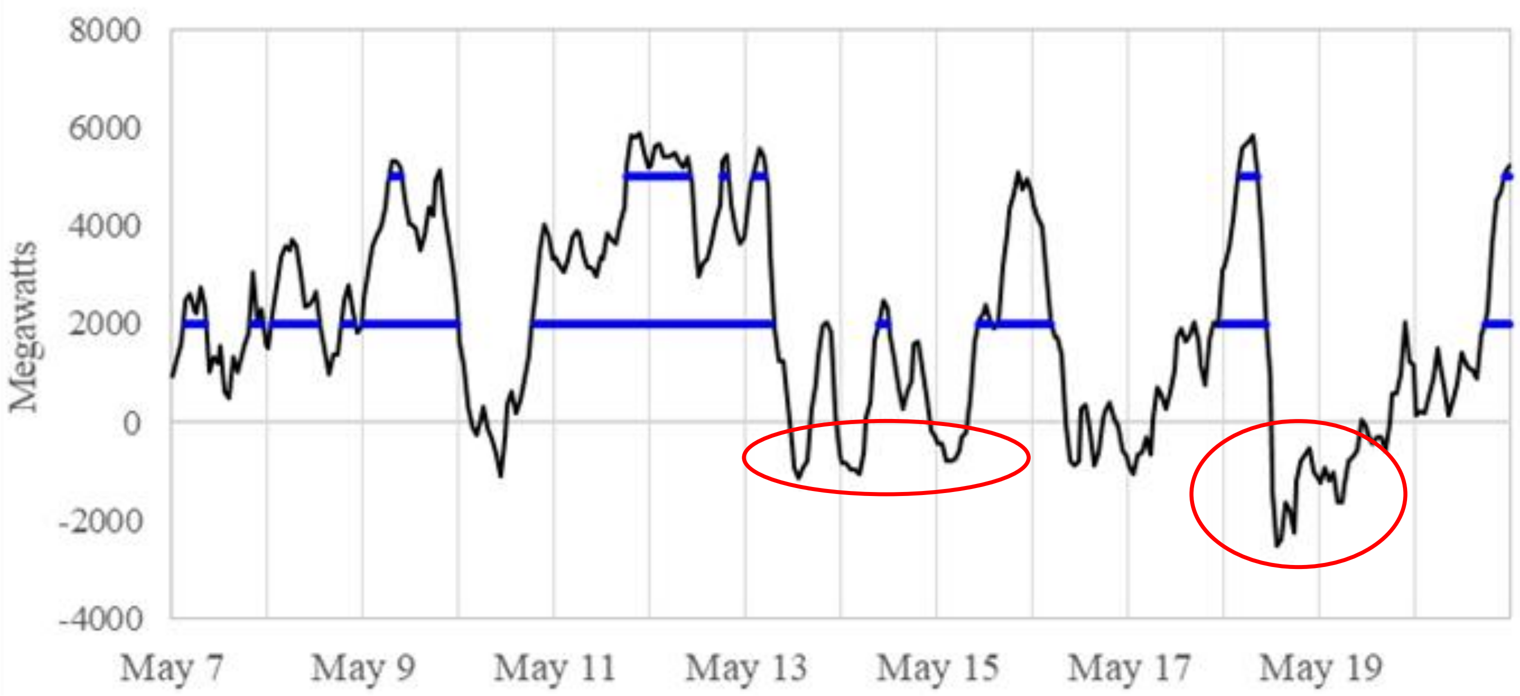
Effects of Nondispatchable Renewables

- As renewable generation increases, the time G5 is needed decreases while the number of starts and stops can increase

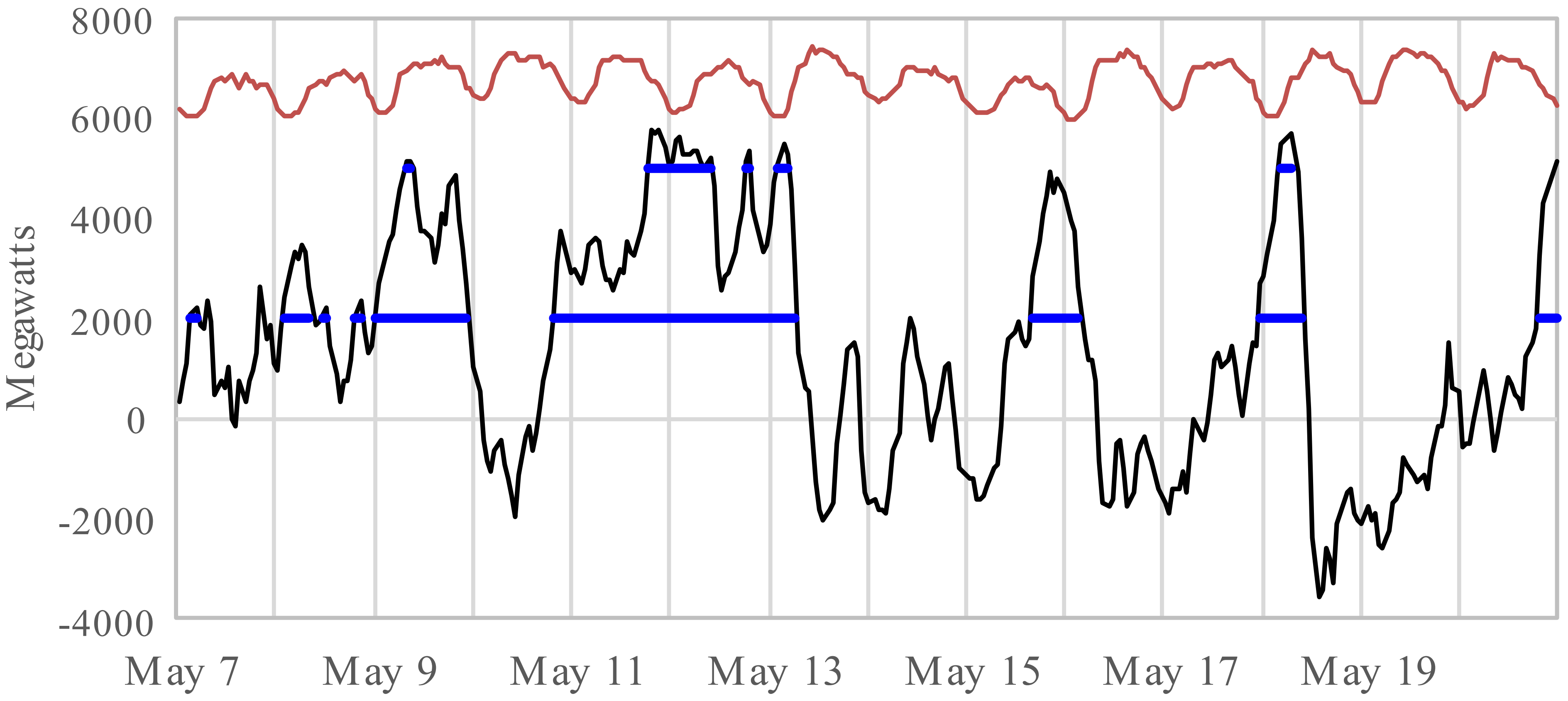


Effects of Nondispatchable Renewables

- As renewables increase further, both G2 and G5 are needed less
  - Energy sales are lower
  - Run cycles are shorter and less predictable
- The rate at which net demand changes is higher
- When net demand would be negative, some renewable generation must be curtailed



