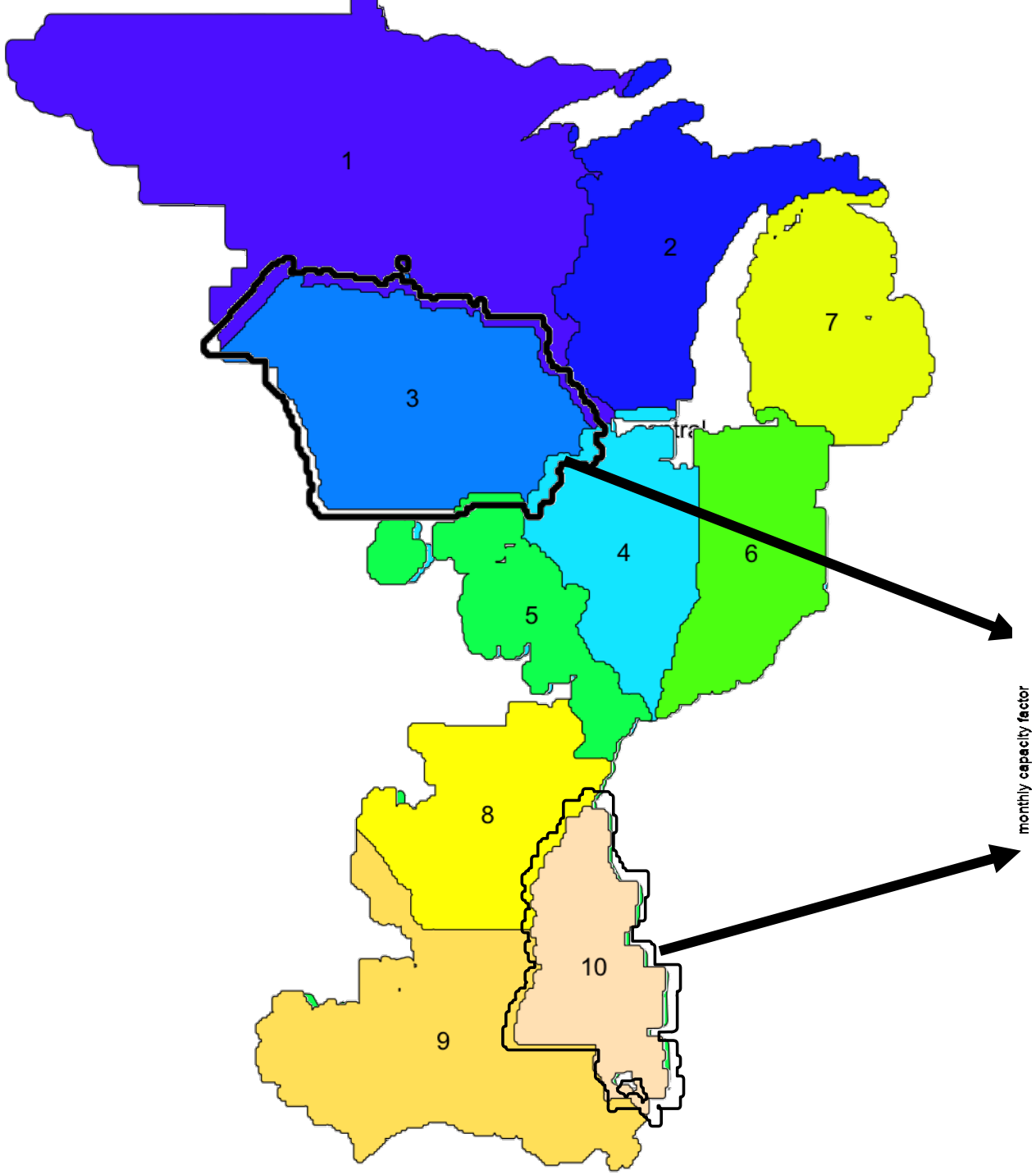
# Pathways to 100% Renewables across the MISO region

