Scaling Up - High PV and Renewables Penetration Scenarios

How do we build a firm renewable power system at minimal cost?

Thursday 6th May, 2021

Marc Perez, Ph.D.

ISES International Solar Energy Society

Clean Power Research | AMERICAN SOLAR ENERGY SOCIETY | SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy | MN | CLCA Columbia University Center for Life Cycle Analysis | NSF

Scaling Up - High PV and Renewables Penetration Scenarios

Are renewables large enough?
Are renewables cheap enough?
How do we overcome intrinsic intermittency?

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Are renewables large enough?

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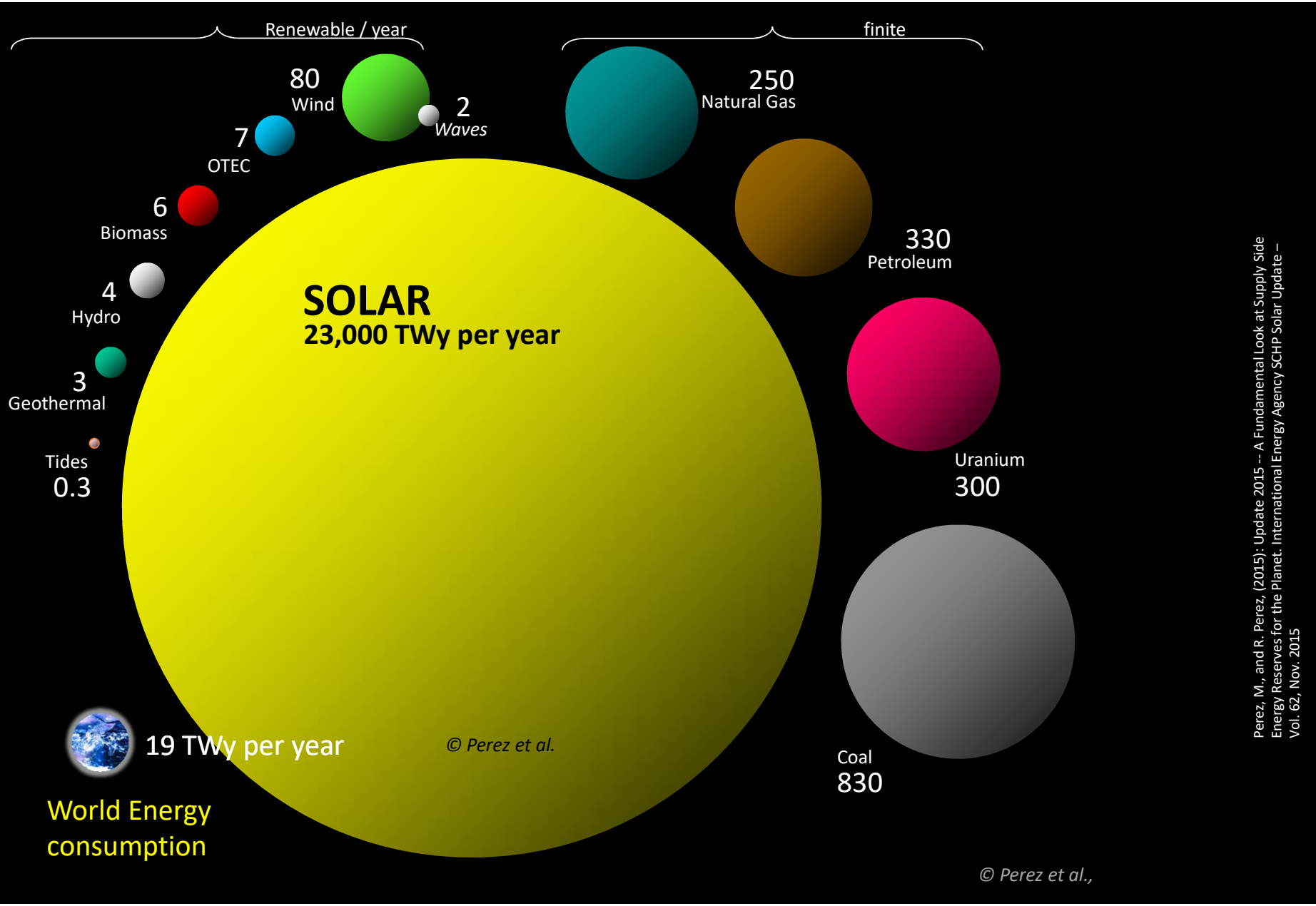
How do we overcome intrinsic intermittency?


Renewable / year
finite
80
Wind
2
Waves
7
OTEC
6
Biomass
4
Hydro
3
Geothermal
Tides
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250
Natural Gas
330
Petroleum
Uranium
300
Coal
830
SOLAR
23,000 TWy per year
19 TWy per year
World Energy
consumption
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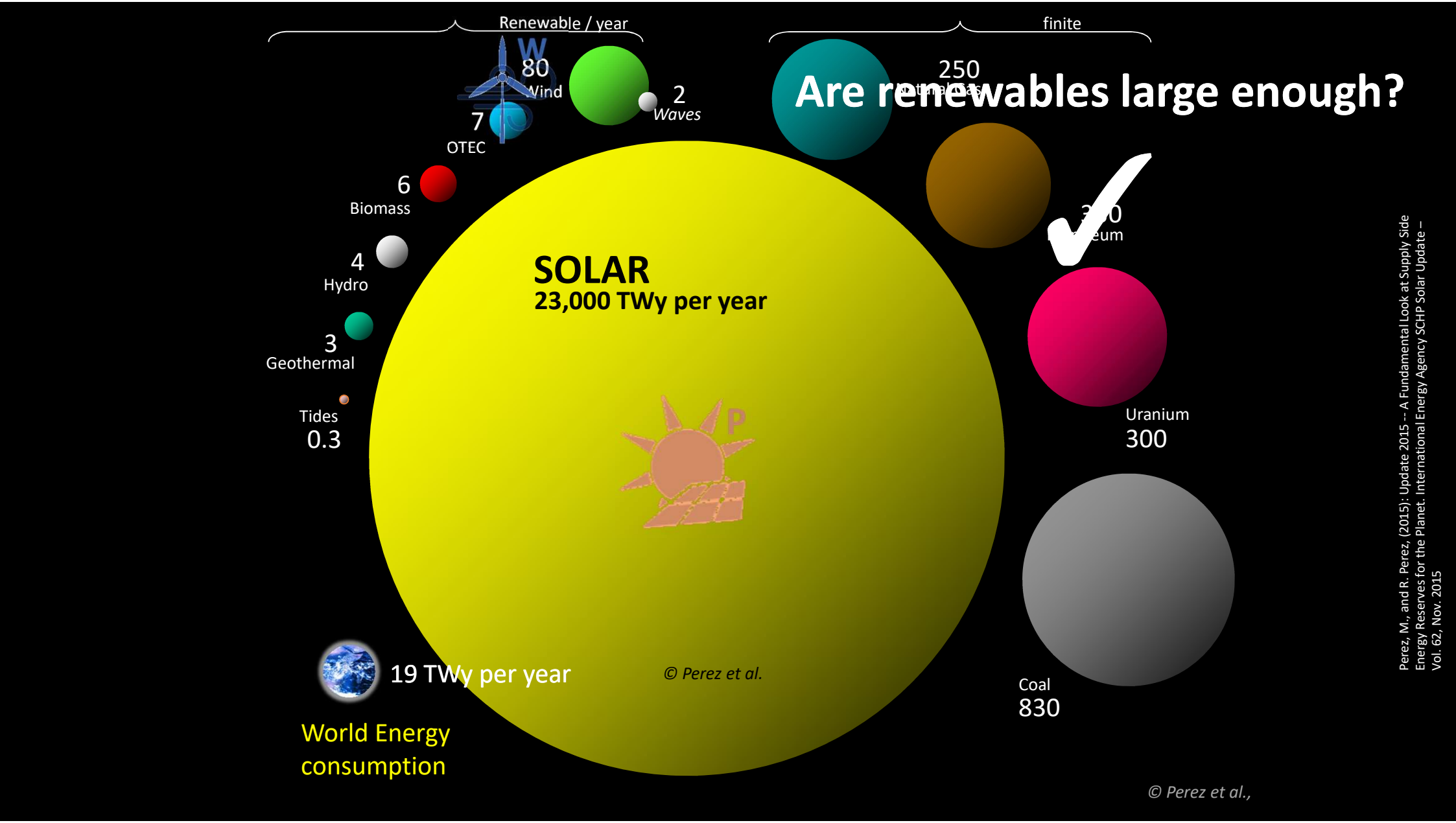
Perez, M., and R. Perez, (2015): Update 2015 -- A Fundamental Look at Supply Side Energy Reserves for the Planet. International Energy Agency SCHP Solar Update – Vol. 62, Nov. 2015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✓

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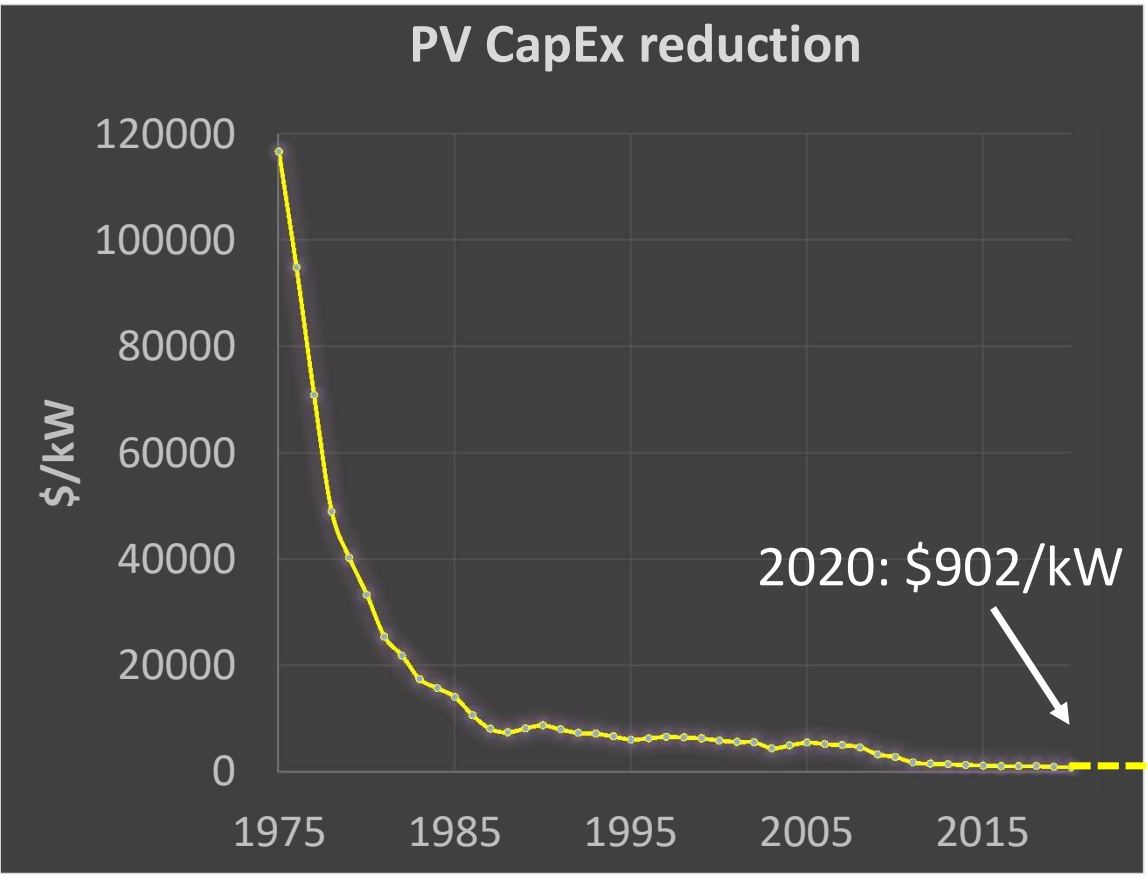

"Solar PV is rapidly becoming the least expensive technology to generate electricity on a pure energy (kWh) basis"

(Fortune Magazine)

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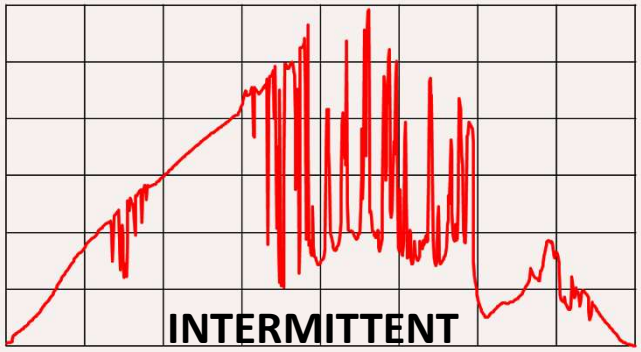
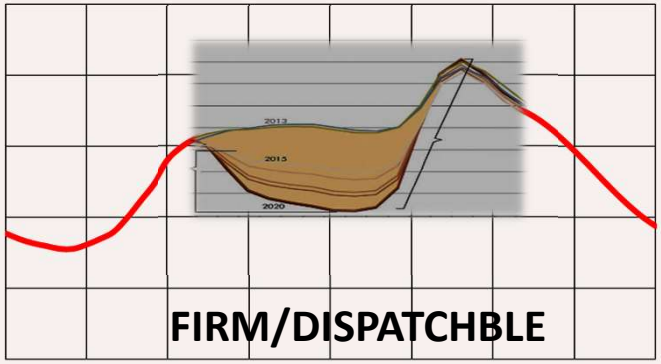
INTRADAY





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Are renewables large enough?