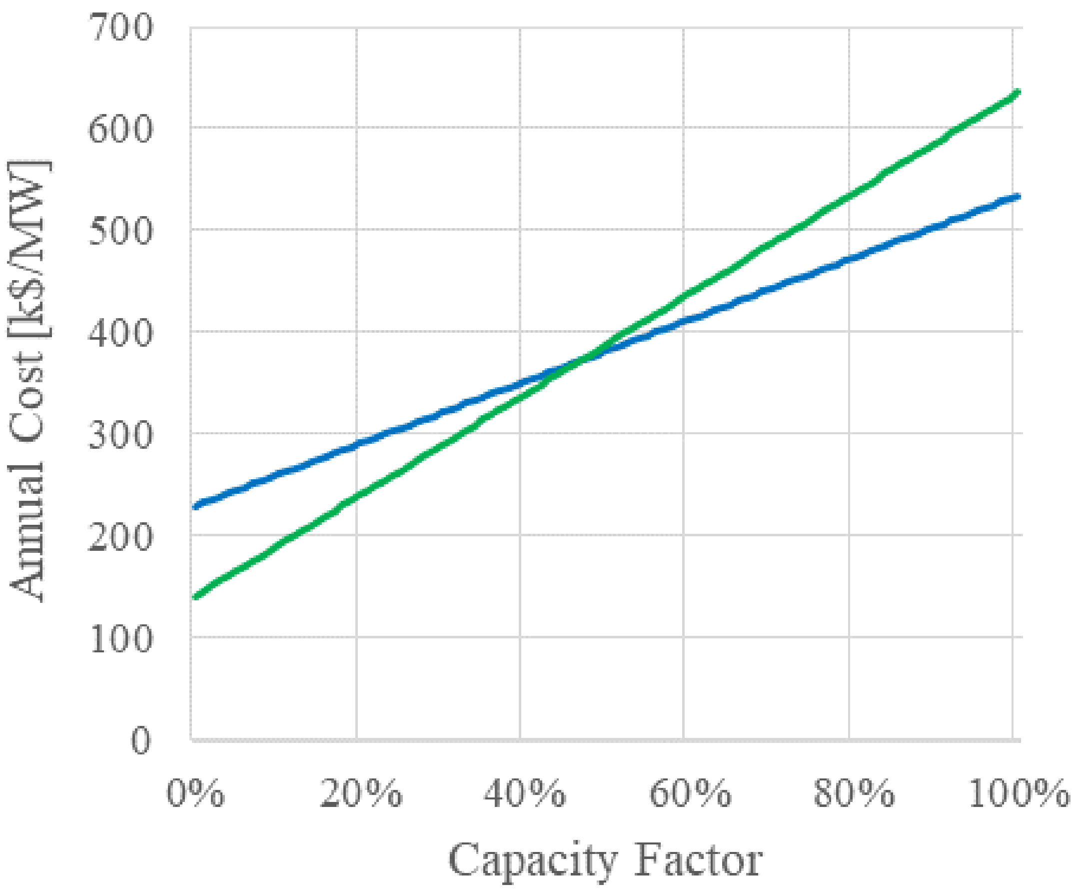
Effects of Nondispatchable Renewables

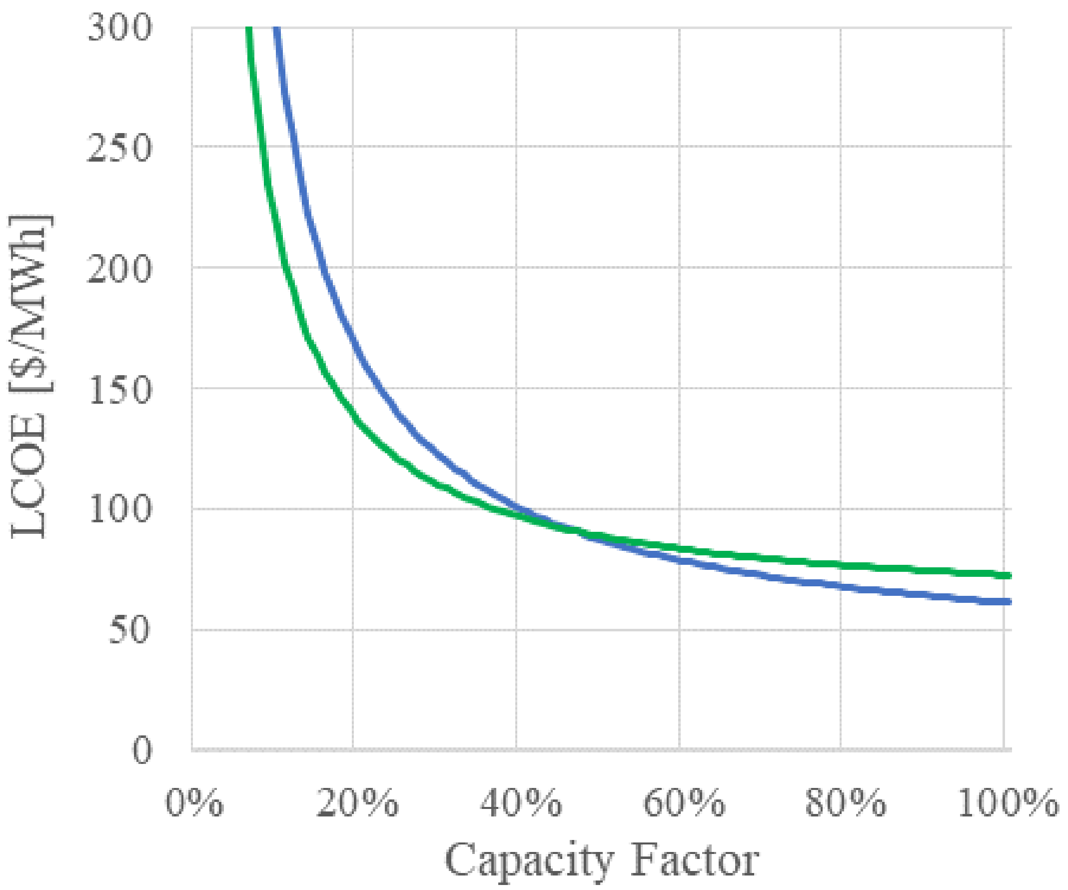


Effects of Nondispatchable Renewables*

- Supply surpluses
- Supply shortfalls
- Extra transmission infrastructure
- Transmission congestion and large swings in dominant flows
- Greater financial risks for generators around recovery of start-up and no-load costs, and greater reliability risks if they don't show up
- Greater need for flexible dispatchable resources for ramping and to account for forecast errors

Generator Economics





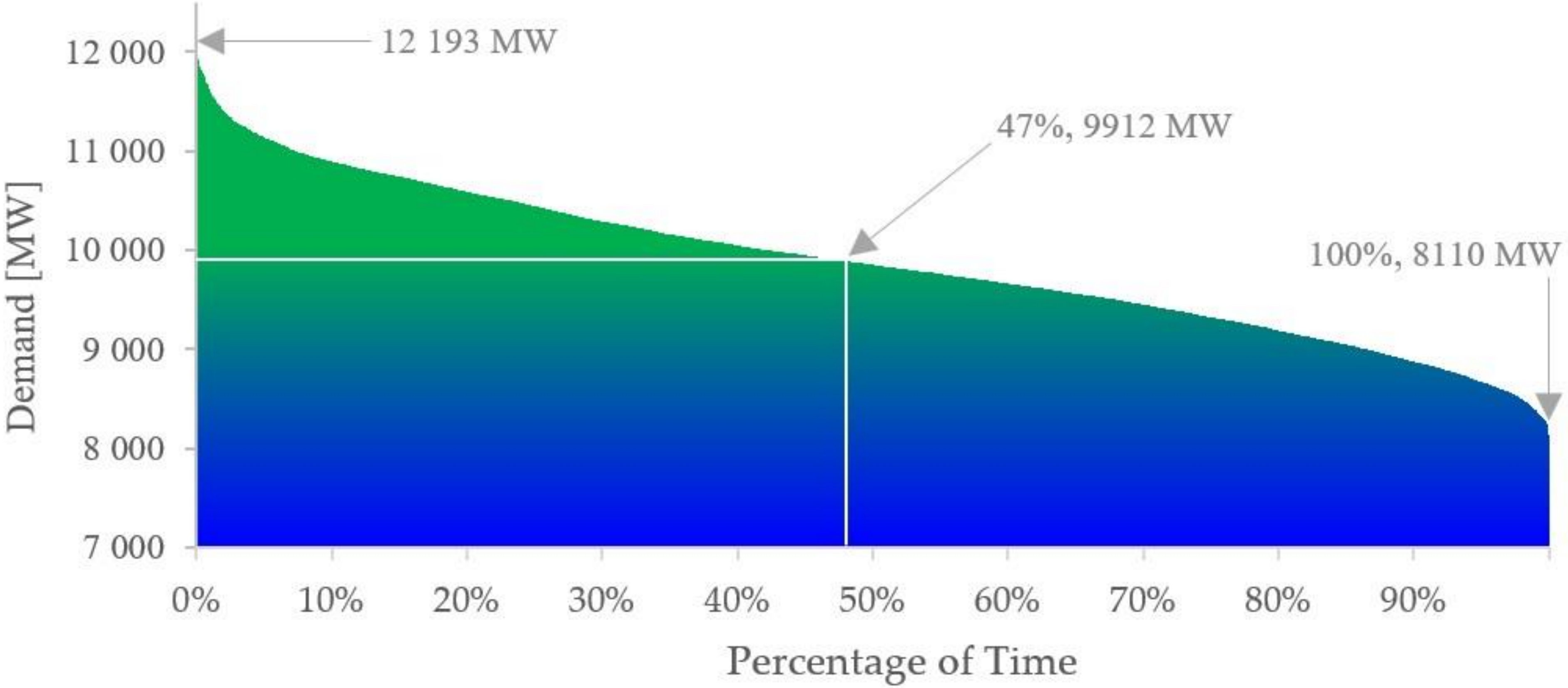
Generator Cost & Performance Characteristics*

Table 1. Cost and performance characteristics of new central station electricity generating technologies

Technology	First available year[a]	Size (MW)	Lead time (years)	Base overnight cost[b] (2022$/kW)	Techno-logical optimism factor[c]	Total overnight cost[d,e] (2022$/kW)	Variable O&M[f] (2022$/MWh)	Fixed O&M (2022$/kWy)	Heat rate[g] (Btu/kWh)
Ultra-supercritical coal (USC)	2026	650	4	$4,507	1.00	$4,507	$5.06	$45.68	8,638
USC with 30% carbon capture and sequestration (CCS)	2026	650	4	$5,577	1.01	$5,633	$7.97	$61.11	9,751
USC with 90% CCS	2026	650	4	$7,176	1.02	$7,319	$12.35	$67.02	12,507
Combined-cycle—single-shaft	2025	418	3	$1,330	1.00	$1,330	$2.87	$15.87	6,431
Combined-cycle—multi-shaft	2025	1,083	3	$1,176	1.00	$1,176	$2.10	$13.73	6,370
Combined-cycle with 90% CCS	2025	377	3	$3,019	1.04	$3,140	$6.57	$31.06	7,124
Internal combustion engine	2024	21	2	$2,240	1.00	$2,240	$6.40	$39.57	8,295
Combustion turbine—aeroderivative[h]	2024	105	2	$1,428	1.00	$1,428	$5.29	$18.35	9,124
Combustion turbine—industrial frame	2024	237	2	$867	1.00	$867	$5.06	$7.88	9,905
Fuel cells	2025	10	3	$6,771	1.08	$7,291	$0.66	$34.65	6,469
Nuclear—light water reactor	2028	2,156	6	$7,406	1.05	$7,777	$2.67	$136.91	10,447
Nuclear—small modular reactor	2028	600	6	$7,590	1.10	$8,349	$3.38	$106.92	10,447
Distributed generation—base	2025	2	3	$1,915	1.00	$1,915	$9.69	$21.79	8,912
Distributed generation—peak	2024	1	2	$2,300	1.00	$2,300	$9.69	$21.79	9,894
Battery storage	2023	50	1	$1,270	1.00	$1,270	$0.00	$45.76	NA
Biomass	2026	50	4	$4,996	1.00	$4,998	$5.44	$141.50	13,500
Geothermal[i,j]	2026	50	4	$3,403	1.00	$3,403	$1.31	$153.98	8,881
Conventional hydropower[j]	2026	100	4	$3,421	1.00	$3,421	$1.57	$47.06	NA
Wind[e]	2025	200	3	$2,098	1.00	$2,098	$0.00	$29.64	NA
Wind offshore[j]	2026	400	4	$5,338	1.25	$6,672	$0.00	$123.81	NA
Solar thermal[j]	2025	115	3	$8,732	1.00	$8,732	$0.00	$96.10	NA
Solar photovoltaic (PV) with tracking[e, i, k]	2024	150	2	$1,448	1.00	$1,448	$0.00	$17.16	NA
Solar PV with storage[i, k]	2024	150	2	$1,808	1.00	$1,808	$0.00	$32.42	NA