Tue Aug 16th, 2022

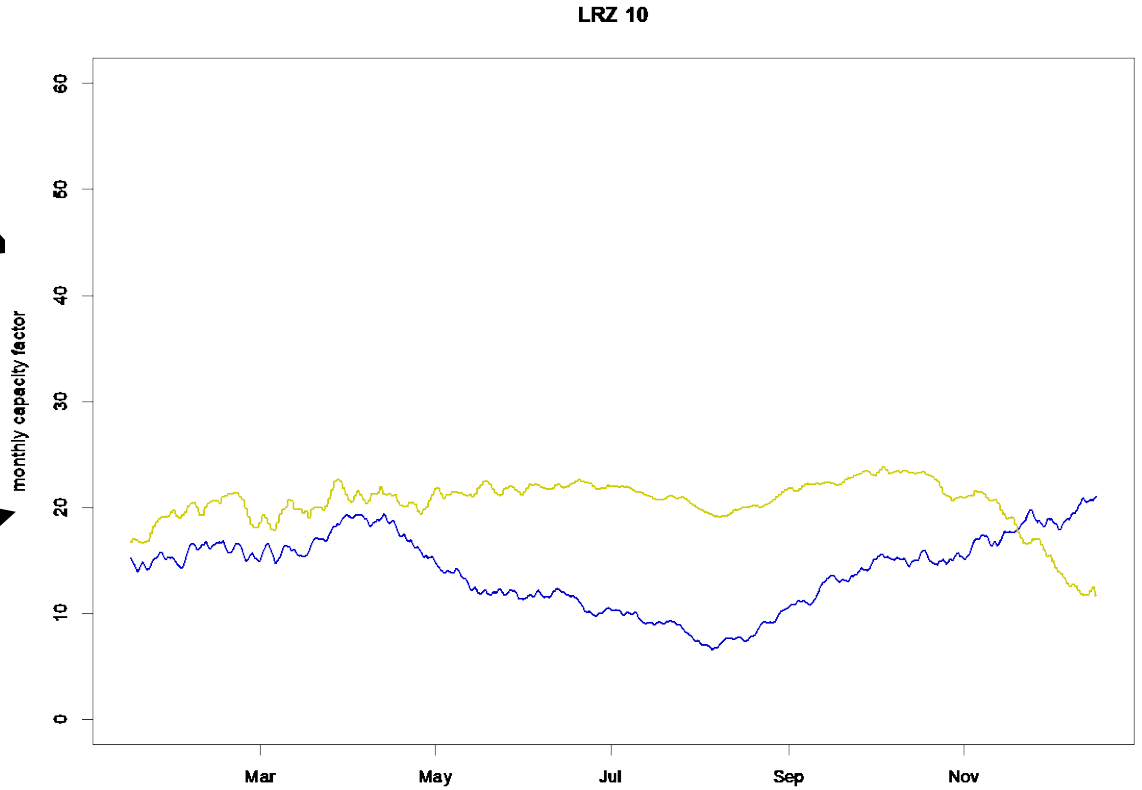
Marc Perez, Ph.D.