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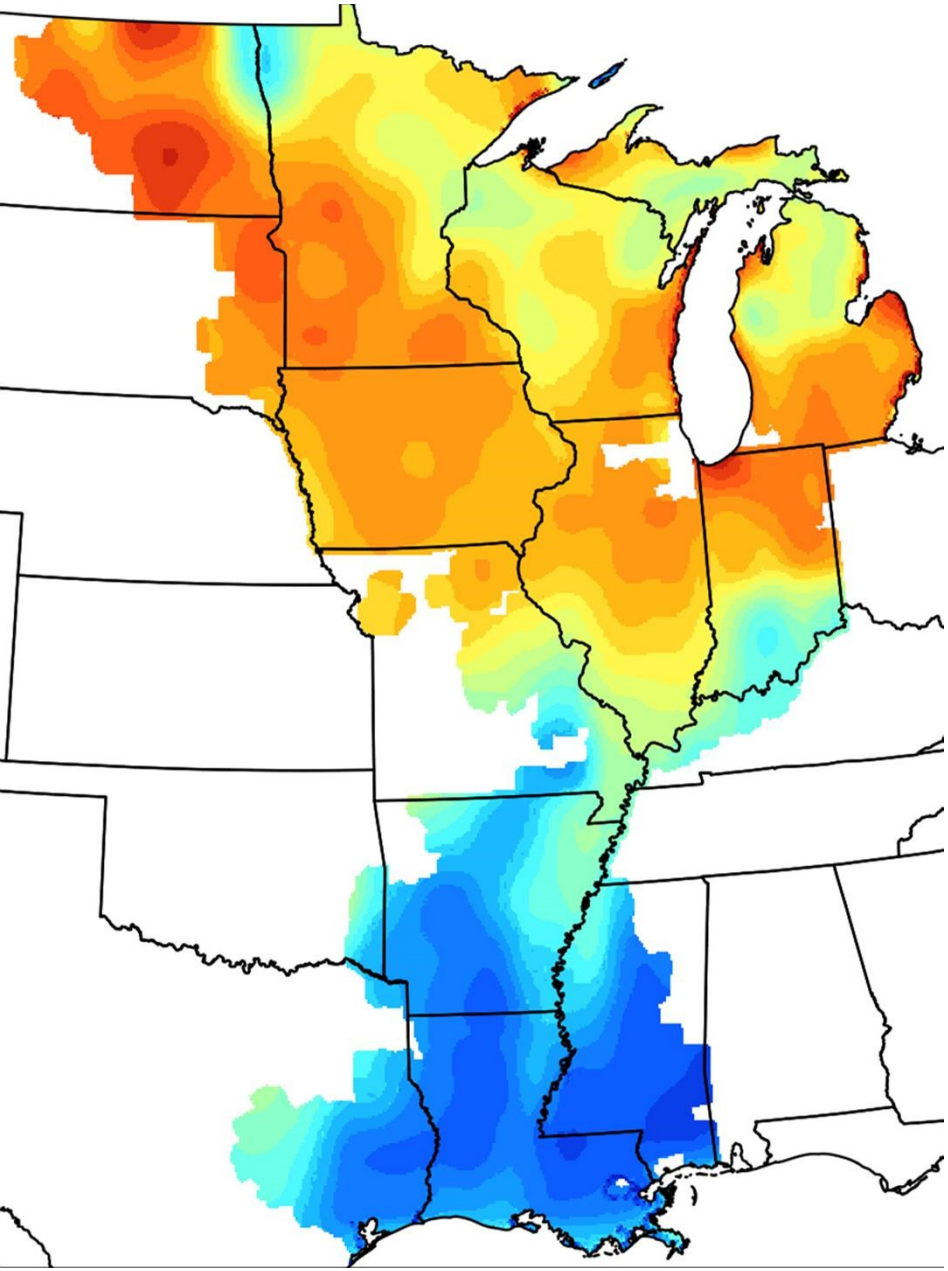
MULTI-DAY SEASONAL

24/7/365

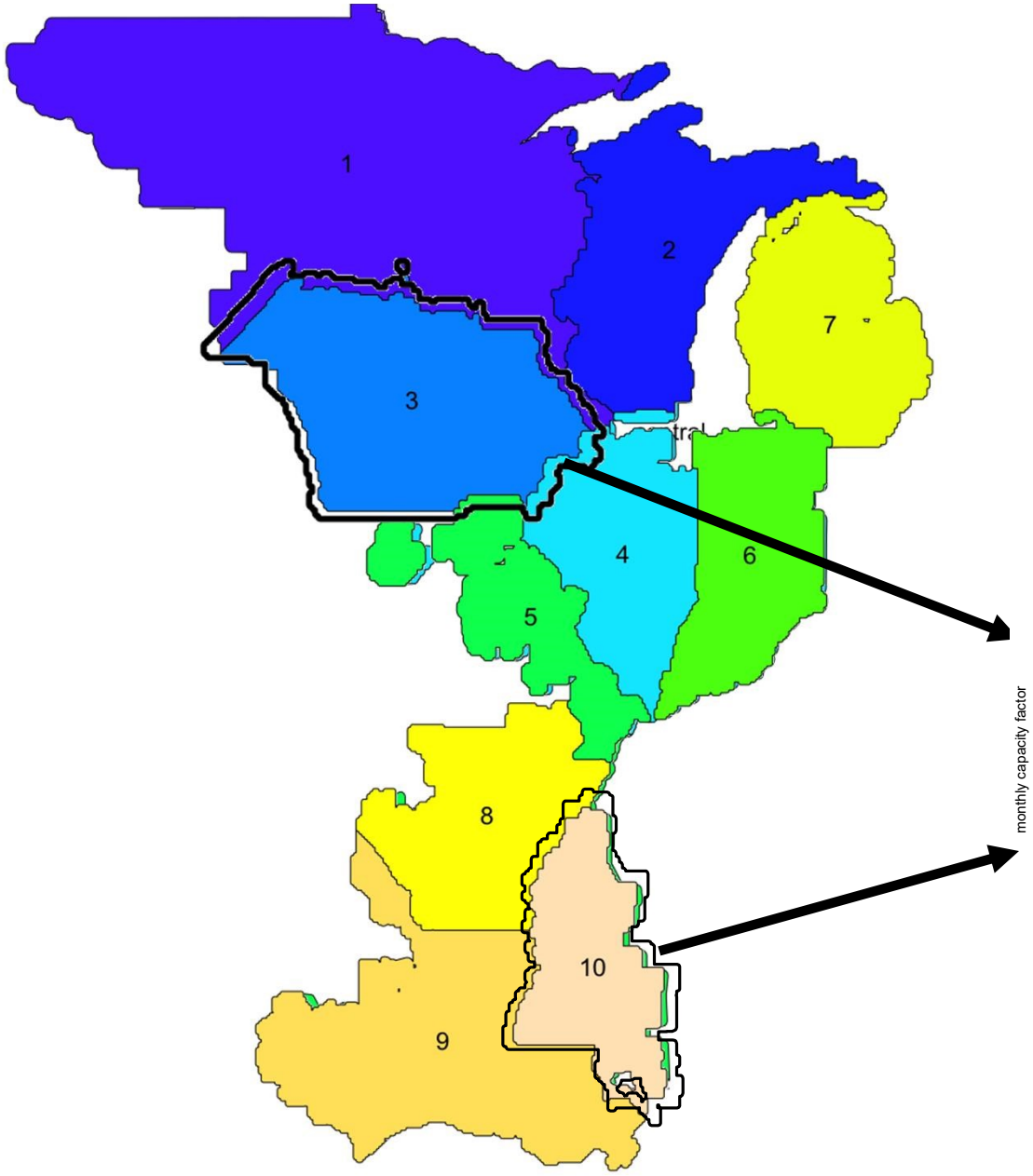


MN Solar Pathways

- 3-year DoE-funded project to investigate high-penetration solar across the state and then the Midwest.

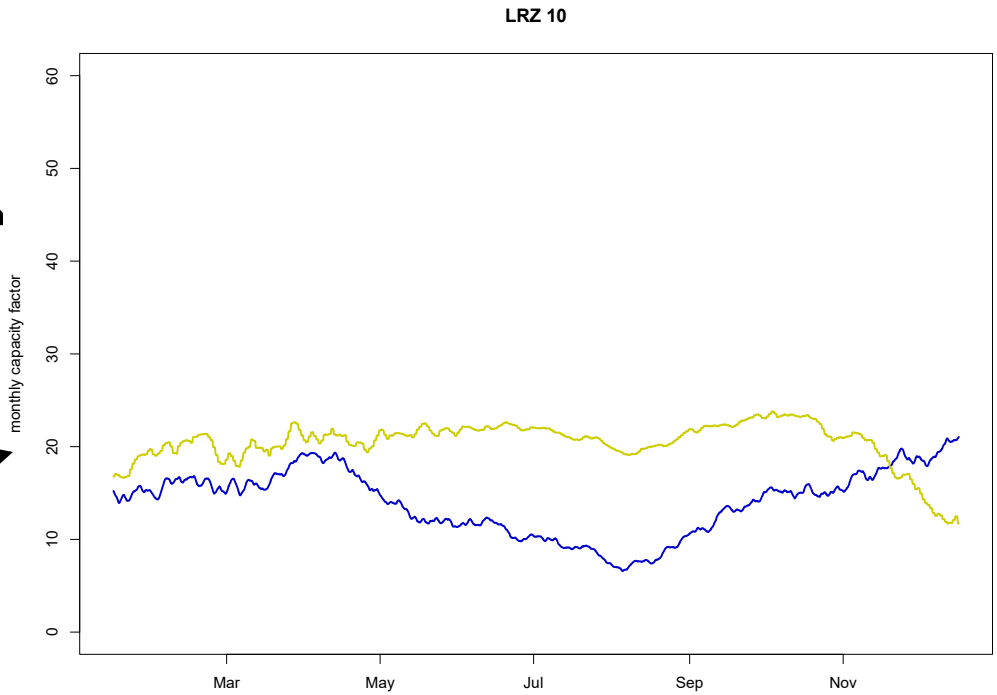
How do we investigate 100% renewables?

- **CPT Model→** Using an optimized portfolio of solutions (storage, geographic dispersion, dispatchable backup, renewable hybridization), how far down can we drive costs when firmly serving load (24/7/365) with high levels of renewables?
- Solar and Wind resource have different spatial and temporal characteristics across large spatial regions: how does this affect cost?
- How do the expected prices of system components change the picture?



Some Characteristics regarding MISO

- **Load:** 120 GW peak, 670 TWh/yr
- **Renewables:** 21 GW wind | 330 MW PV
- **Geography:**
  - 3 Macro Regions
  - 10 Load Resource Zones
- **Resource:** Vastly different resource characteristics



Let's examine the influence these characteristics have on optimized capacity expansion and the costs that result

How do we optimize capacity expansion and dispatch?

Enter the **Clean Power Transformation (CPT)** model (used across MN Solar Pathways, Réunion, Italy, New York, Los Angeles)

- Optimizes capacities and dispatch of the following technologies:
  - Generation: Wind, solar, can include dispatchable gen like gas
  - Balancing: electricity storage and *implicit storage* (overbuilding + curtailment)

- Optimization is LCOE cost-based and four scenarios that include component costs and characteristics have been developed from the latest NREL ATB[1]:
  - 2050, high and low technological development
  - 2025, high and low technological development

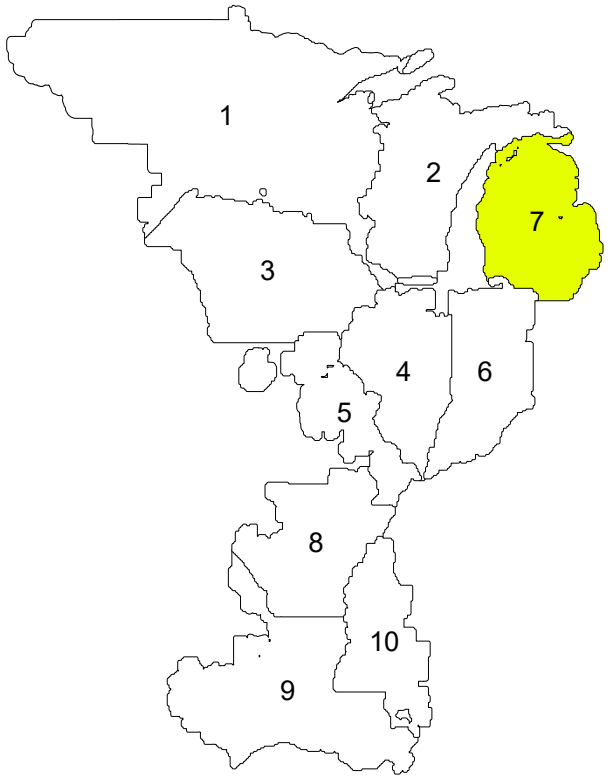
		Utility PV		Wind		Storage				Gas			
		CapEx $/kW	Opex $/kW-yr	CapEx $/kW	Opex $/kW-yr	CapEx $/kWh -pack	CapEx $/kW -BoS	Opex % total CapEx / yr	RT eff	CapEx $/kW	Opex fixed $/kW-yr	Opex variable $/MWh	Fuel cost $/MWh
2025	High	$ 733	$ 9	$ 1,311	$ 38	$ 99	$ 323	2.5%	85%	$ 872	$ 11	$ 5	$ 26
	Low	$ 1,042	$ 13	$ 1,500	$ 42	$ 155	$ 552	2.5%	85%	$ 872	$ 11	$ 5	$ 39
2050	High	$ 356	$ 4	$ 813	$ 24	$ 41	$ 133	2.5%	85%	$ 800	$ 11	$ 5	$ 29
	Low	$ 899	$ 11	$ 1,294	$ 38	$ 112	$ 471	2.5%	85%	$ 800	$ 11	$ 5	$ 65

- These 4 scenarios are run for 14 distinct geographic zones (10 LRZs, 3 Regions and MISO) pictured on previous page. Each region has it's own distinct: Load shape and Resource Characteristics.

[1]NREL (National Renewable Energy Laboratory). 2019. 2019 Annual Technology Baseline. Golden, CO: National Renewable Energy Laboratory.