Data source: Sargent & Lundy, Cost and Performance Estimates for New Utility-Scale Electric Power Generating Technologies, December 2019;

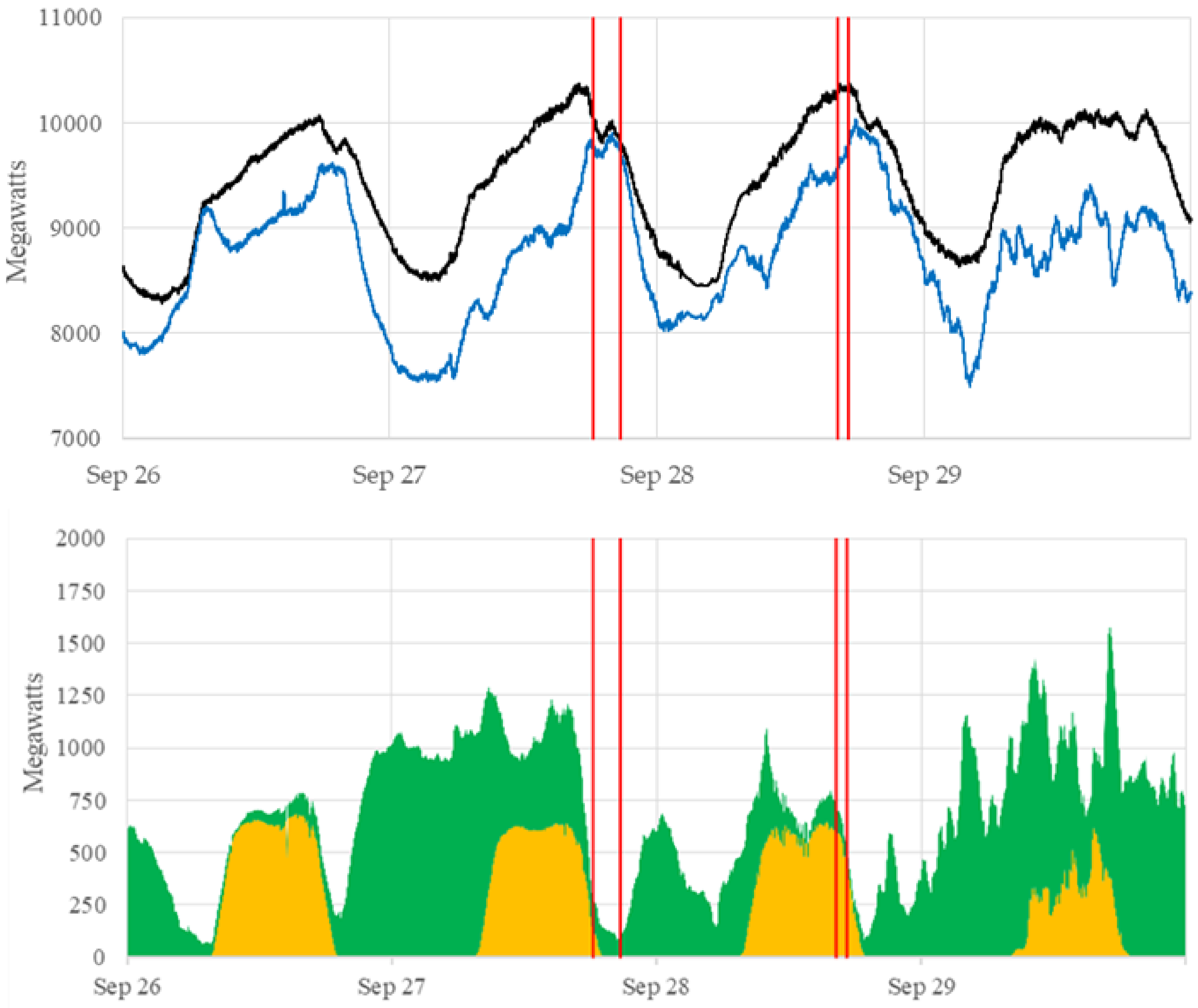
Alberta Load Duration Curve, 2023*



A duration curve shows the amount of time (hours, days, percent, etc.) that a quantity was at or above some value. The white lines show that, 47% of the time, Alberta demand is at or above 9912 MW

Energy Emergency Alerts

- Red lines show start and finish of EEAs
- Top graph shows demand and net demand
- Bottom graphs shows wind and solar generation



Energy Emergency Alerts

Last Update : Jan 12, 2024 16:23

column represents the asset's gross MW value

GENERATION

GROUP	MC	TNG	DCR
GAS	11832	9145	79
HYDRO	894	362	240
ENERGY STORAGE	190	48	115
SOLAR	1650	36	0
WIND	4481	8	0
OTHER	444	329	0
DUAL FUEL	466	465	0
COAL	820	813	0
TOTAL	20777	11206	434

INTERCHANGE

PATH	
British Columbia	
Montana	
Saskatchewan	
TOTAL	

WIND

ASSET	MC	TNG
Ardenville Wind (ARD1)*	68	0
BUL1 Bull Creek (BUL1)*	13	0
BUL2 Bull Creek (BUL2)*	16	0
Blackspring Ridge (BSR1)*	300	1
Blue Trail Wind (BTR1)*	66	0
Buffalo Atlee 1 (BFL1)*	18	0
Buffalo Atlee 2 (BFL2)*	16	0
Buffalo Atlee 3 (BFL3)*	18	1
Buffalo Atlee 4 (BFL4)*	10	0
Castle River #1 (CR1)*	39	0
Castle Rock Ridge 2 (CRR2)*	29	0
Castle Rock Wind Farm (CRR1)*	77	0
Cowley Ridge (CRE3)*	20	0
Cypress 1 (CYP1)*	196	0
Cypress 2 (CYP2)*	46	0
Enmax Taber (TAB1)*	81	5
Forty Mile Granlea (FMG1)*	200	0
Garden Plain (GDP1)*	130	0
Ghost Pine (NEP1)*	82	0
Grizzly Bear (GRZ1)*	152	0
Halkirk Wind Power Facility (HAL1)*	150	0
Hand Hills (HHW1)*	145	0
Hilda Wind (HLD1)*	100	0
Jenner 1 (JNR1)*	122	1
Jenner 2 (JNR2)*	71	0
Jenner 3 (JNR3)*	109	0
Kettles Hill (KHW1)*	63	0
Lanfine Wind (LAN1)*	151	0
McBride Lake Windfarm (AKE1)*	73	0
Oldman 2 Wind Farm 1 (OWF1)*	46	0
Paintearth Wind Project (PAW1)*	198	0
Rattlesnake Ridge Wind (RTL1)*	130	0
Riverview (RIV1)*	105	0
Sharp Hill Wind (SHH1)*	297	0
Soderglen Wind (GWW1)*	71	0
Stirling Wind (SWP1)*	113	0
Summerview 1 (IEW1)*	66	0
Summerview 2 (IEW2)*	66	0
Suncor Chin Chute (SCR3)*	30	0
Suncor Magrath (SCR2)*	30	0
Wheatland Wind (WHE1)*	120	0
Whitla 1 (WHT1)*	202	0
Whitla 2 (WHT2)*	151	0
Windrise (WRW1)*	207	0
Wintering Hills (SCR4)*	88	0

Energy Emergency Alerts*

Capacity factors by Fuel Type During 2022 Energy Emergency Alerts								
Event	BESS	Coal	Dual Fuel	Natural Gas	Hydro	Other	Solar	Wind
Sep 27, 18:14 – 20:44	7.9	65.0	N/A	74.5	54.9	65.7	2.3	4.7
Sep 28, 16:17 – 17:14	45.0	65.3	N/A	73.9	56.8	59.9	54.4	3.7
Nov 29, 16:47 – 18:04	44.2	99.7	99.9	80.9	40.5	73.4	0.0	1.0
Dec 1, 16:53 – 18:17	14.3	99.7	99.9	80.5	51.3	75.6	0.0	2.5
Dec 20, 16:47 – 18:09	0.0	99.2	99.8	85.7	38.3	73.6	0.0	2.0
Dec 21, 08:25 – 12:19	7.6	99.4	99.9	81.0	40.0	71.2	9.6	5.2
Dec 21, 16:24 – 18:28	0.0	99.4	95.0	82.9	40.1	74.1	0.0	16.4

Unit Commitment Problem*

- The *unit commitment problem* is a complex problem in economic optimization, the objective of which is to decide which plants should be turned on and synchronized to the grid so they can provide power when needed
  - the problem must be solved in advance based on forecasts of the future state of the power system
  - generators that have long start-up times must be "committed" in advance if they are to be available when needed
- The problem is extremely difficult because different types of generators have different operating constraints
  - for thermal units, these include minimum start times (which can depend on whether the unit is hold, warm, or cold), minimum run times, and maximum ramp rates