Clean Power Research®




# 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



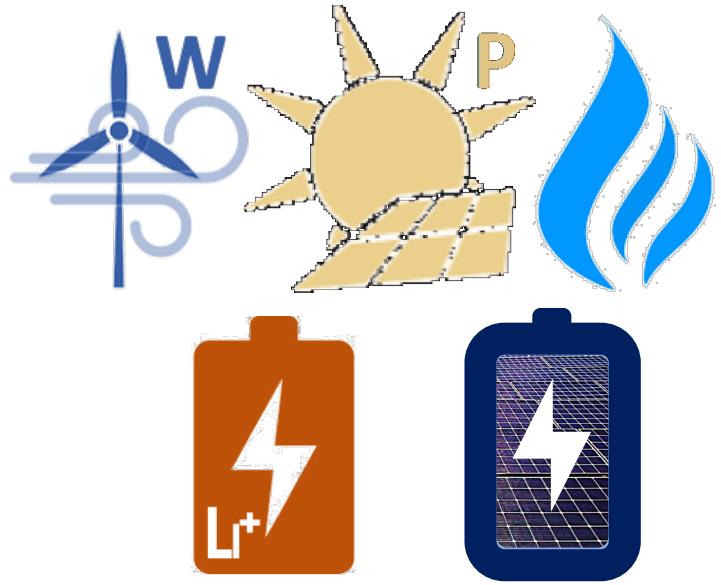

*Let's examine the influence these characteristics have on optimized capacity expansion and the costs that result*

# How do we optimize capacity expansion and dispatch?

MISO

- **Matching Supply to Demand**

  Generation: Wind, solar, gas
  Balancing: electricity storage and *implicit storage* (overbuilding + curtailment)



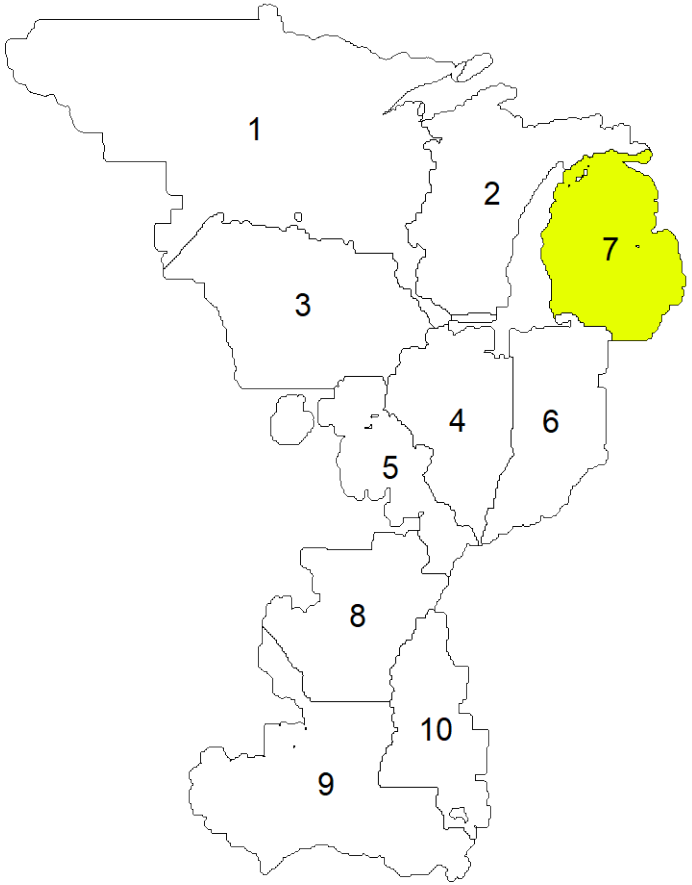

- **Cost Scenarios**
  - 2050, high and low technological development
  - 2025, high and low technological development

- 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.