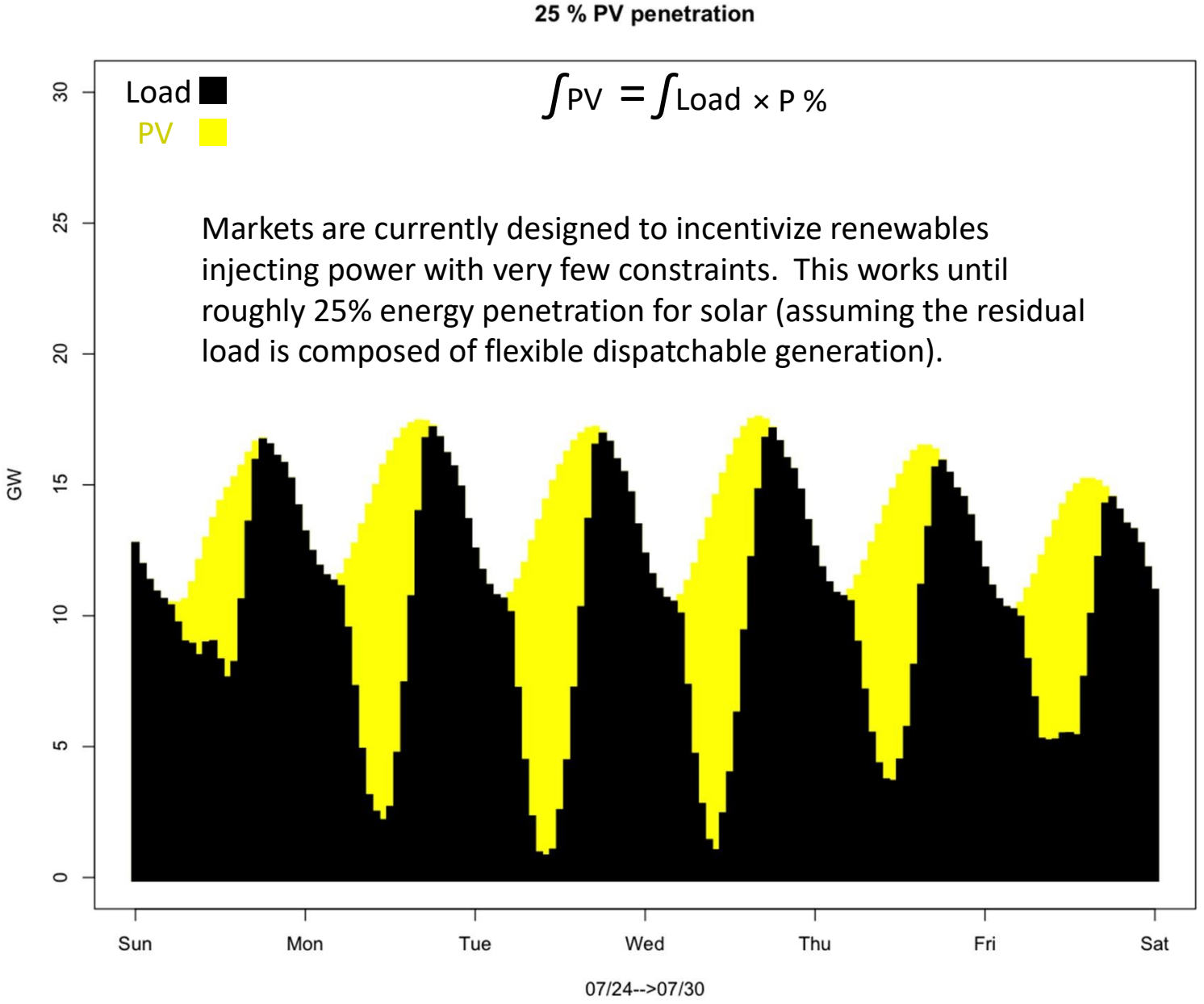
23,243 year-long hourly-interval dispatch simulations have been performed in seeking the optimal across these 56 distinct scenarios. *Let's dive in.*

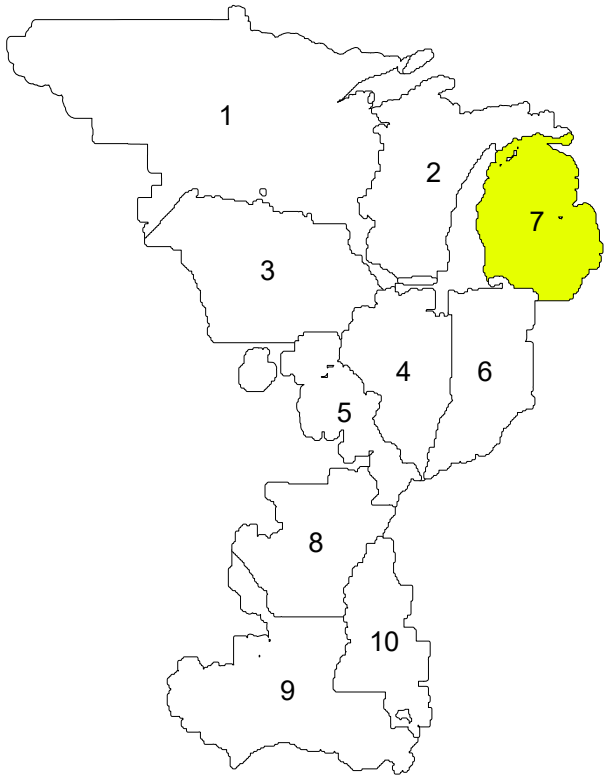
Let's start the story when renewables are small enough in capacity to never exceed load in any given hour.



Consider LRZ 7

2025, low technological development, PV *alone*, no overbuild





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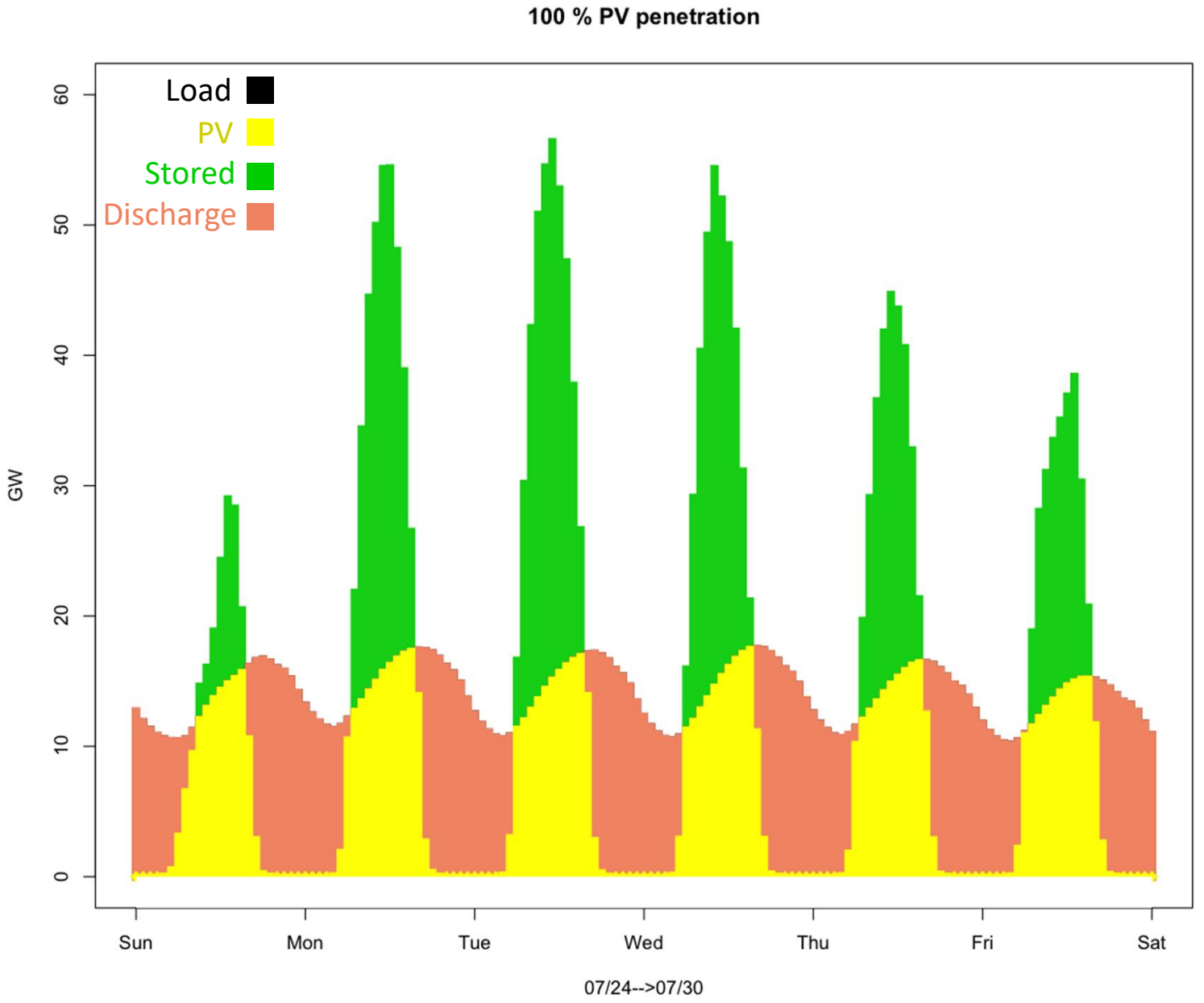

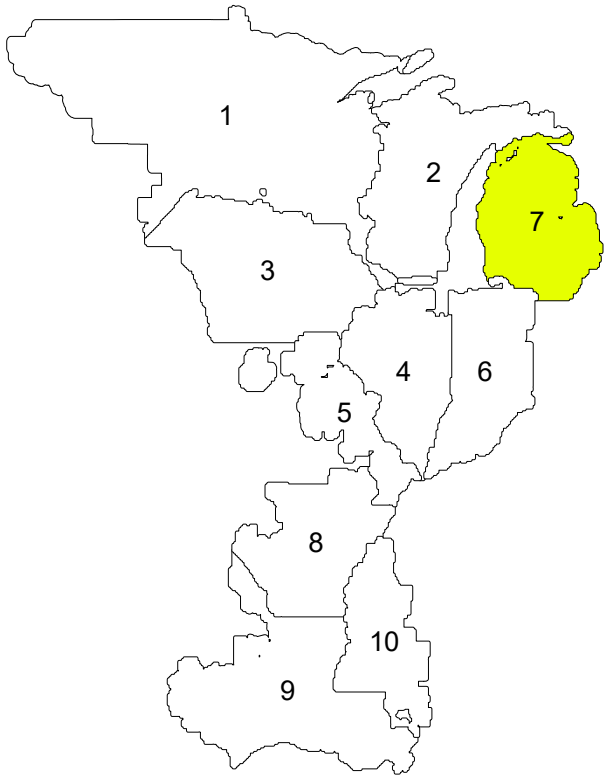

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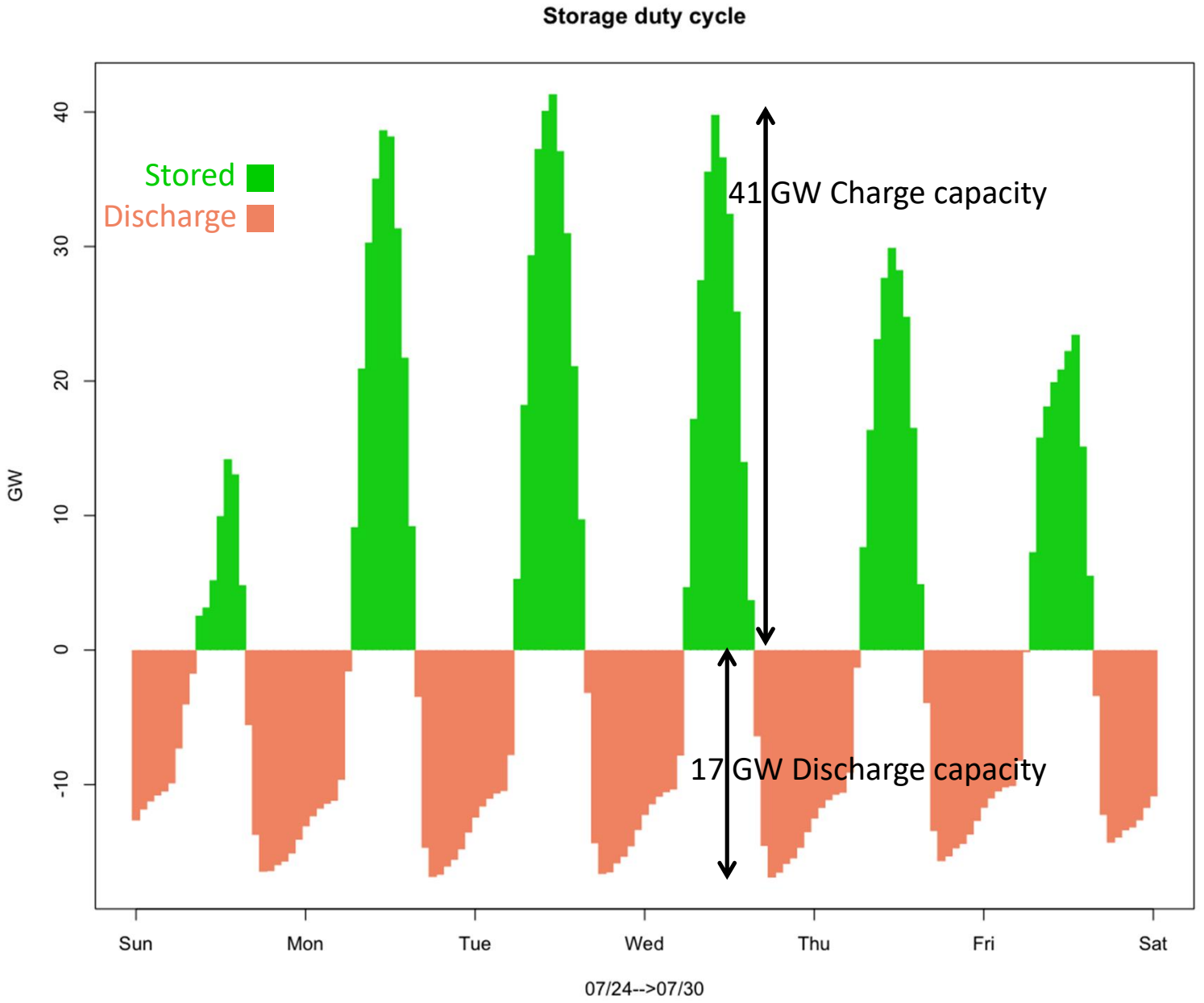