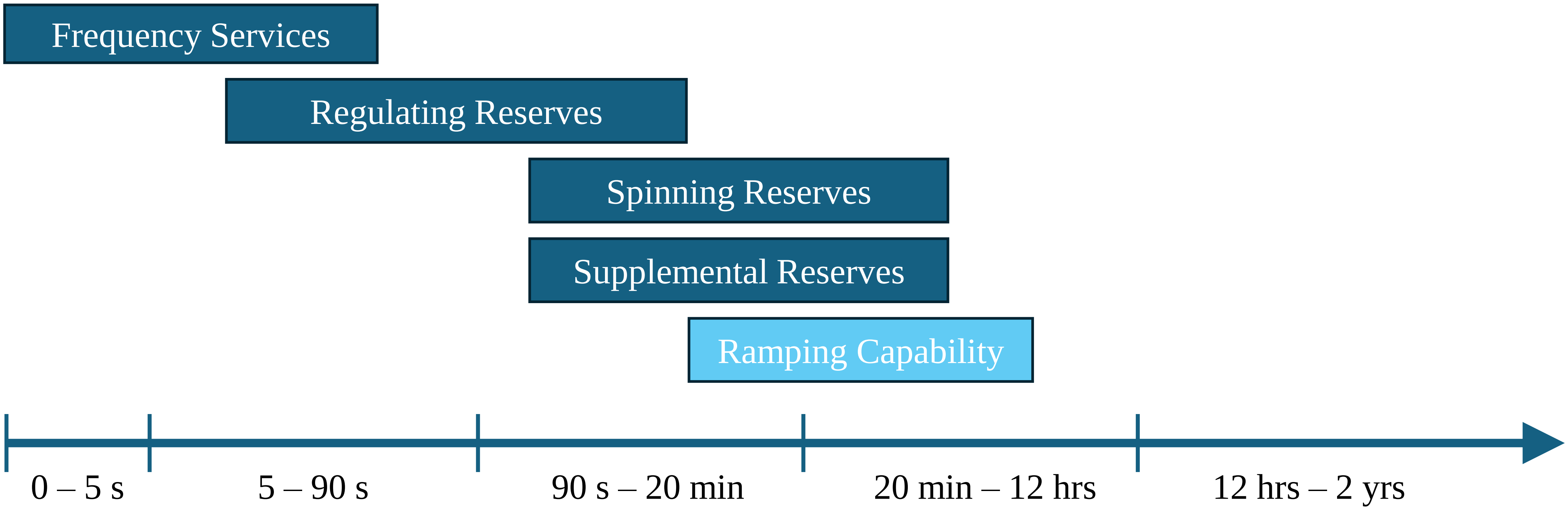
Contingencies*

- A *contingency* is an event that we know will happen, but we don't know where, where, or how large it will be
- Examples
  - generator trips (sudden loss of supply)
  - load trips (sudden loss of demand)
  - transmission line faults due to wind, lightning, icing (sudden loss of supply and/or demand)
- The power system must be able to withstand all single contingencies and high-impact multiple contingencies

Ancillary Services

- The *Electric Utilities Act* defines *ancillary services* to be “those services required to ensure that the interconnected electric system is operated in a manner that provides a satisfactory level of service with acceptable levels of voltage and frequency”
- Voltage and frequency are two characteristics of *alternating current* (ac) power systems
  - Batteries provide *direct current* (dc) power
  - AT THE RISK OF MAKING THE ENGINEERS CRINGE…
    - Voltage is like the pressure that forces electric current to flow in wires
    - The higher the voltage, the lower the current, and therefore the lower the losses, for the same power flow—which is why we raise voltages for long-distance transmission

Ancillary Services



Ancillary Services*

- Fast Frequency Response
  - provided by supply resources that can respond in less than one second
  - batteries are good providers of FFR
- Regulating Reserve
  - provided by generators that are loaded at less than full capacity
  - must increase or decrease their output within a specified range to balance the momentary fluctuations in supply and demand (response time < 28 seconds)

Ancillary Services*

- Contingency Reserve (two types)
  - *Spinning reserve* is provided by generators loaded at less than capacity so they can increase their output in response to an outage (response time < 10 minutes)
  - *Supplemental reserve* is provided by
    - generators that may be offline but can be started quickly in response to an outage
    - loads that can come off quickly
    - response time < 15 minutes
- Ramping Capability
  - New ancillary services are being considered by the Alberta Electric System Operator to account for the increasing variability of net demand and the increasing magnitude of forecast errors
- Wind and solar generators are not controllable and are therefore not eligible to provide reserves

Potential Changes to the Electricity Market

- Create a day-ahead market with day-ahead unit commitment
  - helps to reduce generators' risk of not recovering their start-up and no-load costs
  - this, in turn, will help to ensure that long-lead-time units are available when needed to ensure reliability
- Develop new ancillary services products
  - a "ramping" or "load following" service will help to ensure there is sufficient ramping capability within the online generators to follow the large swings in renewable generators' outputs
- Reduce the price floor to less than zero
  - allowing negative-price offers will help the ISO to curtail generator output in the most economically efficient manner
  - THIS COMES WITH CHALLENGES!

Potential Changes to Electricity Regulations

- Allocate some of the costs of ancillary services to generators
  - currently, loads pay all ancillary services costs
  - allocating some of the costs to generators may encourage them to minimize the variability they present to the system (e.g., by adding storage)
- Eliminate the long-standing "congestion free" approach to transmission system development
  - historically, policy was to build transmission to serve every last megawatt that could be in merit
  - this led to inefficient and expensive transmission developments

Beyond Market Design Changes*

- Hydrogen
  - with modifications, generators can burn hydrogen instead of natural gas
  - eliminates CO_2 emissions
  - economic viability is uncertain
  - leakage and material embrittlement are problematic
- Carbon [Dioxide] Capture and Storage
  - incomplete CO_2 capture
  - significant parasitic load (more generation needed to supply the same load)
  - economic viability remains uncertain
- Small Modular Nuclear Reactors
  - commercial viability has yet to be established

Toward Full Electrification*

- The two technologies most often touted to achieve economy-wide net zero energy are electric vehicles and heat pumps
- Both technologies, as they currently stand, will be materially less convenient and efficient in Alberta than in many other places
- Alberta is at a further disadvantage given its current heavy reliance on fossil fuels for electricity generation, transportation, and building energy
  - full electrification will require massive upgrades to the province’s transmission system and its distribution systems

Comparative Energy Use*

ENERGY USE (FINAL DEMAND), 2022, IN TERAJOULES

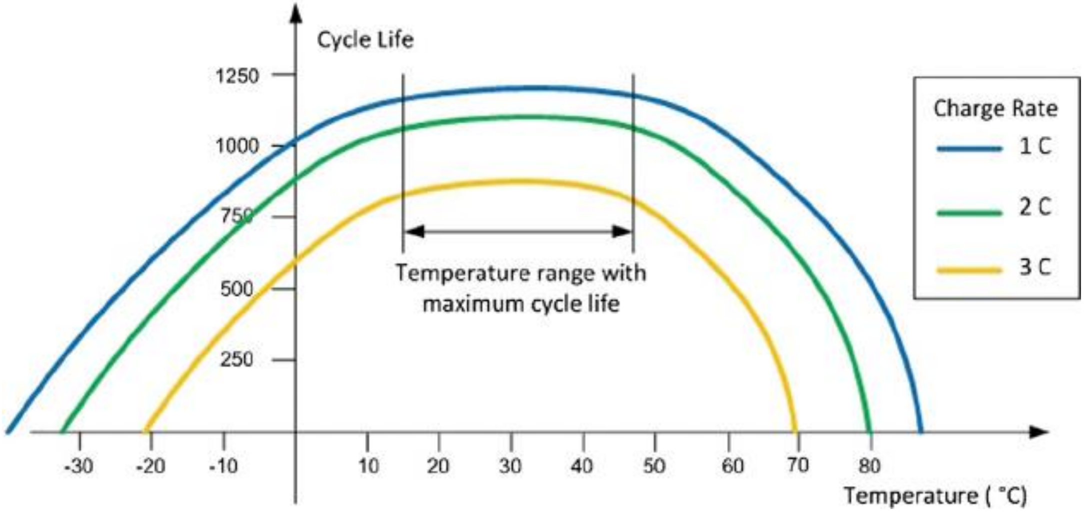
Energy Source	**Alberta**	**Quebec**	**Ontario**	**BC**	**Canada**
Electricity	227 065	765 432	503 977	217 182	2 015 537
Natural gas incl. liquids	1 517 005	257 651	936 769	294 992	3 416 941
Refined petroleum	467 699	608 139	904 580	427 184	3 001 038
Coal, coke, coke oven gas	542	15 975	97 239	3 431	121 655
Steam	14 077	3 653	5 228	0	29 688
Total	2 226 388	1 650 850	2 447 794	942 789	8 584 859
Electricity share	10.2%	46.4%	20.6%	23.0%	23.5%

1 terajoule [TJ] = 277.778 MWh

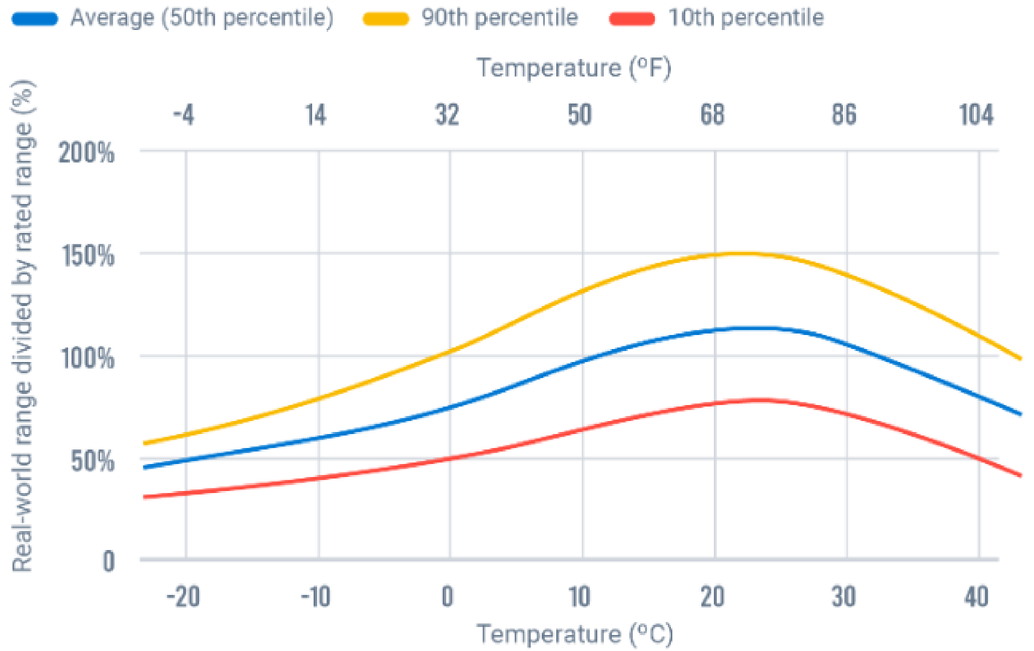
Statistics Canada (May 2, 2022): *Report on Energy Supply and Demand in Canada, 2019 Revision*, page 8.
https://www150.statcan.gc.ca/pub/57-003-x/57-003-x2022001-eng.pdf