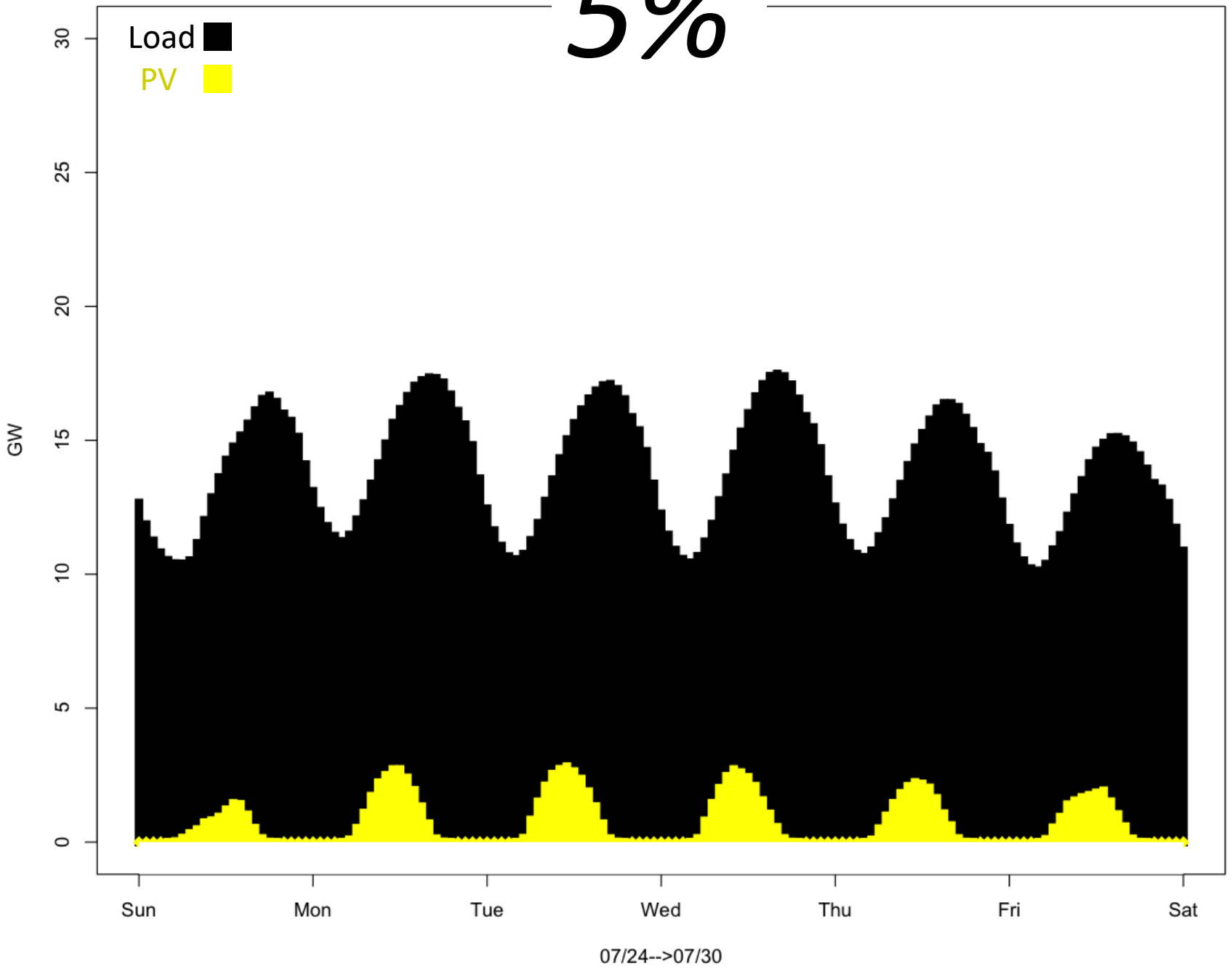
| | | Utility PV | | Wind | | Storage | | | | Gas | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CapEx $/kW | Opex $/kW-yr | CapEx $/kW | Opex $/kW-yr | CapEx $/kWh -pack | CapEx $/kW -BoS | Opex % total CapEx / yr | RT eff | CapEx $/kW | Opex fixed $/kW-yr | Opex variable $/MWh | 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 |

~25k 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.