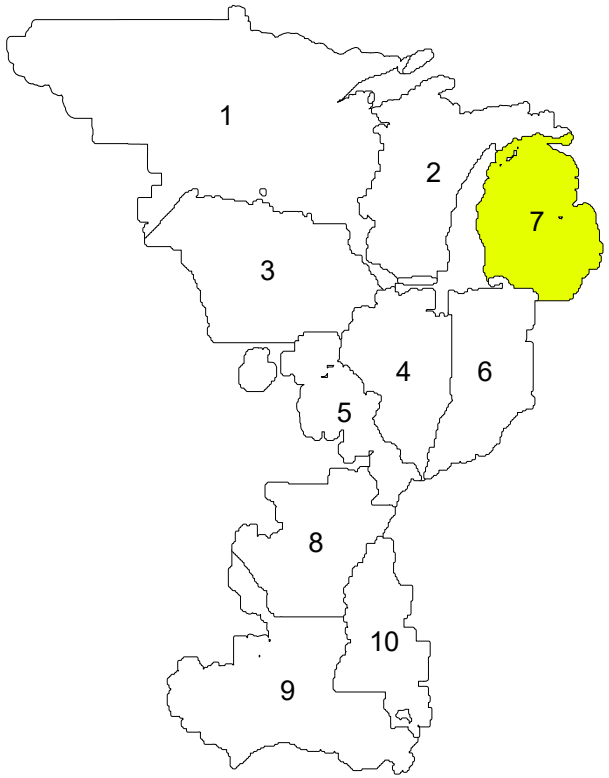

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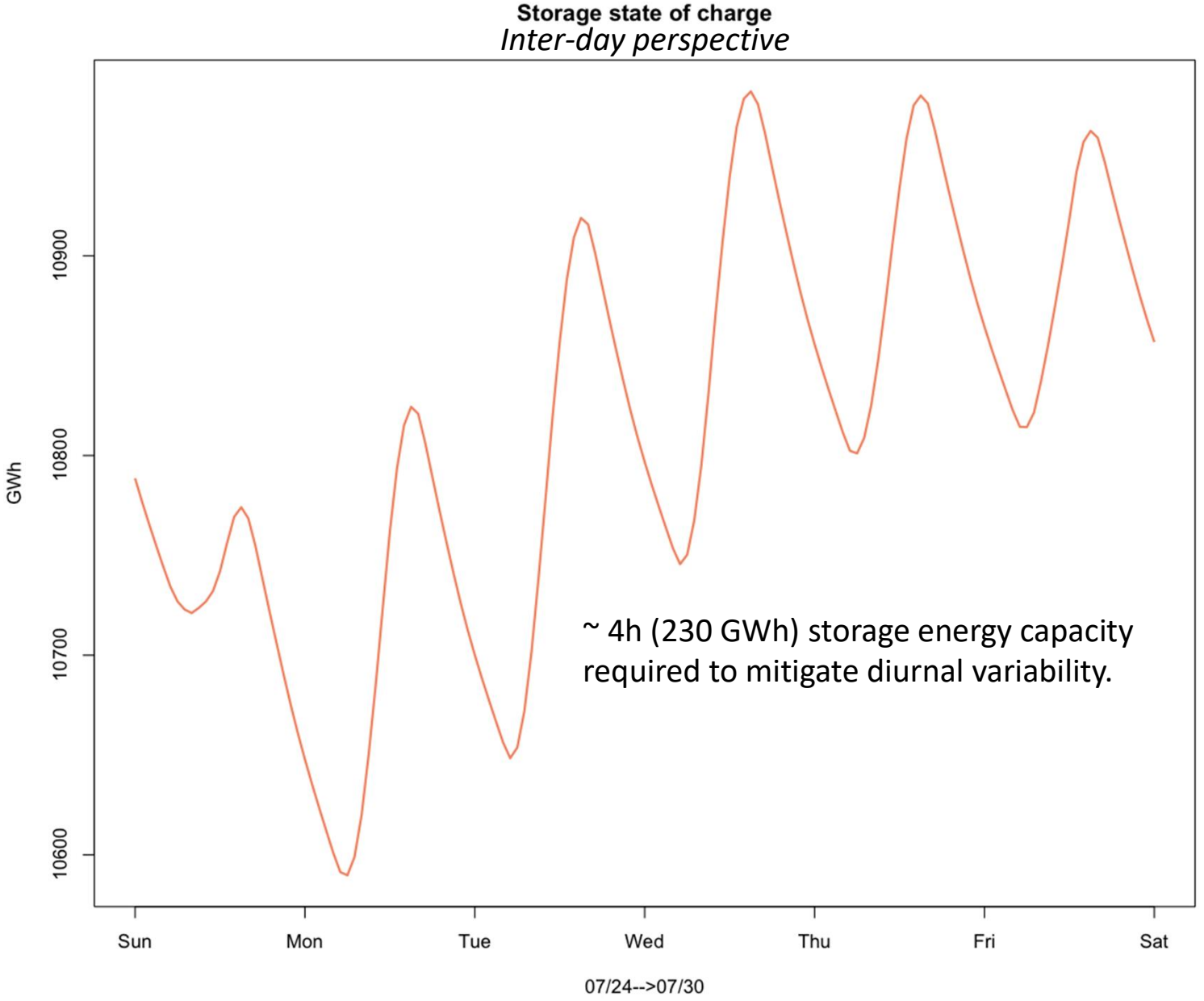

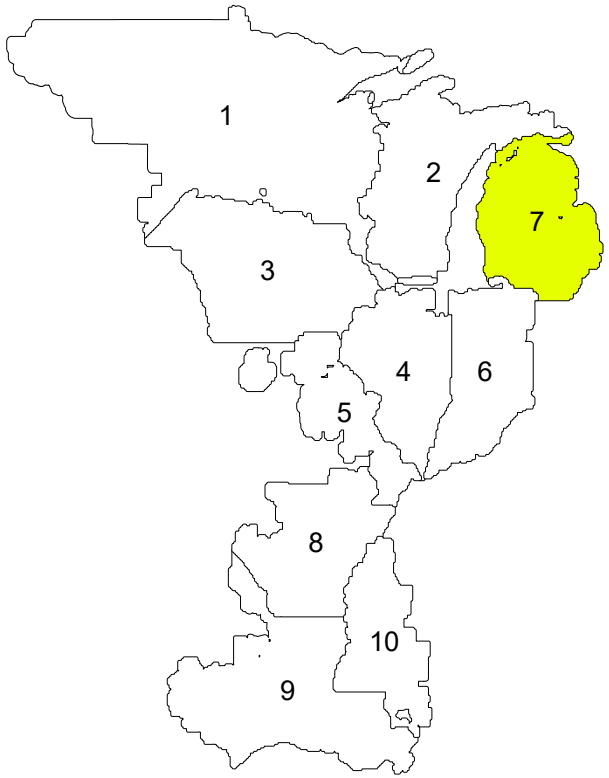

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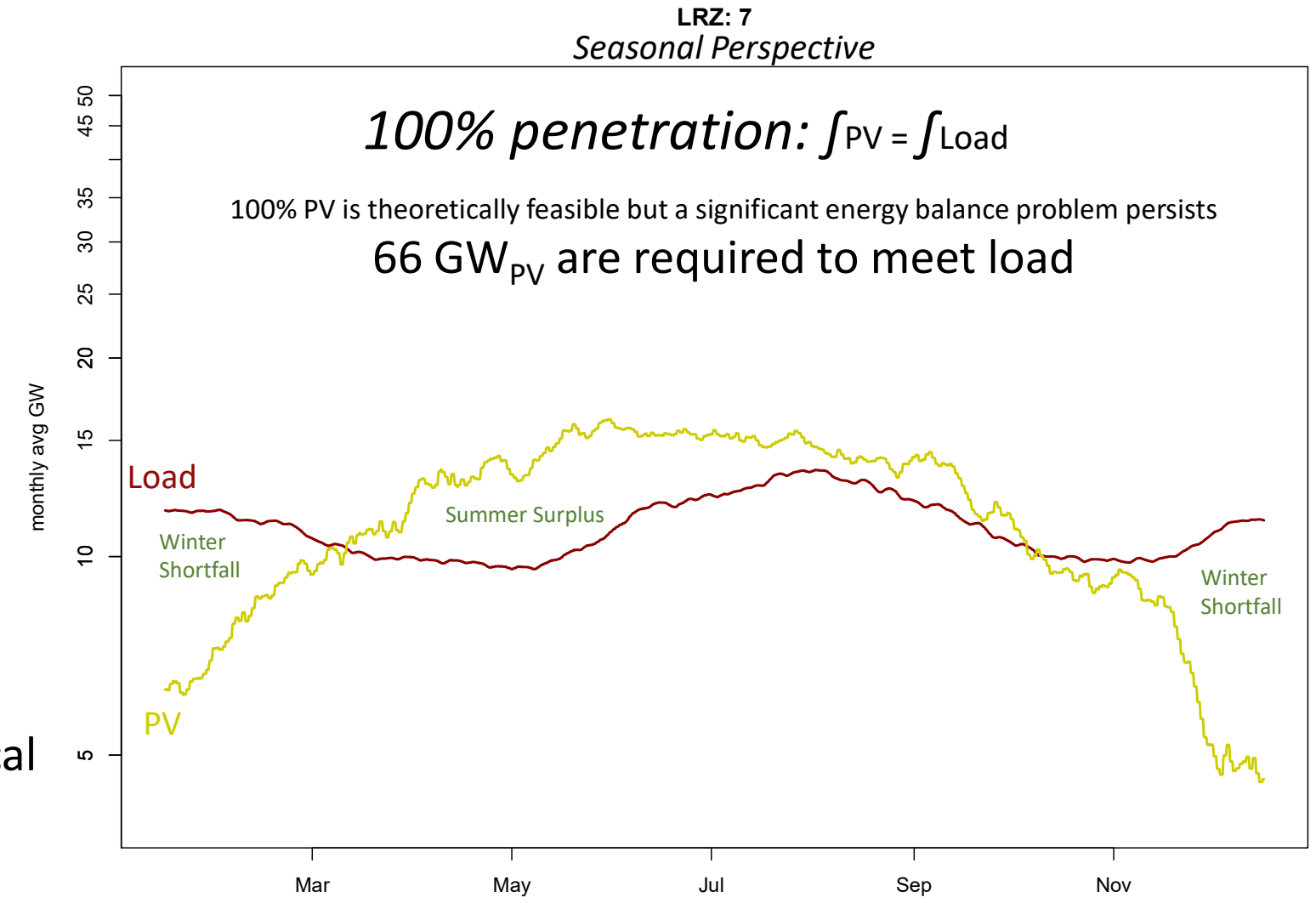

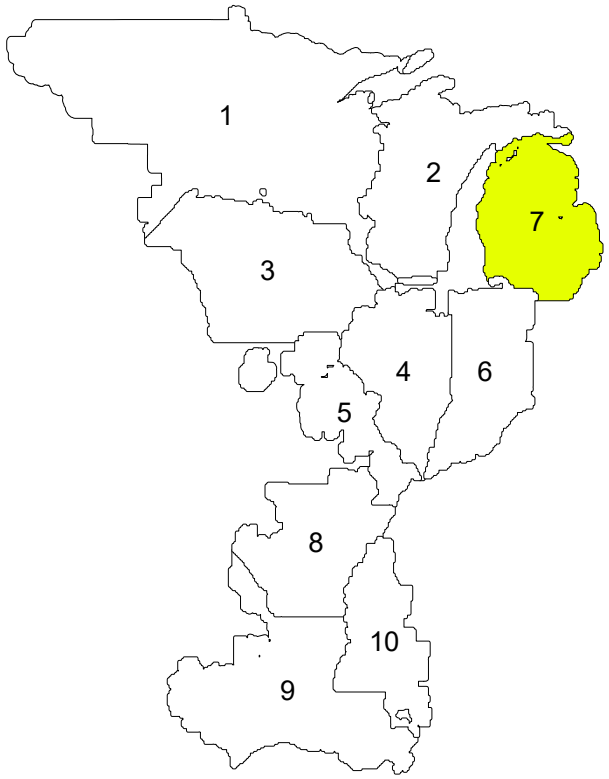

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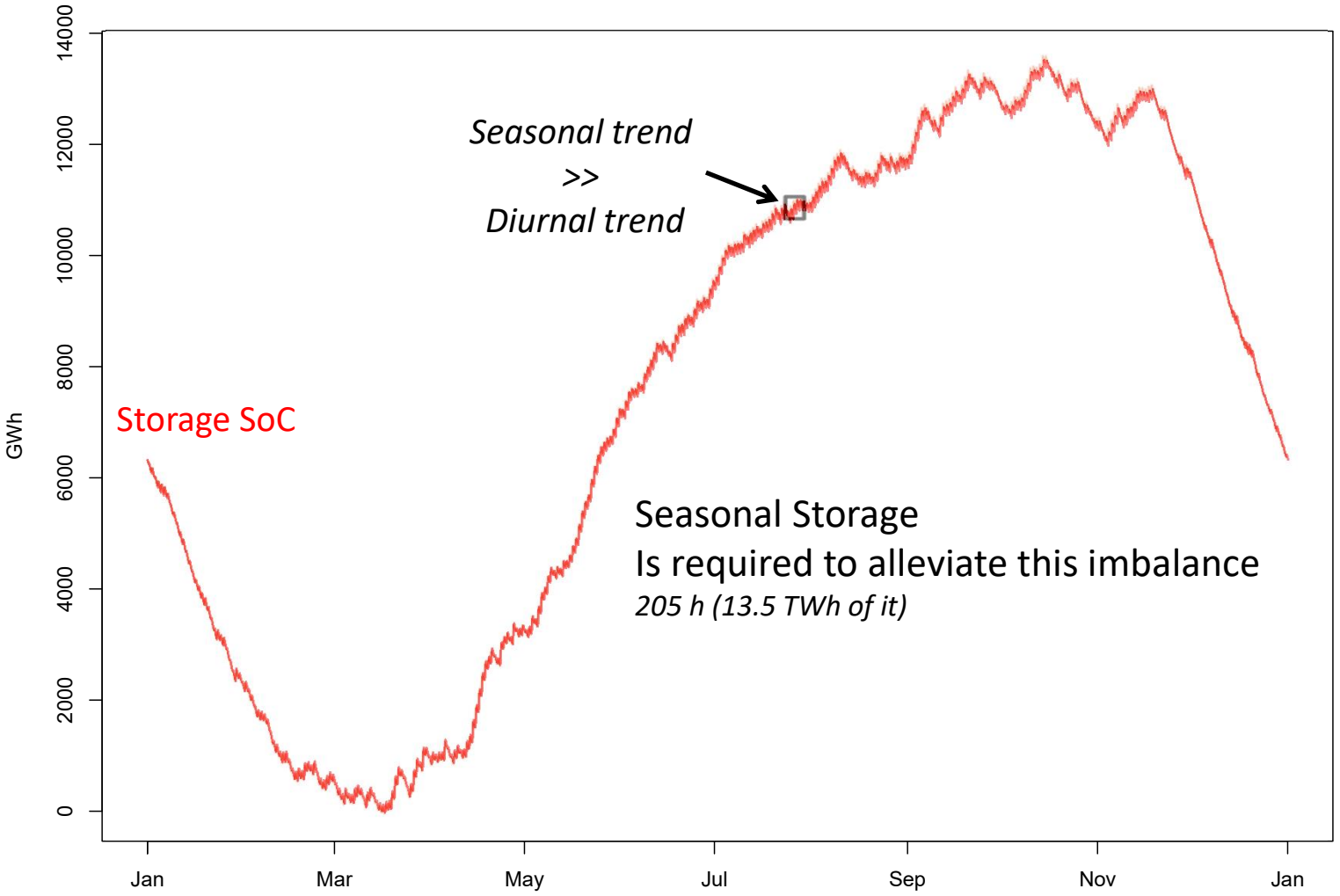