Electric Vehicles

- Alberta's ambient temperatures are often outside the temperature range within which battery cycle life is maximized
- Vehicle range decreases in cold weather
- Charging will take more time and more electricity than in less harsh climates
- There are challenges for fleets, such as police cars, that don't have hours to charge



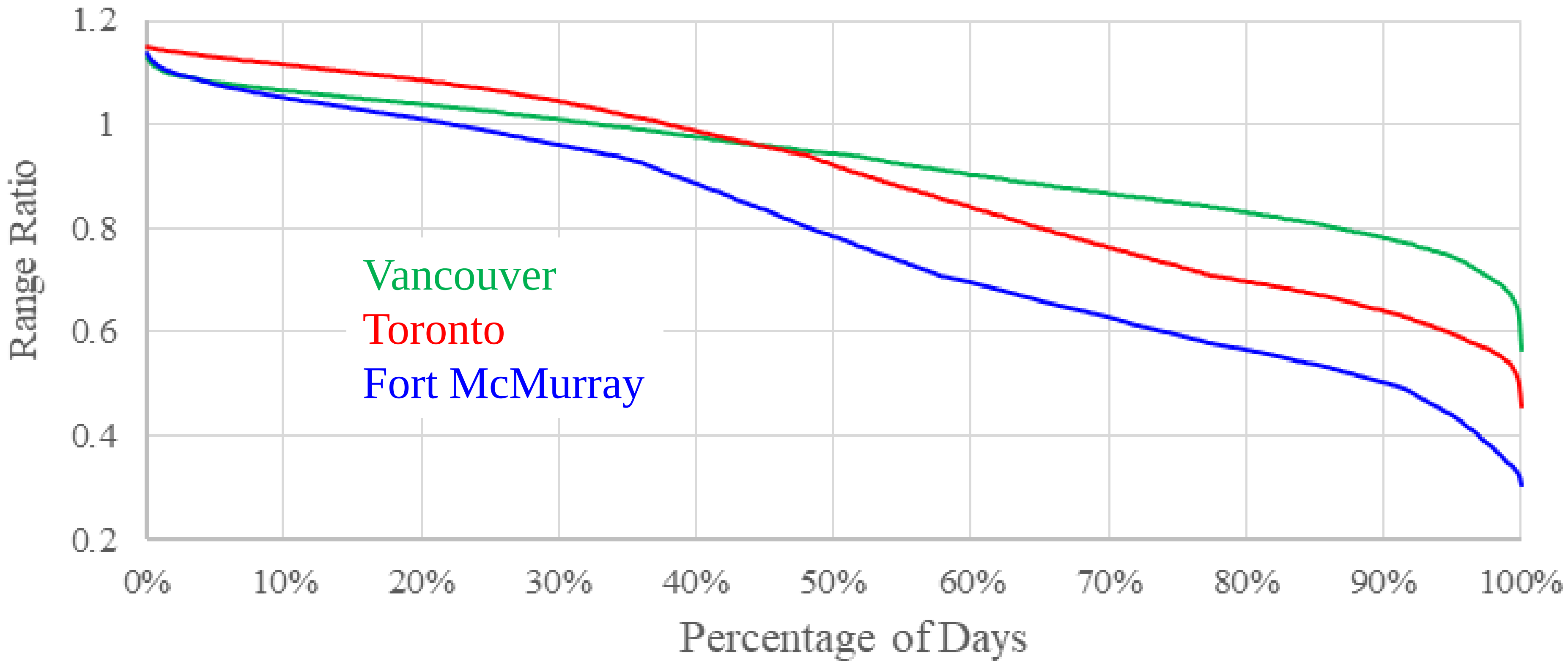
Rezvanizaniani, S.M., et al. (June 2014): "Review and recent advances in battery health monitoring and prognostics technologies for electric vehicle (EV) safety and mobility." *Journal of Power Sources.* 256. 110–124. Retrieved December 22, 2023. Link



Argue, C. (February 6, 2023): *To what degree does temperature impact EV range?* Retrieved December 24, 2023. Link

Electric Vehicles*

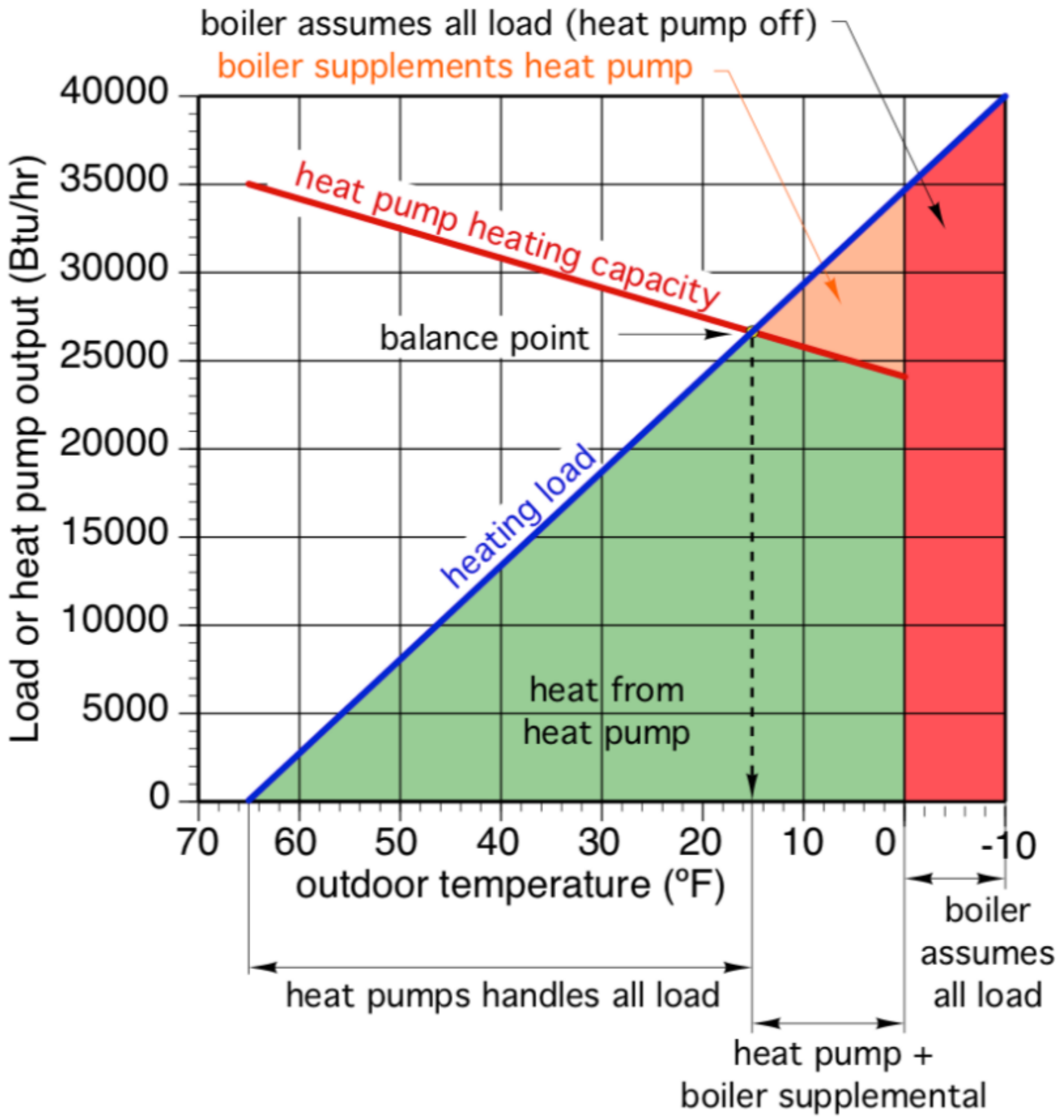
- Combining temperature and range data gives these range duration curves