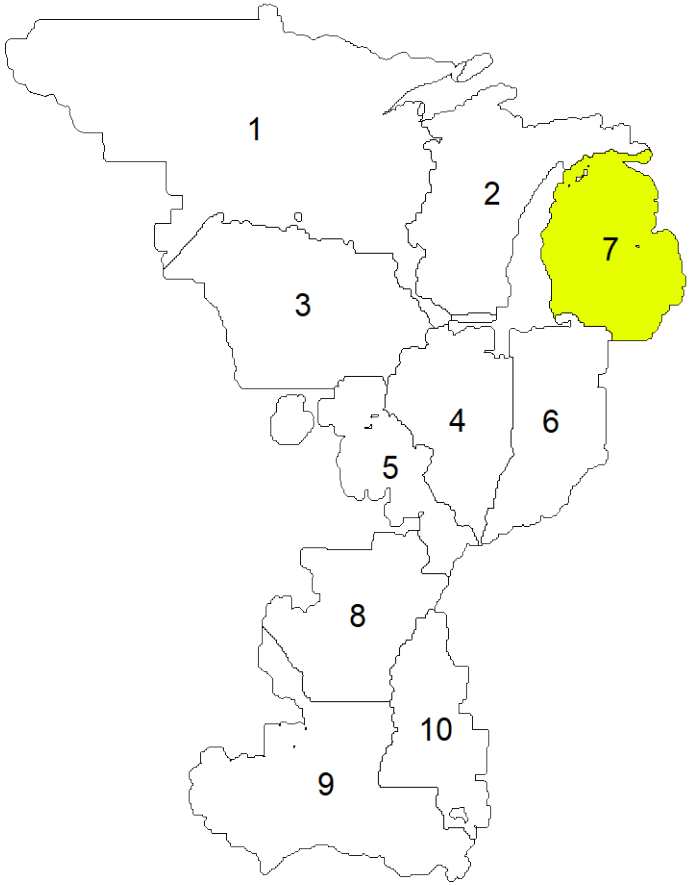



# 5%




## Consider LRZ 7

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