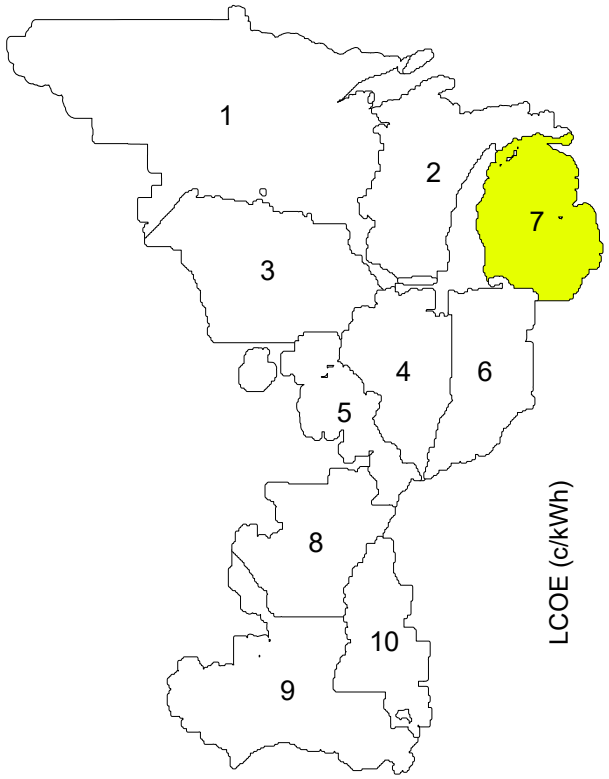

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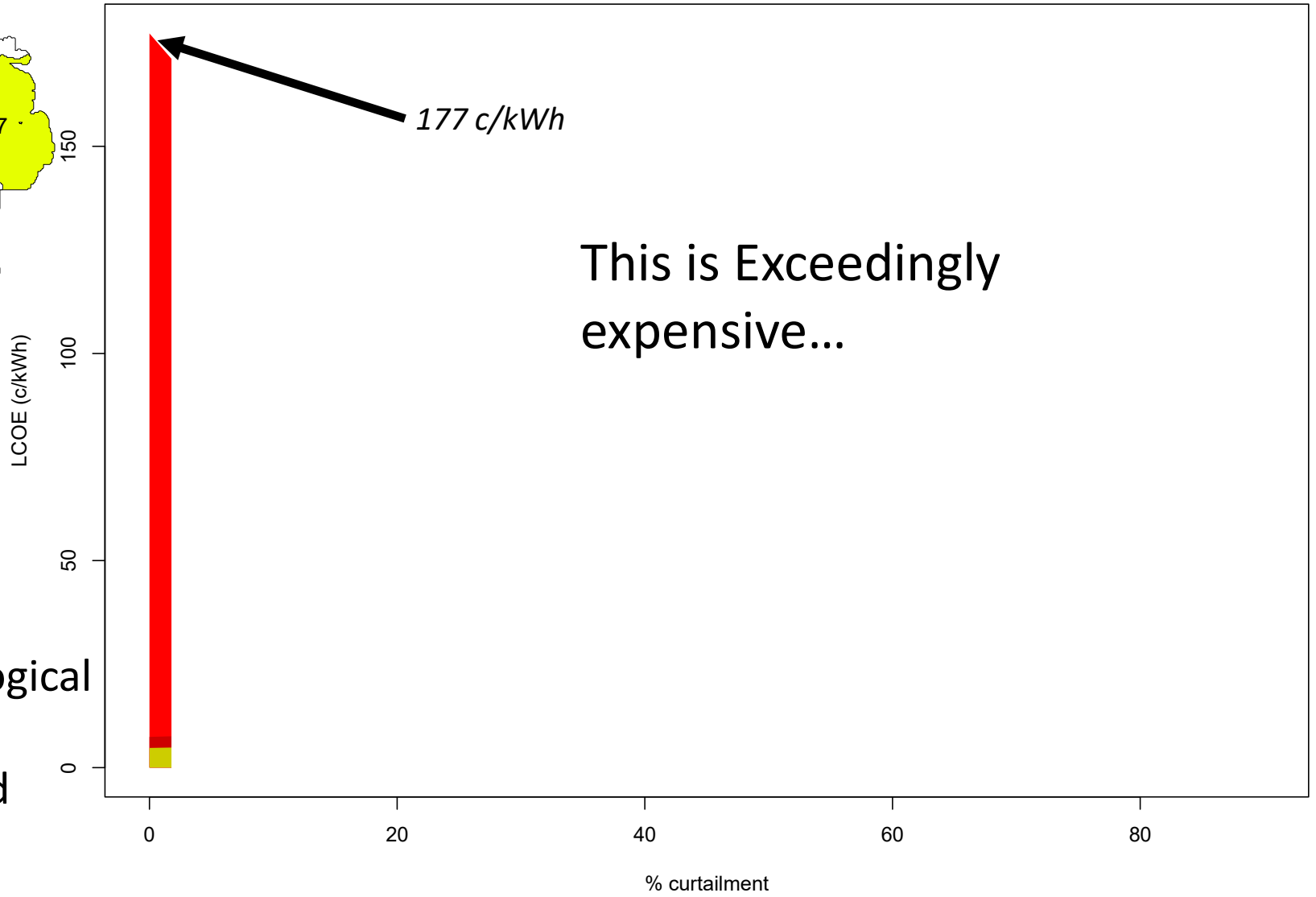

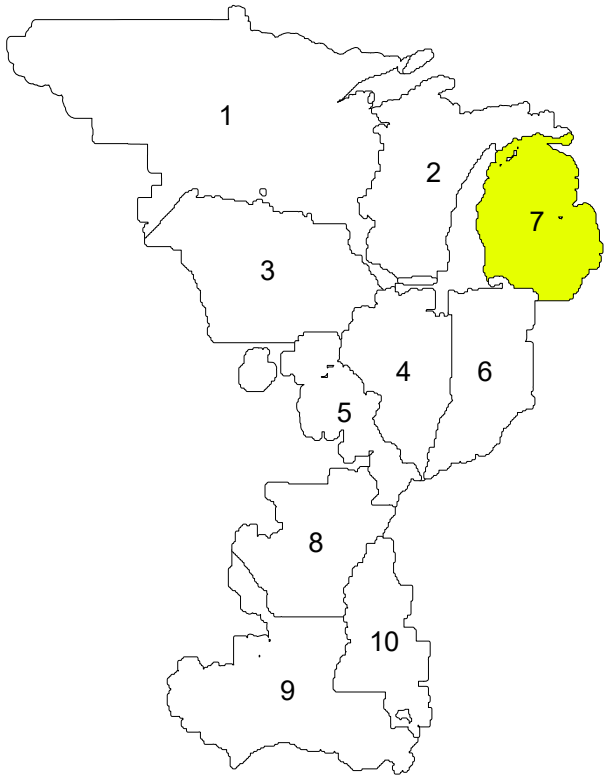

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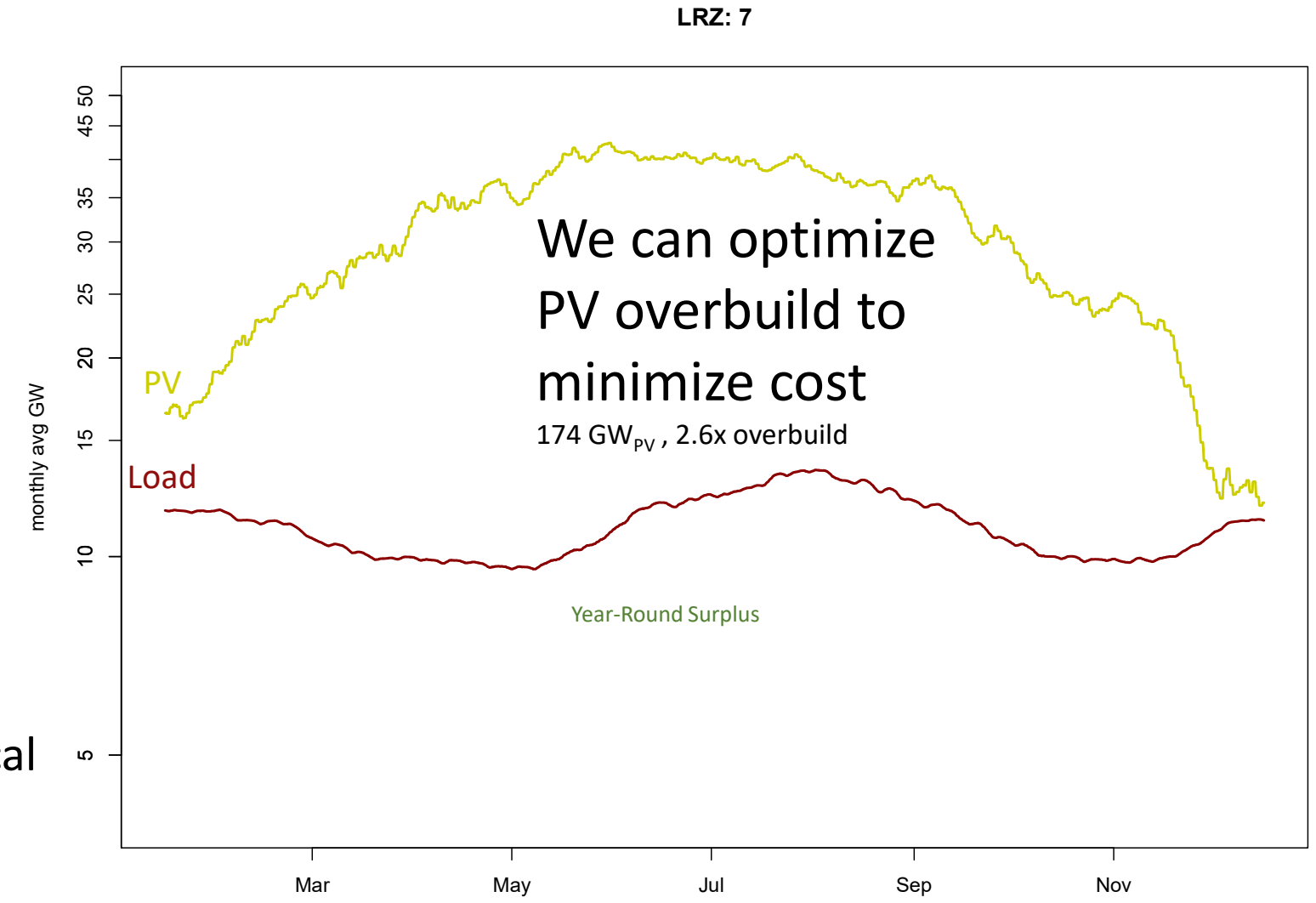
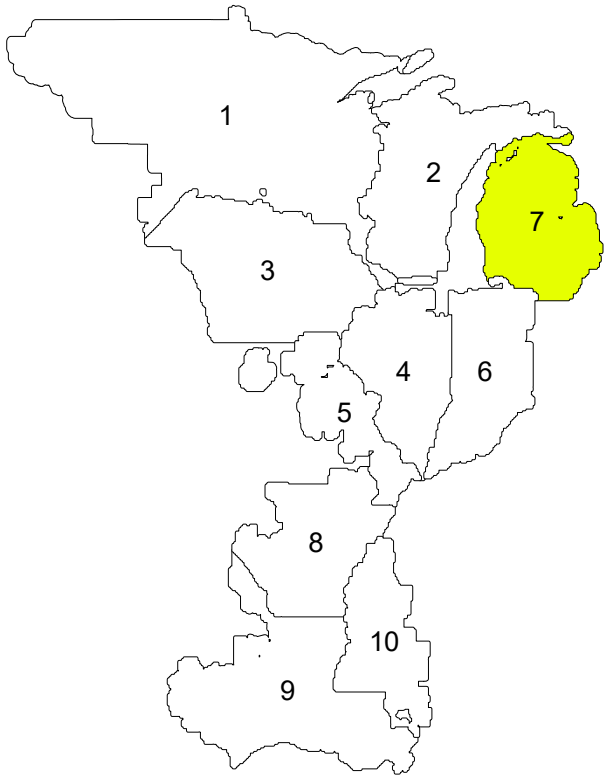
2025, low technological development, PV *alone*, optimal overbuild





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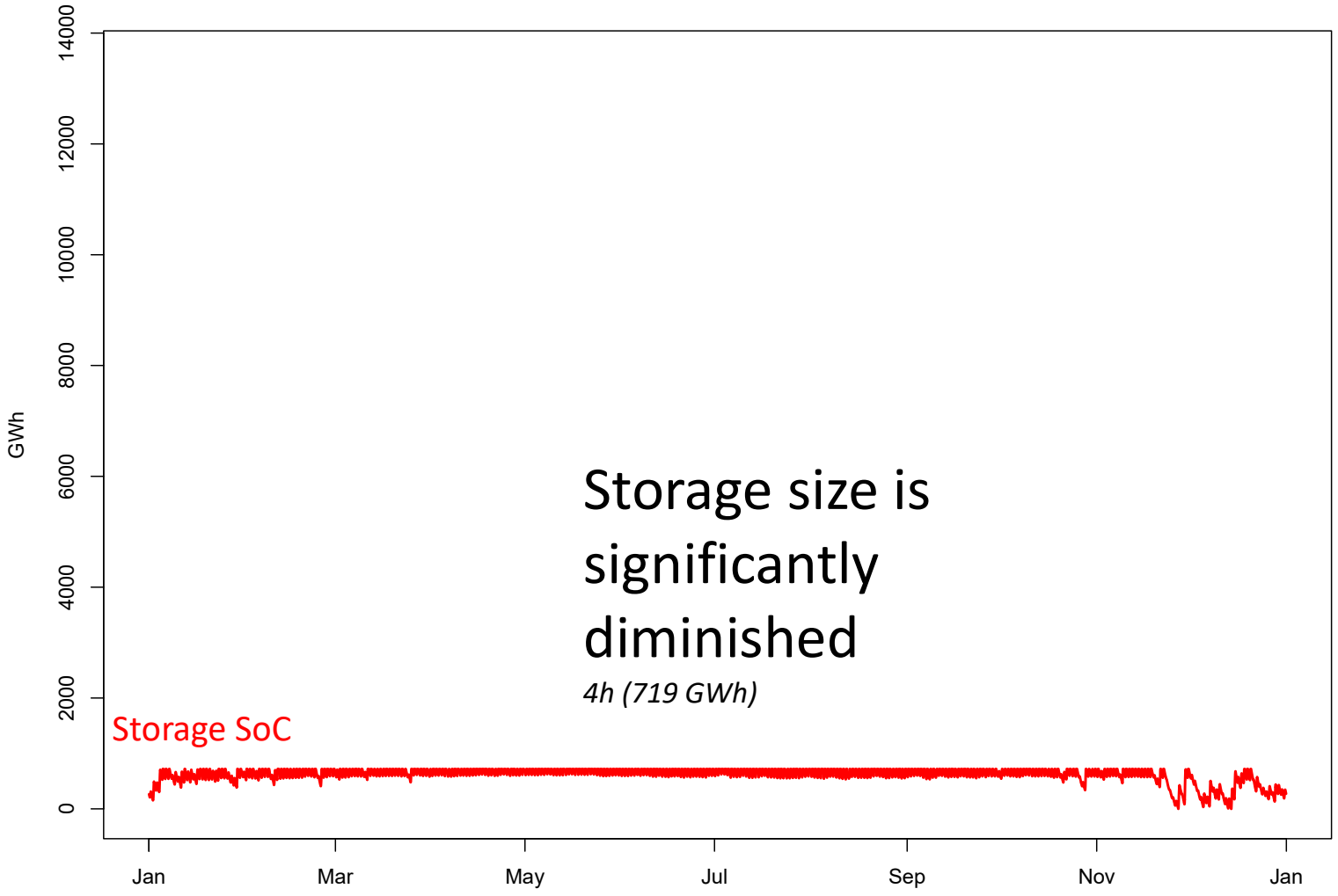