Electric Vehicles

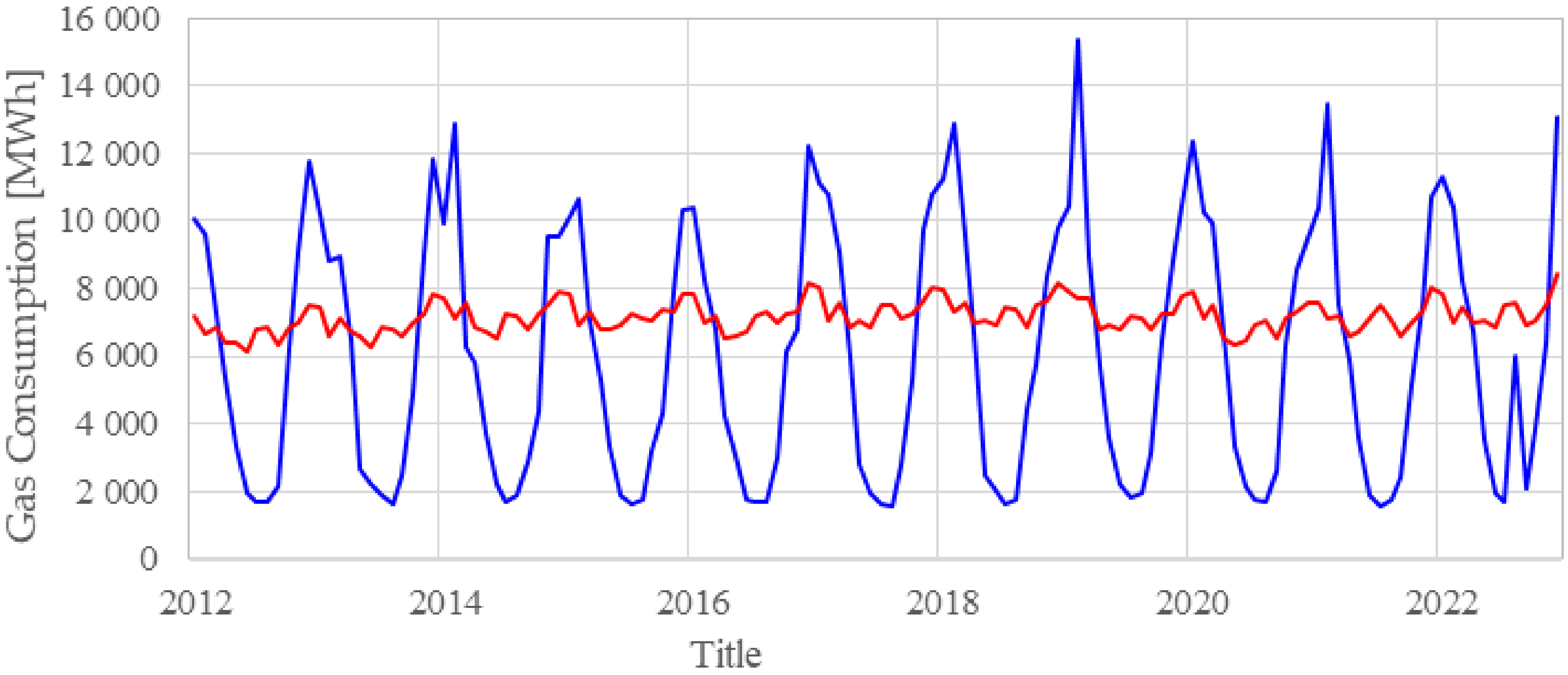
Heat Pumps

- Heat pumps are more efficient than gas furnaces, so energy savings over the course of a year can be significant
- However, at very cold temperature, either gas or electric heating is needed to supplement the heat pump
- Peak electric heating demand for just residential customers would require massive wire upgrades



Heat-pump-balance-point.png (1615×944) (sustainableheating.org)

Heat Pumps



The blue line shows, for each month from 2012 to 2022, the average per-hour energy delivery to **residential customers** in the form of natural gas. The red line shows the average monthly electricity demand for the entire province, excluding industrial load that is served by on-site generation.

Example: Report ST3 from the Alberta Energy Regulator ER gives January 2024 residential consumption as 822 143 thousand cubic metres. The average energy content of Alberta natural gas is about 40.5 GJ, or 11.25 MWh, per thousand cubic metres. So, January residential consumption is 822 143 × 11.25 = 9.25 million MWh, or 12 400 MWh per hour.

Supplemental Slides

Notable Levels of “Carbon Pollution”

Effect / Level	PPM
Plants die below this level	150
Atmospheric level at Mauna Loa (Sep 30, 2024)	**422**
Optimal level for plant growth (greenhouse target levels)	800 to 1200
ASHRAE & OSHA standard for room ventilation	1 000
NIOSH 10-hour exposure limit	5 000
Level experienced by Apollo 13 astronauts	13 000
NIOSH 15-minute exposure limit	30 000
Human breath	40 000
Headaches, sight impairment	50 000
Unconscious, further exposure death	100 000

Environmental Effects of "Carbon Pollution"

United Nations Intergovernmental Panel on Climate Change (IPCC), Sixth Assessment Report (AR6), Working Group I: *Climate Change 2021: The Physical Science Basis*, Table 12.12

High confidence of decrease	Medium confidence of decrease	Low confidence in direction of change	Medium confidence of increase	High confidence of increase

1. *High confidence* except over a few regions (CNA and NWS) where there is *low agreement* across observation datasets.
2. *High confidence* in tropical regions where observations allow trend estimation and in most regions in the mid-latitudes, *medium confidence* elsewhere.
3. *High confidence* in all land regions.
4. Emergence in Australia, Africa and most of Northern South America where observations allow trend estimation.
5. Emergence in other regions.
6. Increase in most northern mid-latitudes, Siberia, Arctic regions by mid-century, others later in the century.
7. Decrease in the Mediterranean area, Southern Africa, South-west Australia.
8. Northern Europe, Northern Asia and East Asia under RCP8.5 and not in low-end scenarios.
9. Europe, Eastern and Western North America (snow).
10. Arctic (snow).
11. Arctic sea ice only.
12. Everywhere except WAN under RCP8.5.
13. With varying area fraction depending on basin.
14. Pacific and Southern oceans then many other regions by 2050.

CID = Climate Impact-Driver

Table 12.12 | Emergence of CIDs in different time periods, as assessed in this section. The colour corresponds to the confidence of the region with the highest confidence: white cells indicate where evidence is lacking or the signal is not present, leading to overall *low confidence* of an emerging signal.

Climatic Impact-driver Type	Climatic Impact-driver Category	Already Emerged in Historical Period	Emerging by 2050 at Least for RCP8.5/SSP5-8.5	Emerging Between 2050 and 2100 for at Least RC8.5/SSP5-8.5
Snow and Ice	Snow, glacier and ice sheet		9	10
	Permafrost			
	Lake, river and sea ice	11		
	Heavy snowfall and ice storm			
	Hail			
	Snow avalanche			
Coastal	Relative sea level		12	
	Coastal flood			
	Coastal erosion			
Open Ocean	Mean ocean temperature			
	Marine heatwave			
	Ocean acidity			
	Ocean salinity	13		
	Dissolved oxygen	14		
Other	Air pollution weather			
	Atmospheric CO_2 at surface			
	Radiation at surface			

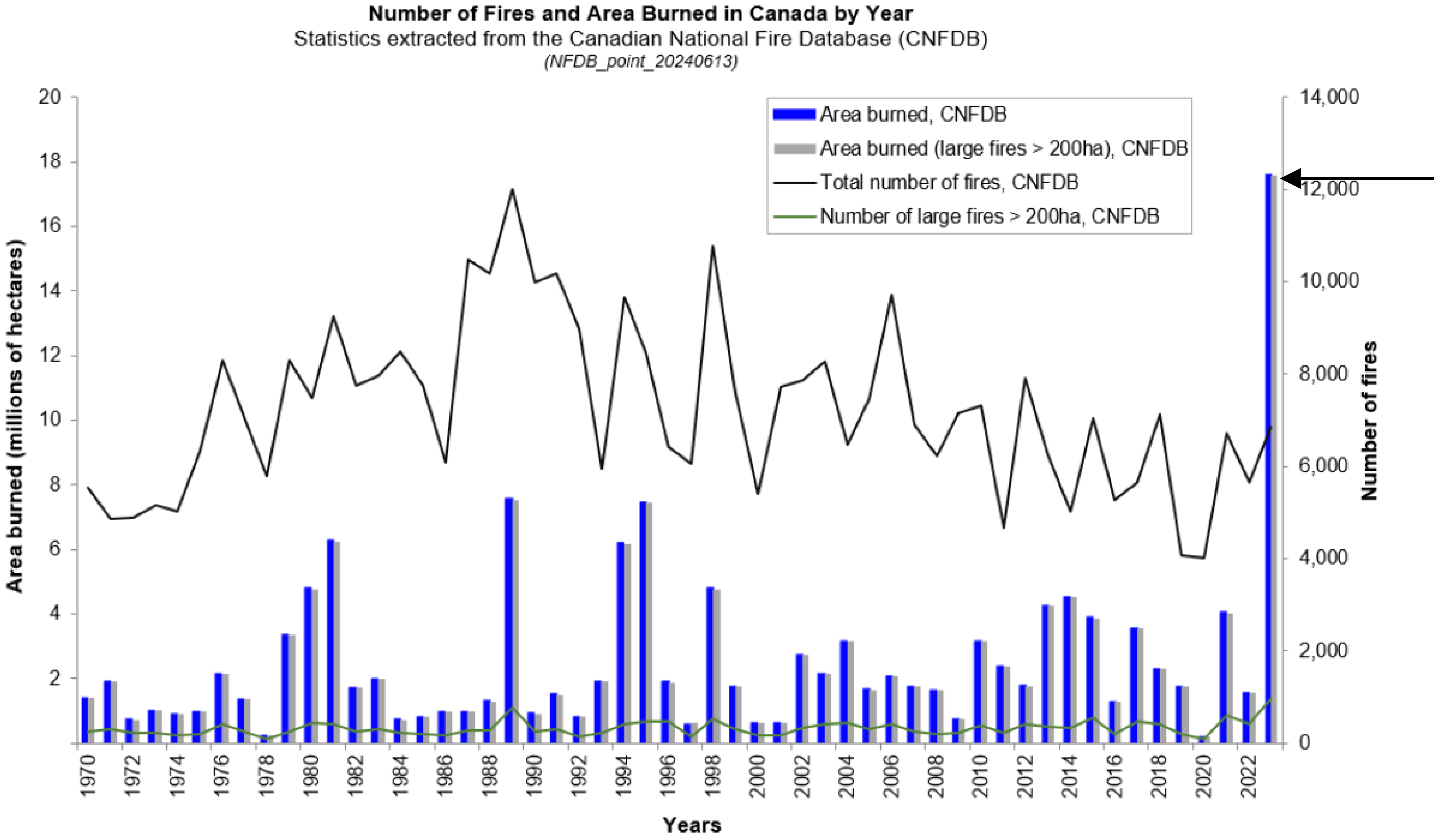
Environmental Effects of "Carbon Pollution"

CID = Climate Impact-Driver

Table 12.12 | Emergence of CIDs in different time periods, as assessed in this section. The colour corresponds to the confidence of the region with the highest confidence: white cells indicate where evidence is lacking or the signal is not present, leading to overall *low confidence* of an emerging signal.