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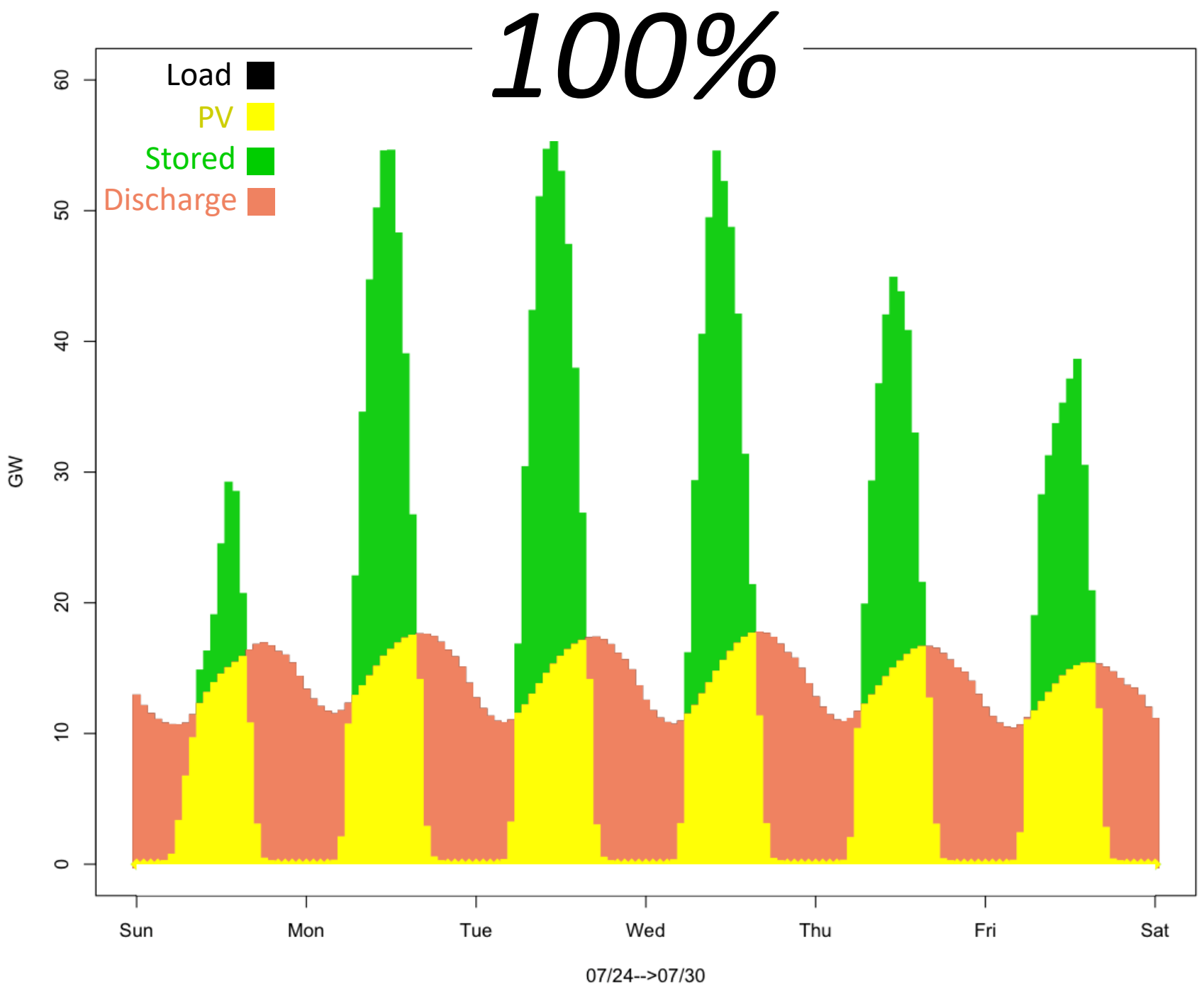
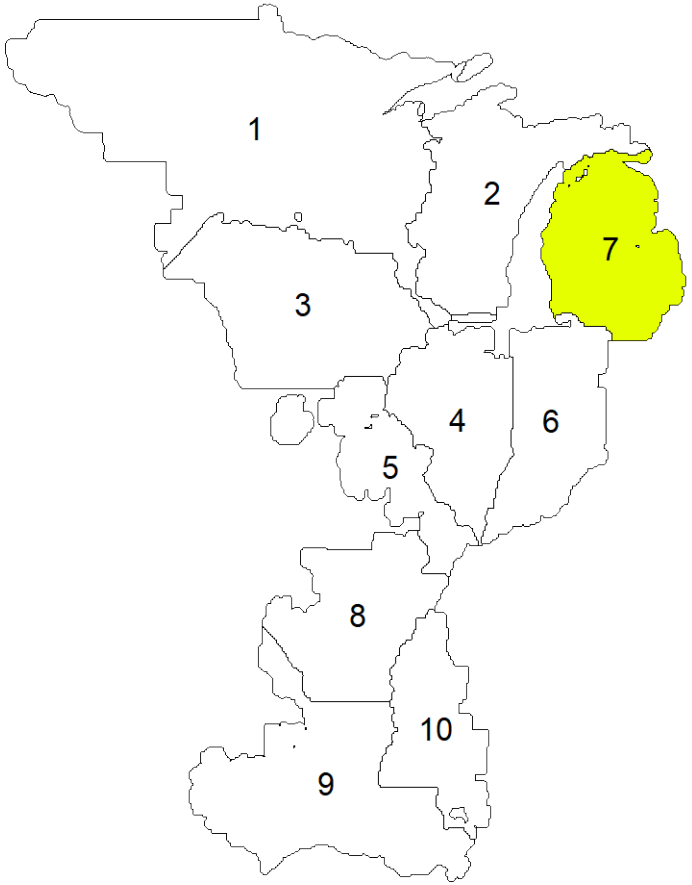