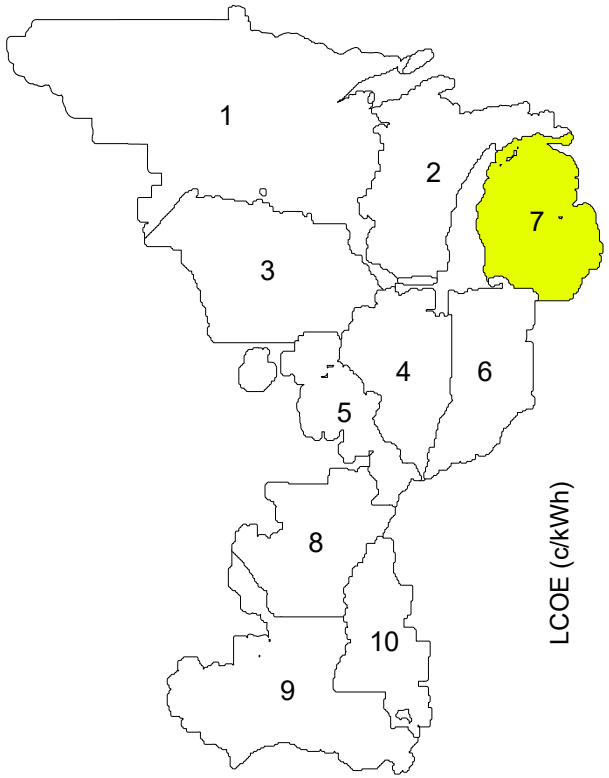

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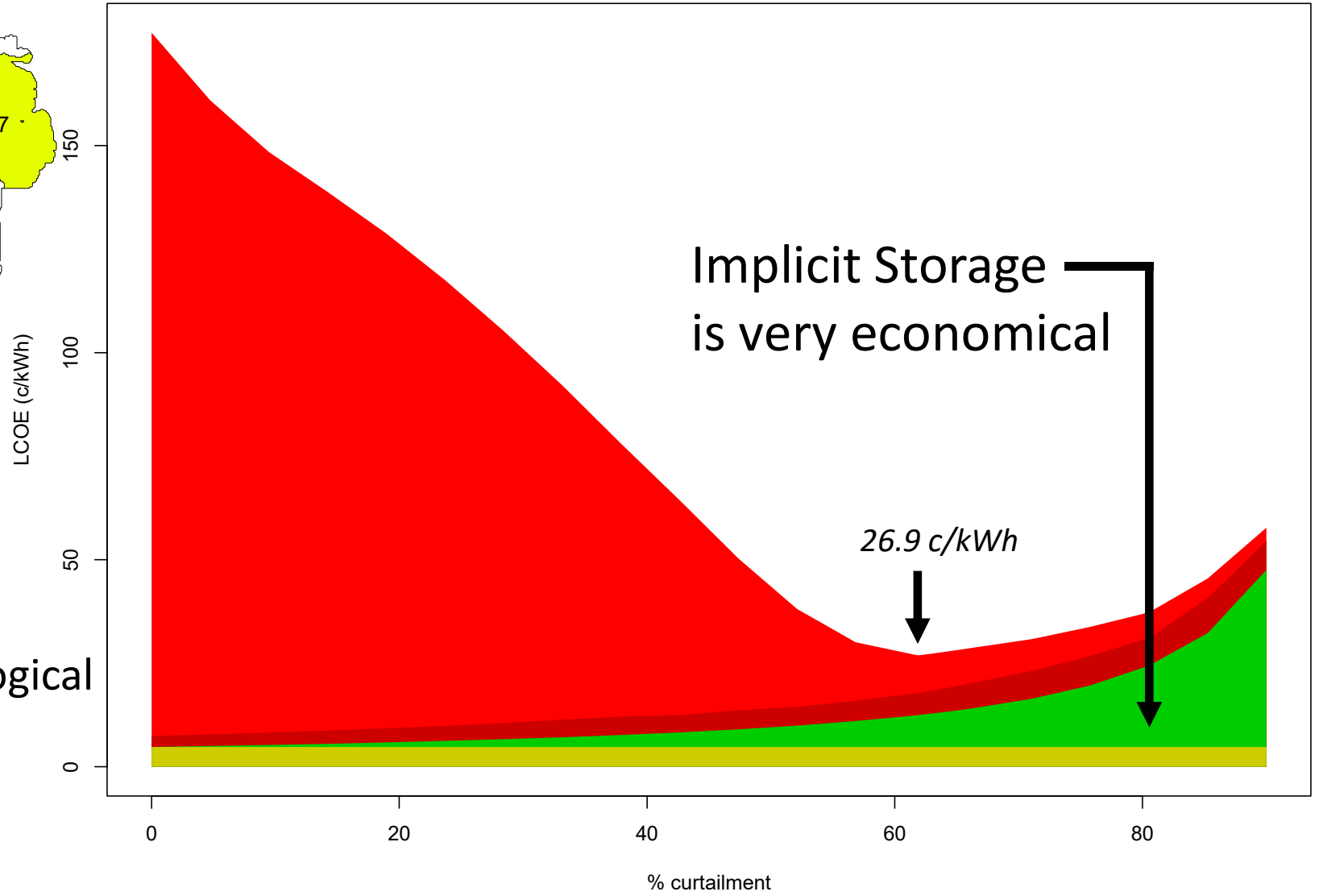