Climatic Impact-driver Type	Climatic Impact-driver Category	Already Emerged in Historical Period	Emerging by 2050 at Least for RCP8.5/SSP5-8.5	Emerging Between 2050 and 2100 for at Least RC8.5/SSP5-8.5
Heat and Cold	Mean air temperature	1		
	Extreme heat	2	3	
	Cold spell	4	5	
	Frost			
Wet and Dry	Mean precipitation		6 7	
	River flood			
	Heavy precipitation and pluvial flood			8
	Landslide			
	Aridity			
	Hydrological drought			
	Agricultural and ecological drought			
	Fire weather			
Wind	Mean wind speed			
	Severe wind storm			
	Tropical cyclone			
	Sand and dust storm			

Environmental Effects of “Carbon Pollution”



5% of Canada’s 347 million hectares of forest

The graph shown during the live presentation was taken from https://cwfis.cfs.nrcan.gc.ca/ha/nfdb. The graph at that link has been replaced by this one, which starts in 1970 instead of 1990.

Environmental Effects of “Carbon Pollution”

Table 1. Characteristics for the 16 fire-history study sites in North American boreal forests including mean burn rate (BR; % of study site area burned per year) estimates during the historical and modern periods.

Fire-history study site	Province, territory, or state	Area surveyed (km^2)	Source	Historical period (1700–1990) Censored data	Record (calendar years) Start	Record (calendar years) End	Mean BR estimate (% per year)	Modern period (1980–2020) Mean BR estimate (% per year)
1: Gaspésie	QC	8669	Lauzon *et al.* (2007)	Y	1790	1990	1.06	0.09
2: Côte Nord	QC	15 515	Cyr *et al.* (2007)	Y	1720	1990	0.48	0.14
3: Lac-Saint-Jean	QC	7915	Bélisle *et al.* (2011)	Y	1700	1990	0.37	0.20
4: Central Québec	QC	3629	Lesieur *et al.* (2002)	Y	1720	1990	0.98	0.53
5: Waswanipi	QC	10 628	Le Goff *et al.* (2007)	Y	1720	1990	0.74	0.56
6: Eastern Abitibi	QC	3505	Kafka *et al.* (2001)	Y	1770	1990	0.77	0.49
7: Southeastern Abitibi	QC	13 319	Drobyshev *et al.* (2017)	Y	1800	1990	1.02	0.00
8: Northern Témiscamingue	QC	2943	Grenier *et al.* (2005)	Y	1740	1990	0.48	0.00
9: Western Abitibi	QC	16 051	Bergeron *et al.* (2004)	Y	1700	1990	0.85	0.06
10: Lake Abitibi	ON	10 182	Lefort *et al.* (2003)	Y	1730	1990	0.69	0.02
11: Central Ontario	ON	13 795	Senici *et al.* (2010)	Y	1750	1990	0.46	0.60
12: Prince Albert	SK	3827	Weir *et al.* (2000)	N	1760	1990	3.78	0.40
13: Rutledge Lake	NT	10	Johnson (1979)	N	1770	1970	5.54	0.00
14: Wood Buffalo	AB	41 231	Larsen (1997)	N	1700	1990	1.90	1.47
15: Northwestern Canada	AB, BC, NT	487 633	Wallenius *et al.* (2011)	N	1770	1990	2.37	0.77
16: Porcupine River	AK	36 000	Yarie (1981)	N	1790	1970	5.91	1.13

Chaverdès et al. (2022): Converging and diverging burn rates in North American boreal forests from the Little Ice Age to the present (csiro.au)

Environmental Effects of “Carbon Pollution”

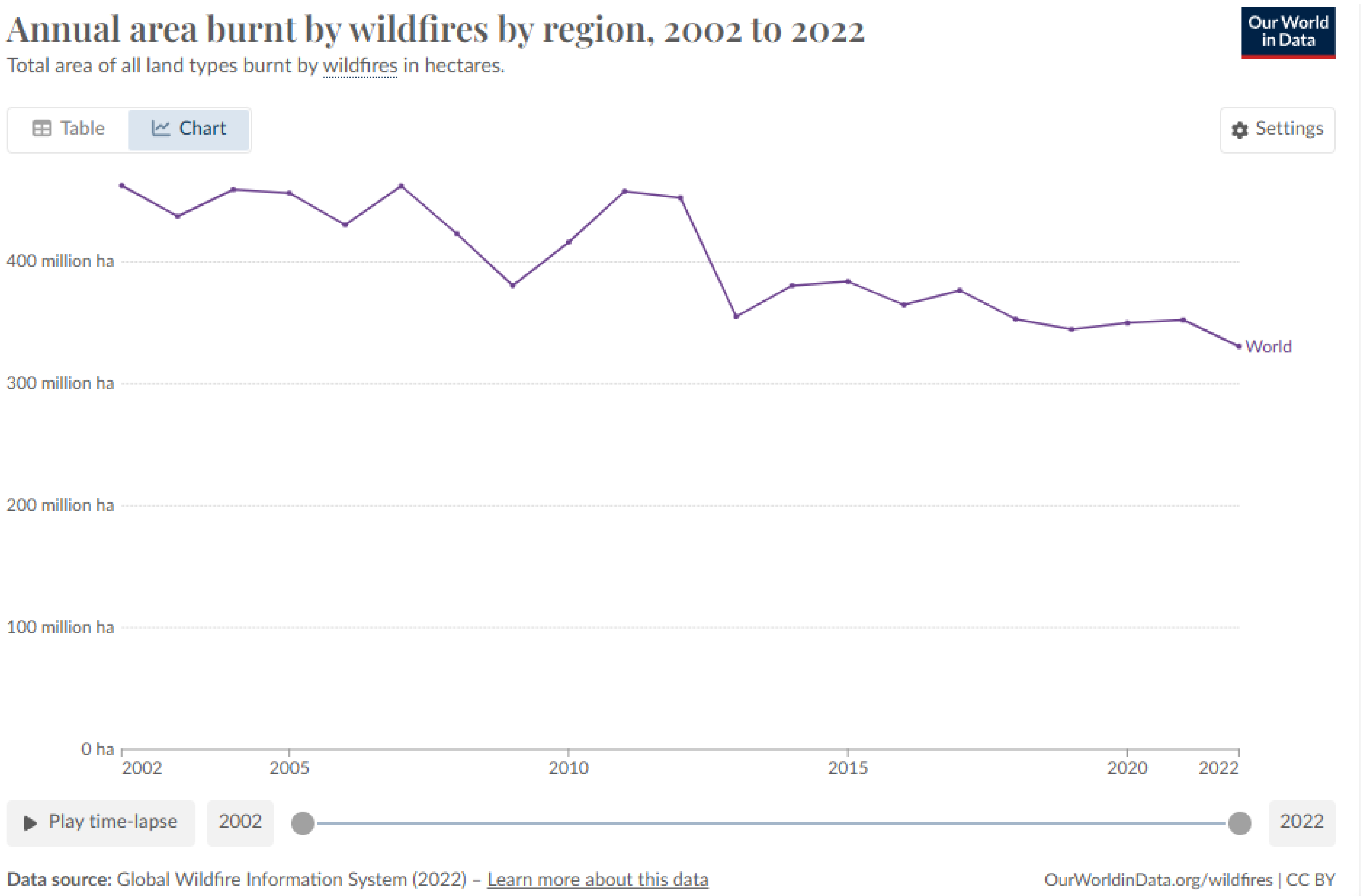
Annual area burnt by wildfires by region, 2002 to 2022

Total area of all land types burnt by wildfires in hectares.

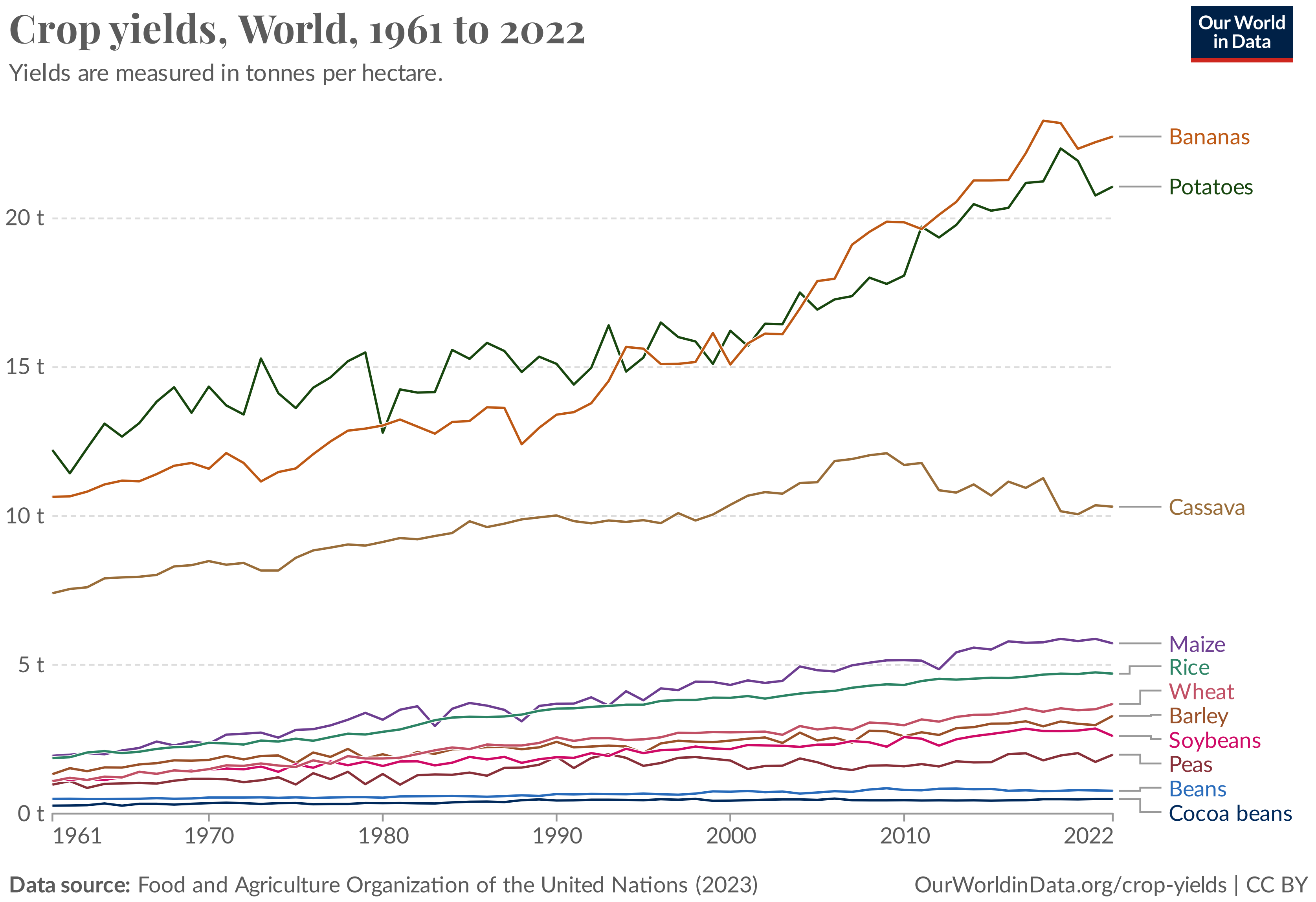
Data source: Global Wildfire Information System (2022) – Learn more about this data