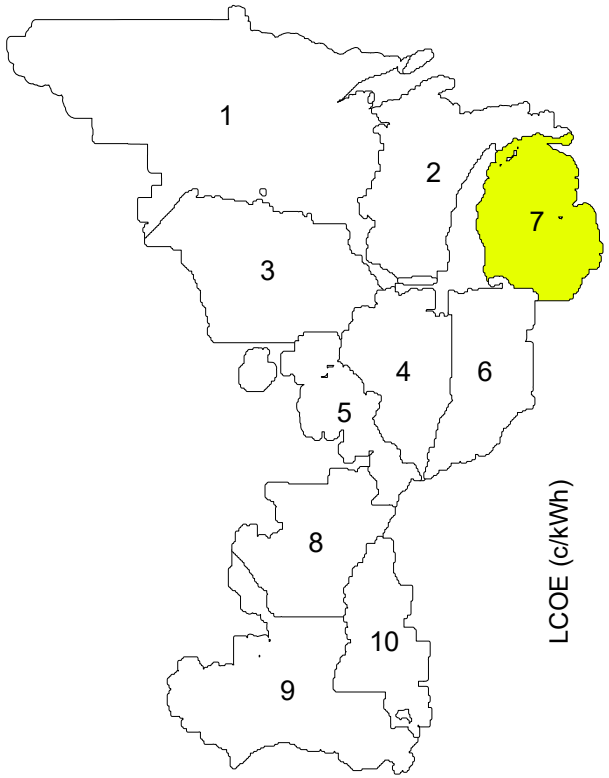
2050 , High

~~2025 , Low~~ Technological Development, MISO LRZ 7, 100% PV + storage

26.9 c/kWh

174 GW_{PV} | 4h (719 GWh) Storage

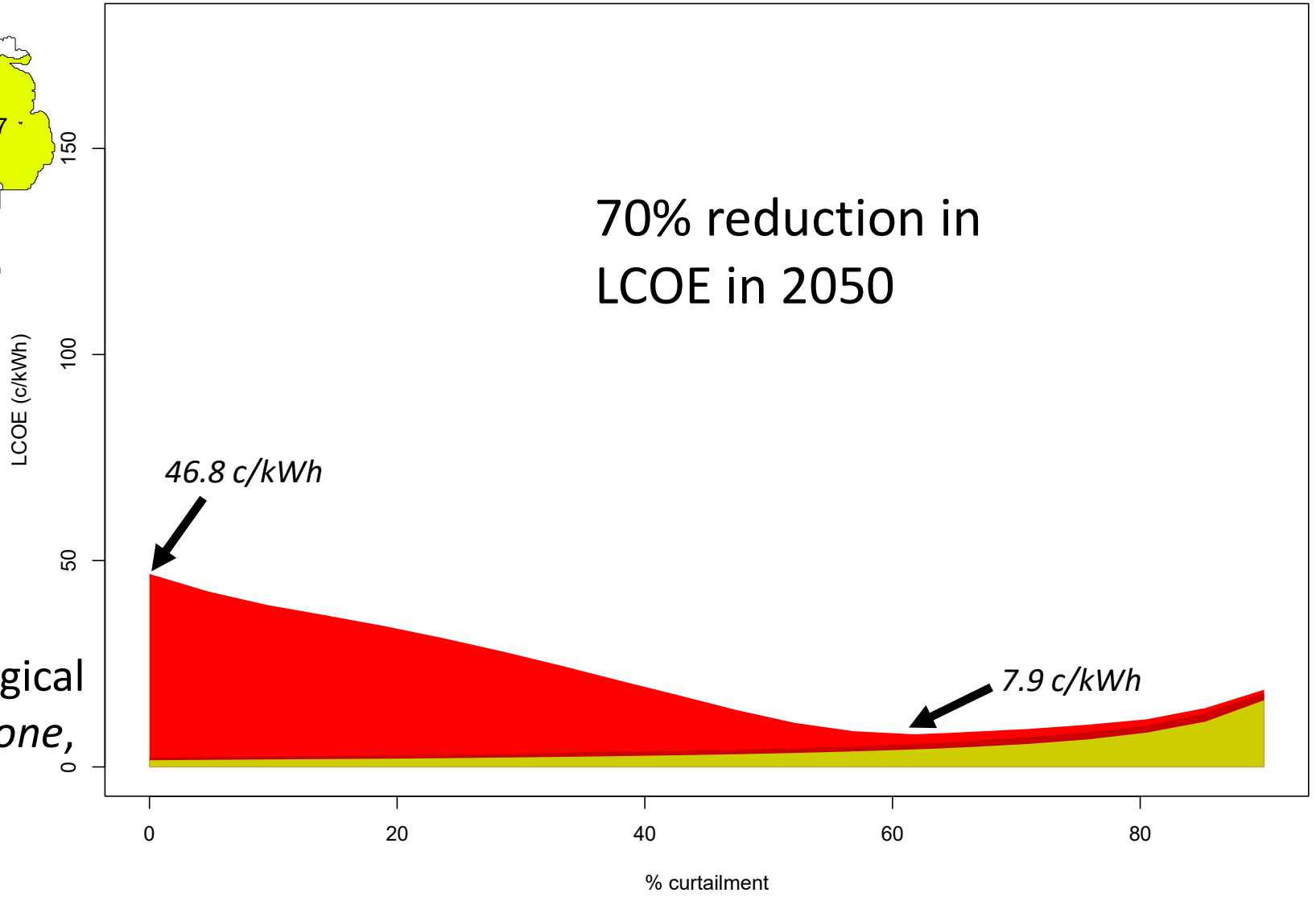
Let’s look at the impact of price



Consider LRZ 7

2050, high technological development, PV *alone*, <u>optimal</u> overbuild

70% reduction in LCOE in 2050



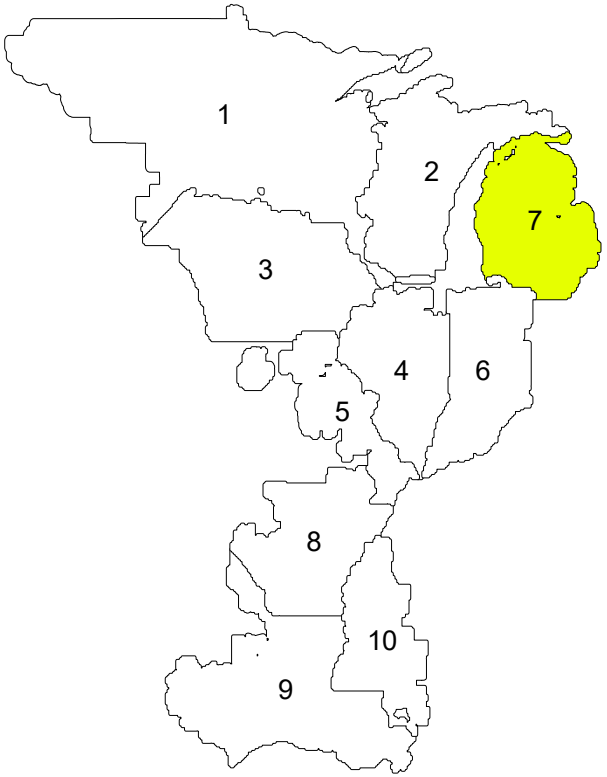
Wind

2050, high Technological Development, MISO LRZ 7, 100% ~~PV~~ + storage

7.9 c/kWh

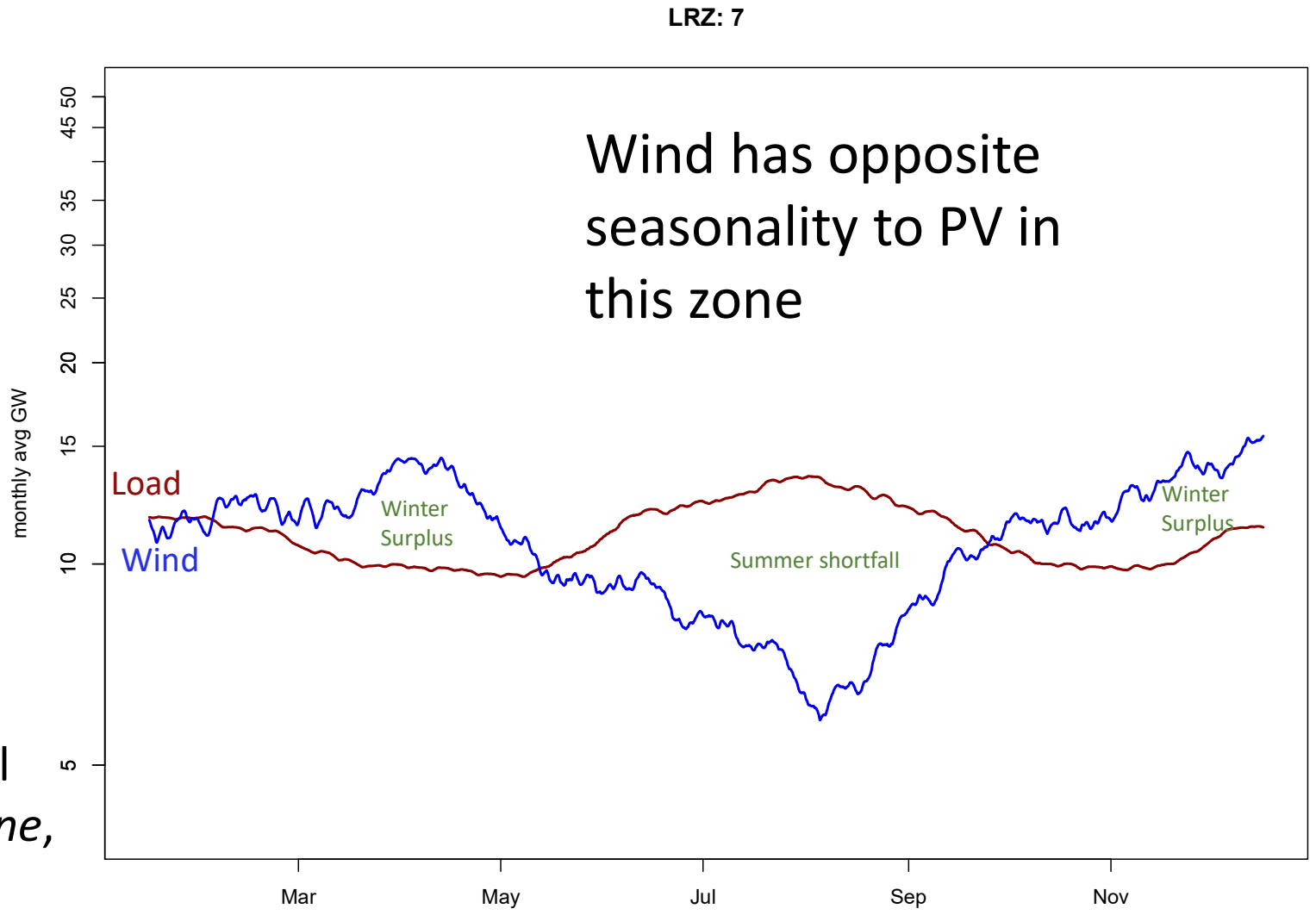
174 GW_{PV} | 4h (719 GWh) Storage

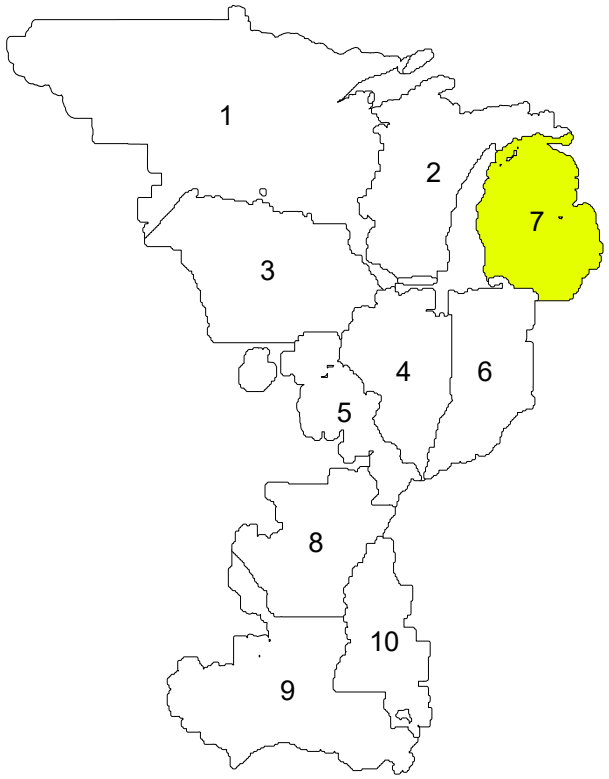
What about wind? Does the same hold true?



Consider LRZ 7

2050, high technological development, Wind *alone*, <u>no</u> overbuild





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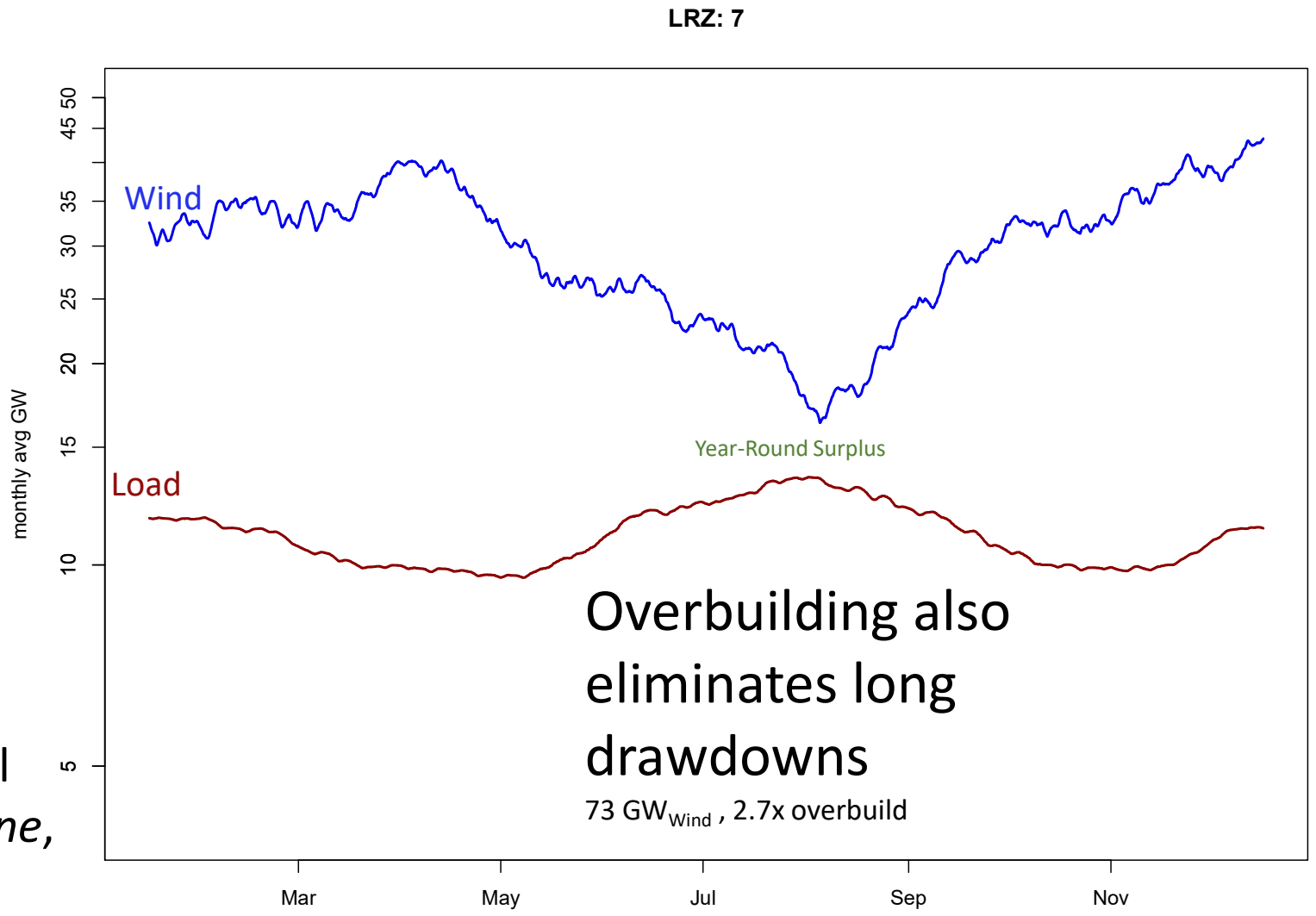

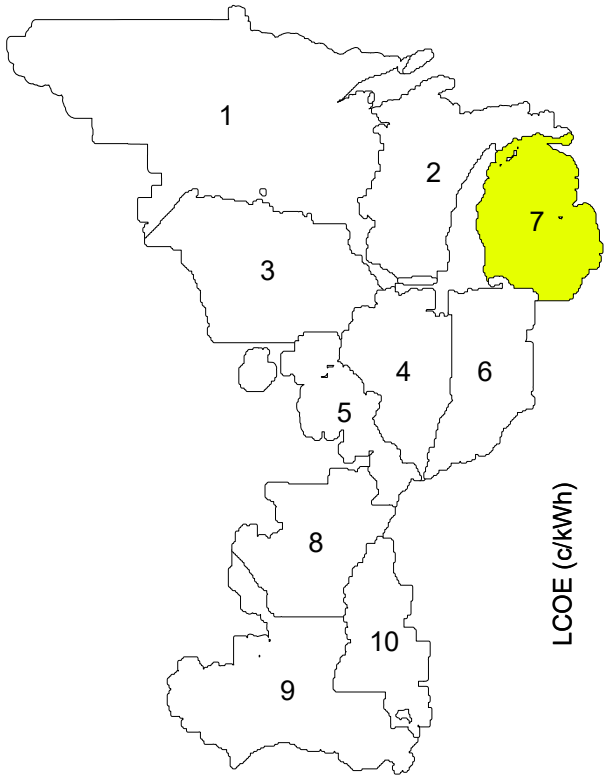

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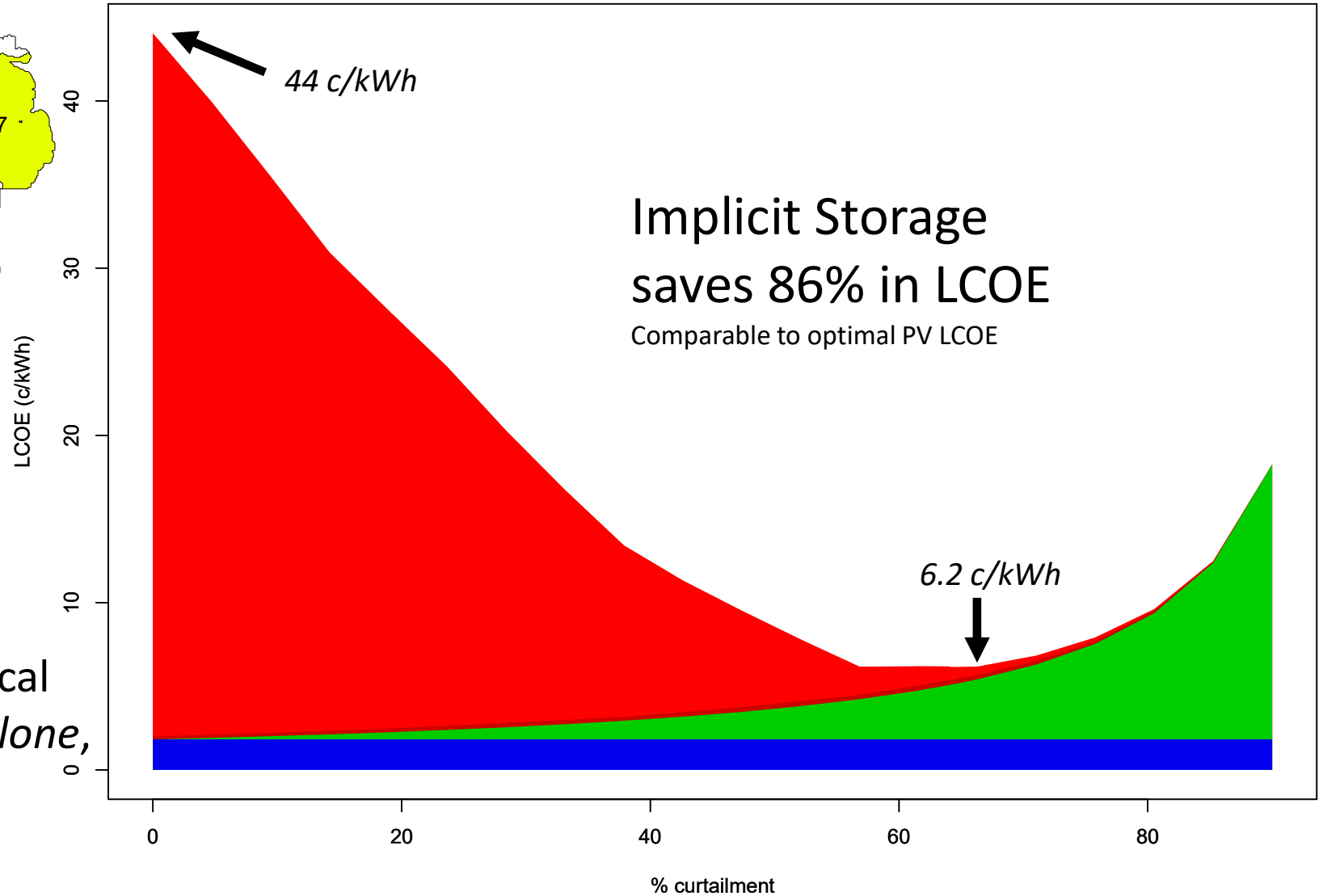