OurWorldinData.org/wildfires | CC BY

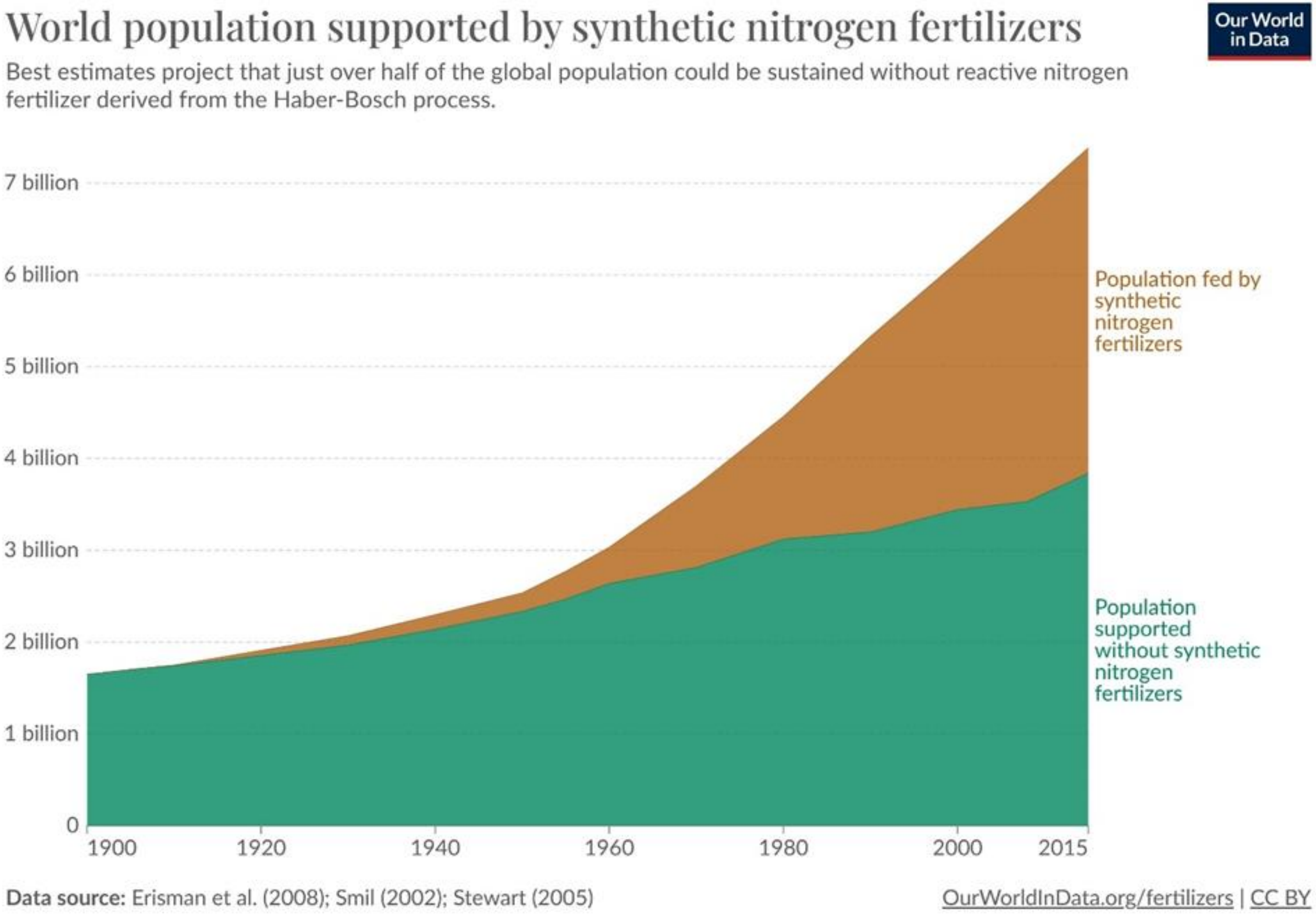
Environmental Effects of "Carbon Pollution"



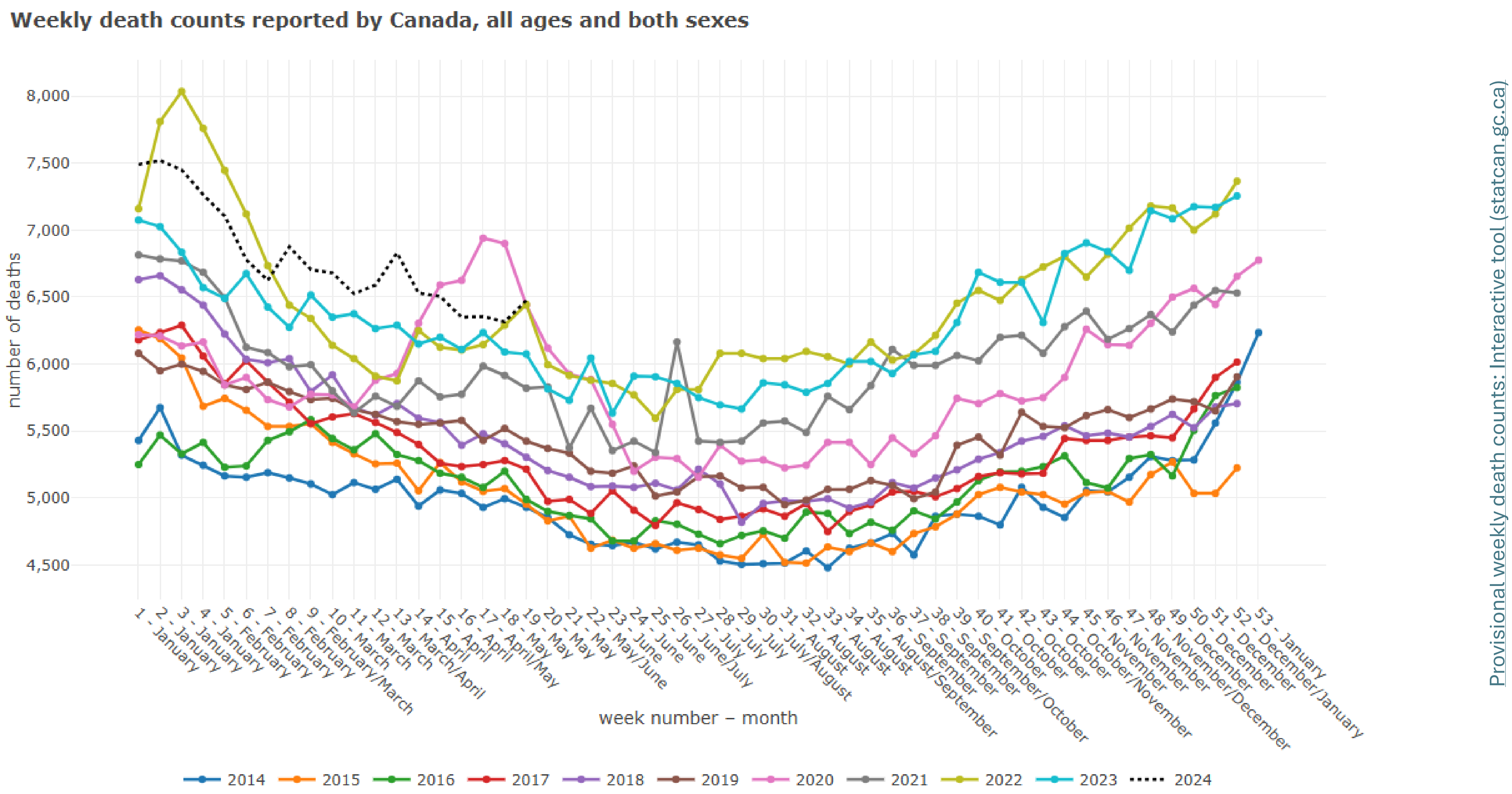
Environmental Effects of "Carbon Pollution"



Environmental Effects of “Carbon Pollution”



Environmental Effects of "Carbon Pollution"



Environmental Effects of "Carbon Pollution"