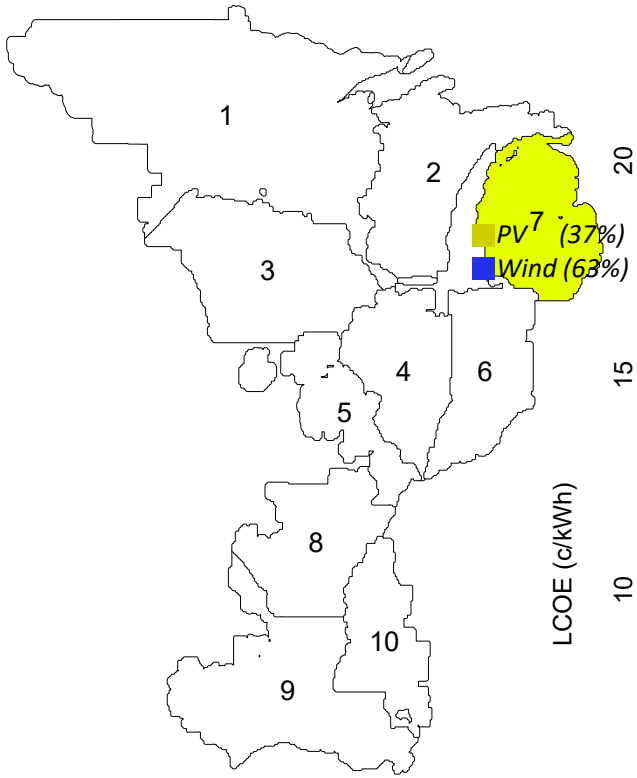
Wind + PV

2050, high Technological Development, MISO LRZ 7, 100% ~~Wind~~ + storage

6.2 c/kWh

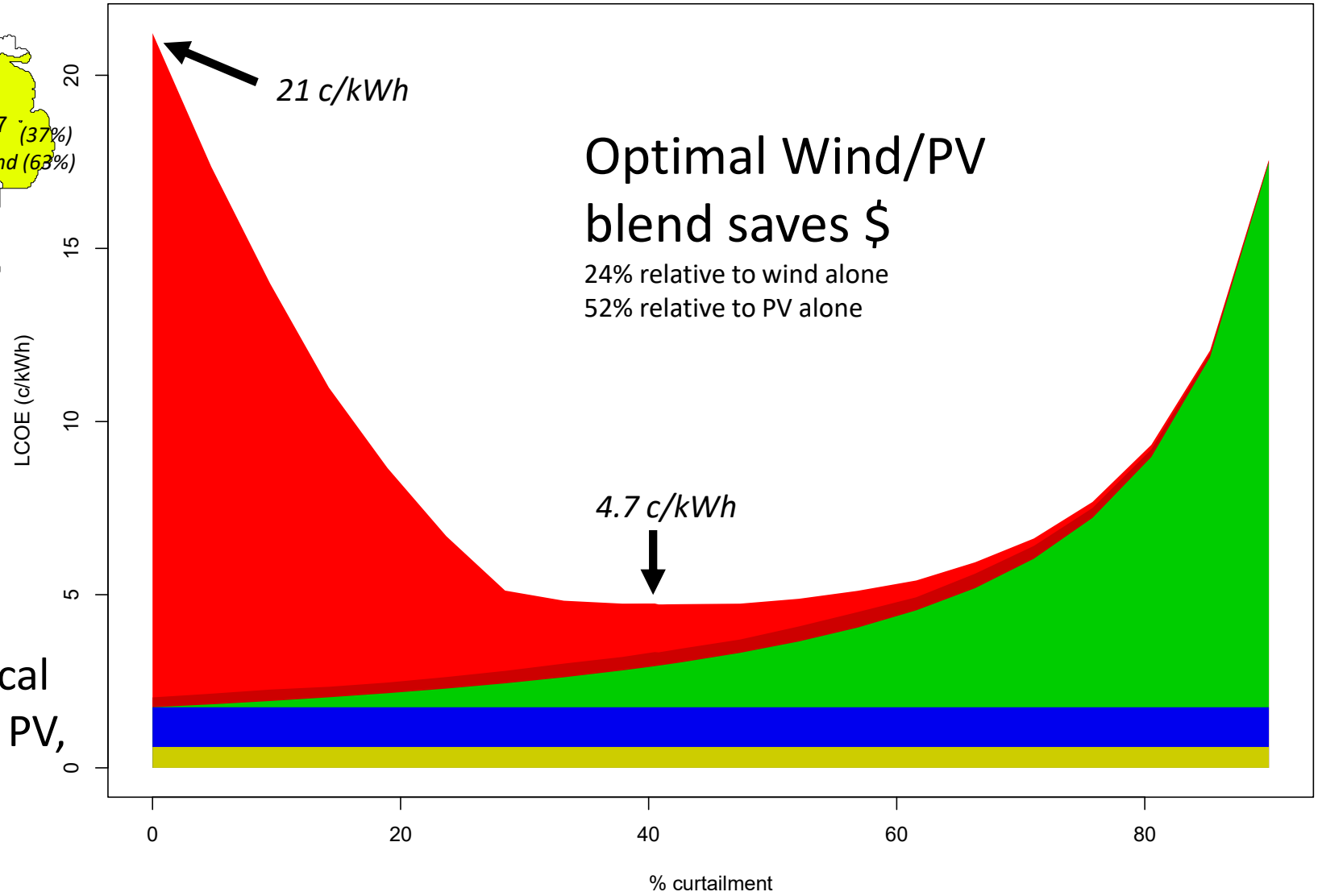
73 GW_{Wind} | 3h (239 GWh) Storage

What about a blend? Can we reduce costs further by hybridizing the resources?



Consider LRZ 7

2050, high technological development, Wind + PV, optimal overbuild



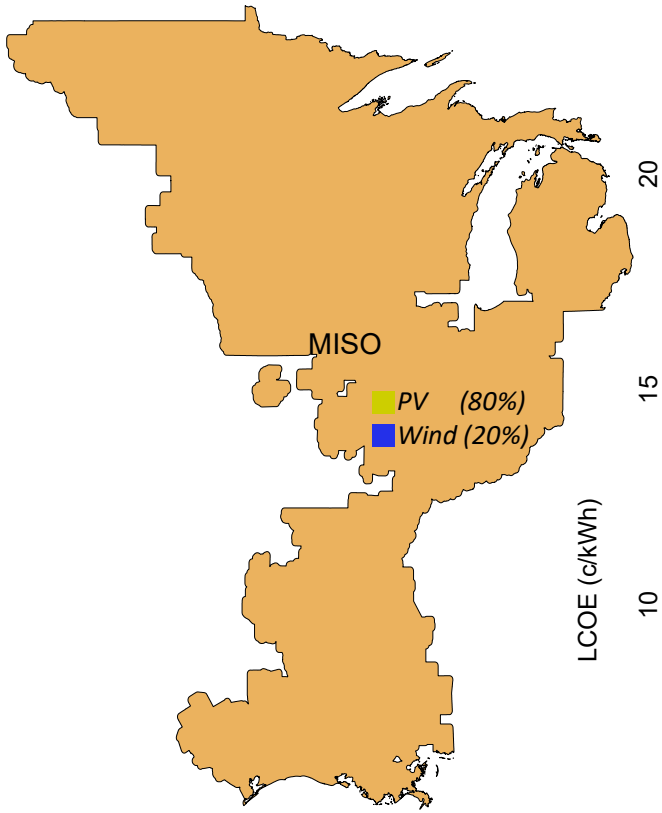
All of MISO

2050, high Technological Development, ~~MISO LRZ 7~~, 100% Wind + PV + storage

4.7 c/kWh

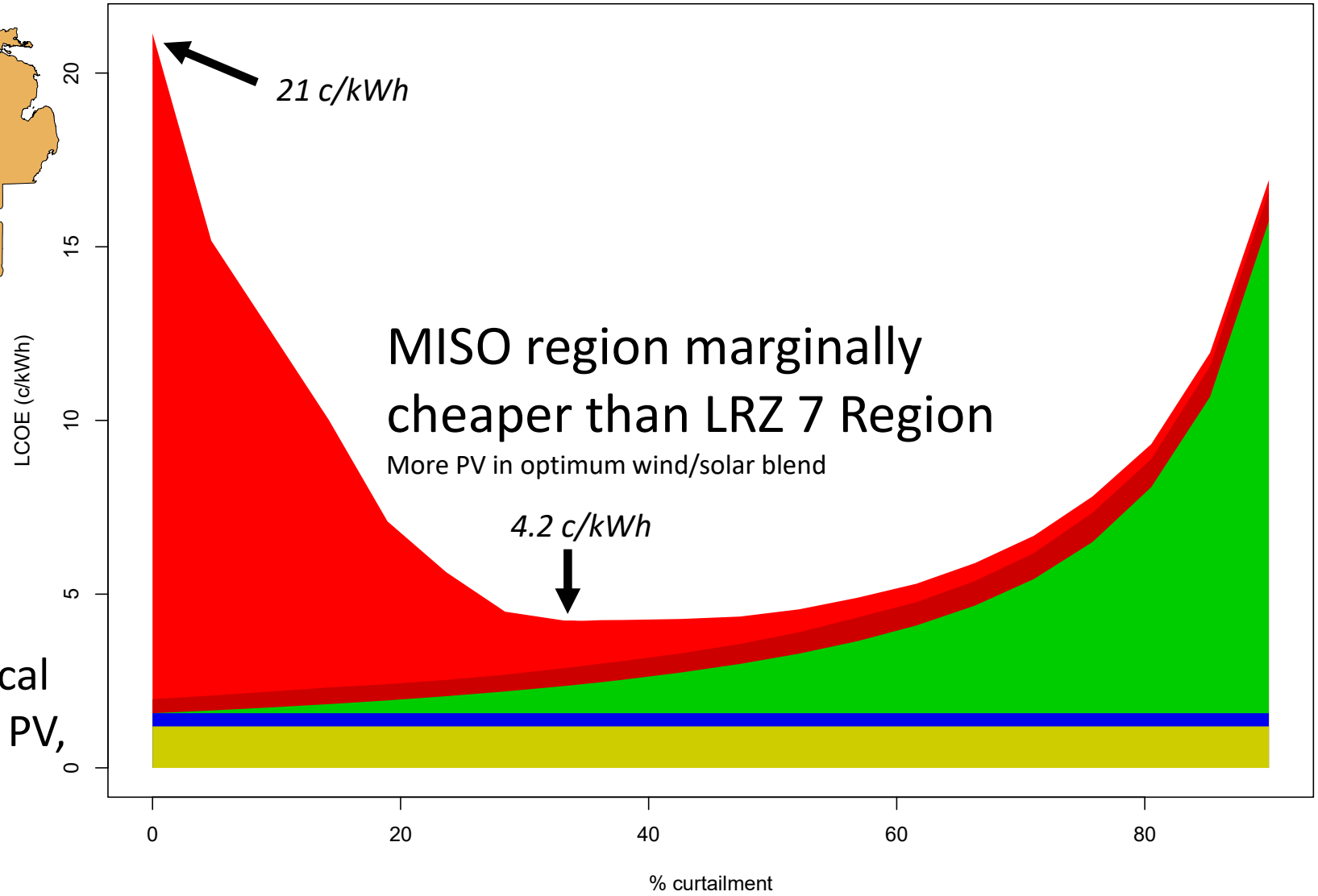
28 GW_{Wind}, 42 GW_{PV} | 6h (419 $GWh_{Storage}$)

What about a larger region, how do the dynamics change here?



Consider *MISO*

2050, high technological development, Wind + PV, <u>optimal</u> overbuild

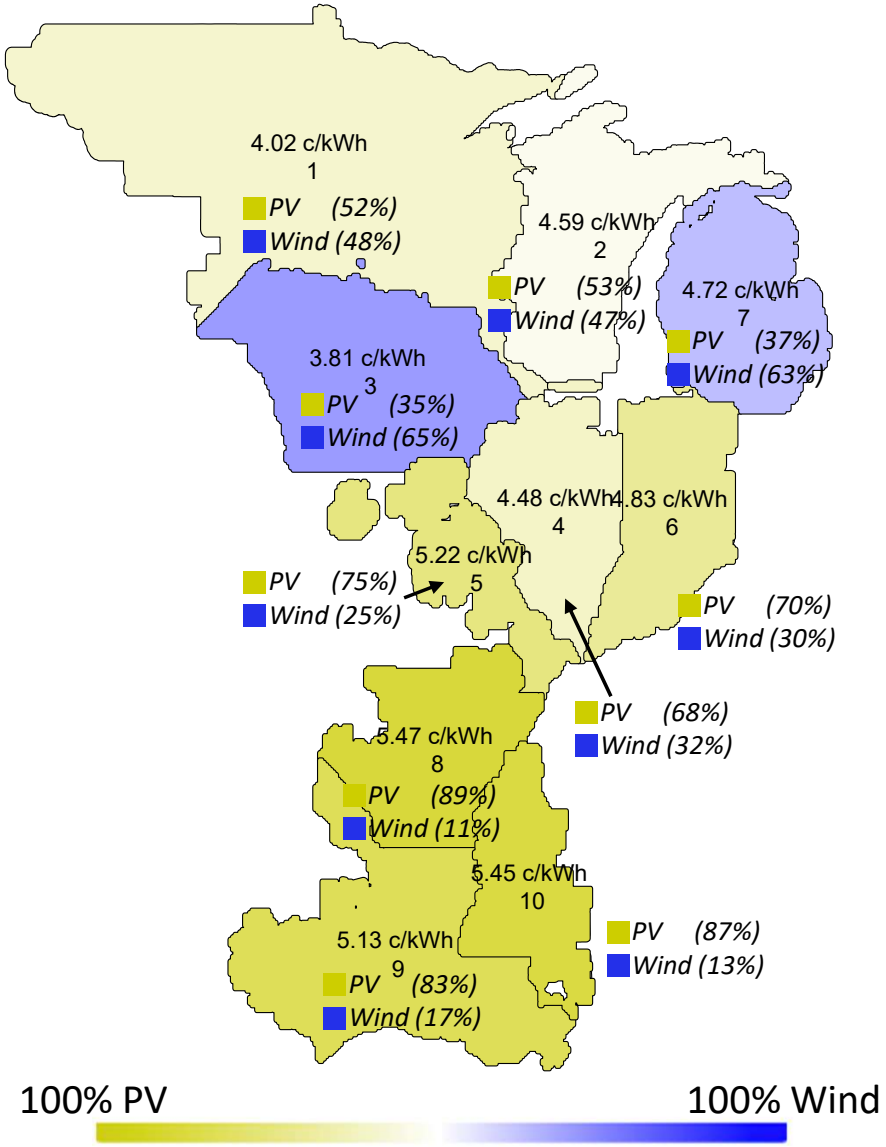


2050, high Technological Development, All of MISO, 100% Wind + PV + storage

4.2 c/kWh

57 GW_{Wind}, 511 GW_{PV} | 5h (2.7 $TWh_{Storage}$)

What if we allowed each region to island themselves,
how do costs and wind/solar blends compare?



If each LRZ islanded themselves and optimized their resource blends, the electricity price would be:

4.65 c/kWh

weighted average cost

Slightly more expensive than the MISO as a whole
>Regional resiliency possible without large-scale interconnection

Color scale shows wind/PV blend
>Despite higher wind capacity factors, PV tends to be dominant

Consider *MISO*

2050, high technological development, Wind + PV, <u>optimal</u> overbuild + gas

Dispatch with 5% gas

17 c/kWh

3.5 c/kWh

95% Renewables

17% cheaper than 100% across MISO

Significantly less optimal curtailment (only 17% vs 36%)

Gas does the same job implicit storage does

LCOE (c/kWh)

0 5 10 15

0 20 40 60 80

% curtailment

Storage energy component | Storage power component | PV | Wind | Implicit Storage | gas

Key takeaways of the MISO study

- **Intrinsic Intermittency at ultra-high penetrations can be overcome economically** With optimized technological portfolios including
  - **Optimal Wind/PV blend**
  - **Storage : real and implicit**
- **Large-scale interconnection is cheaper** But not indispensible. Smaller sub-regions are slightly more expensive but provide resiliency benefits and are likely easier to implement.
- **Seasonal storage** is not required

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Are renewables large enough?
Are renewables cheap enough?
How do we overcome intrinsic intermittency?

30% Wind 65% Solar 5% Gas

3.5 c/kWh

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