# *Storage operation*

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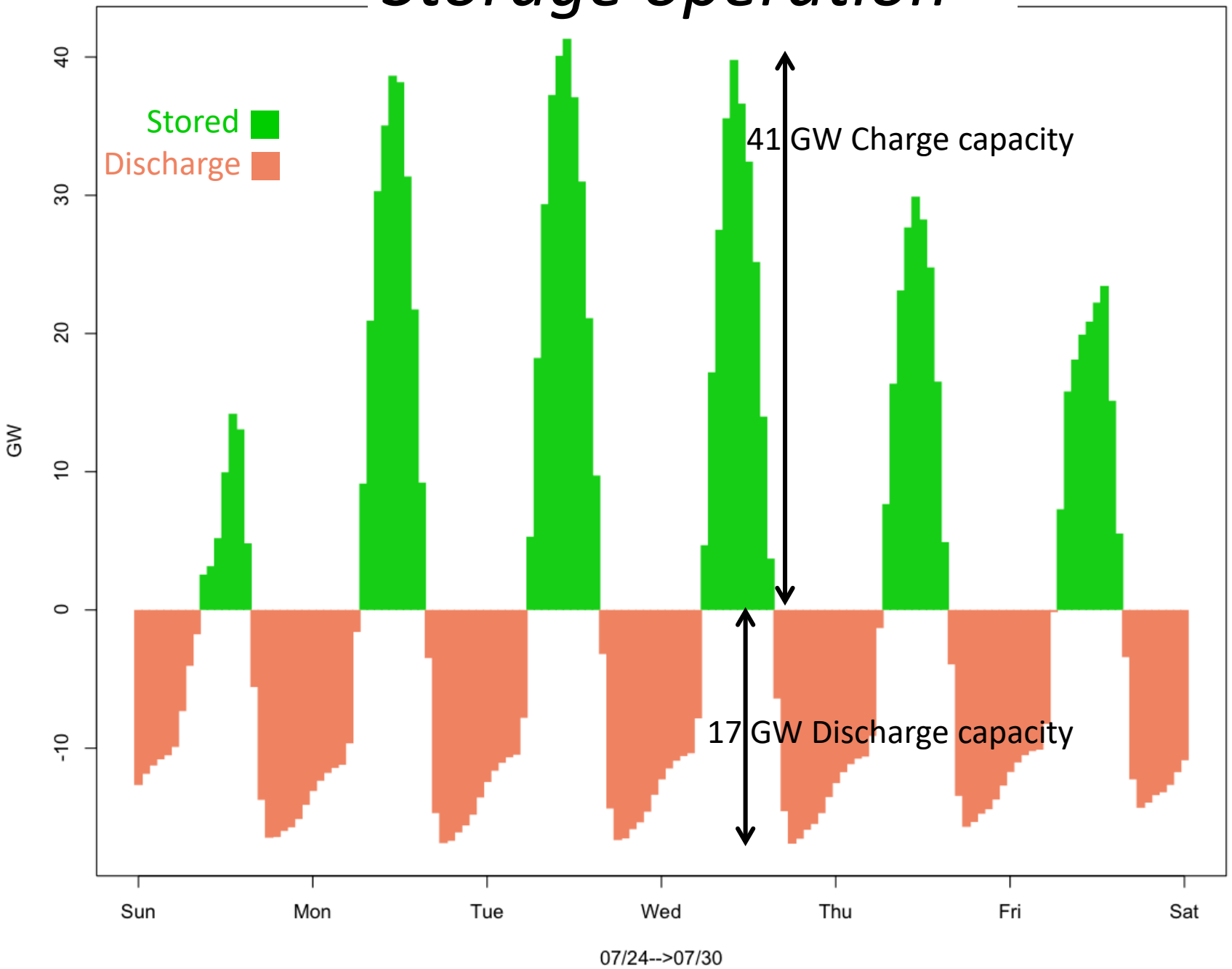

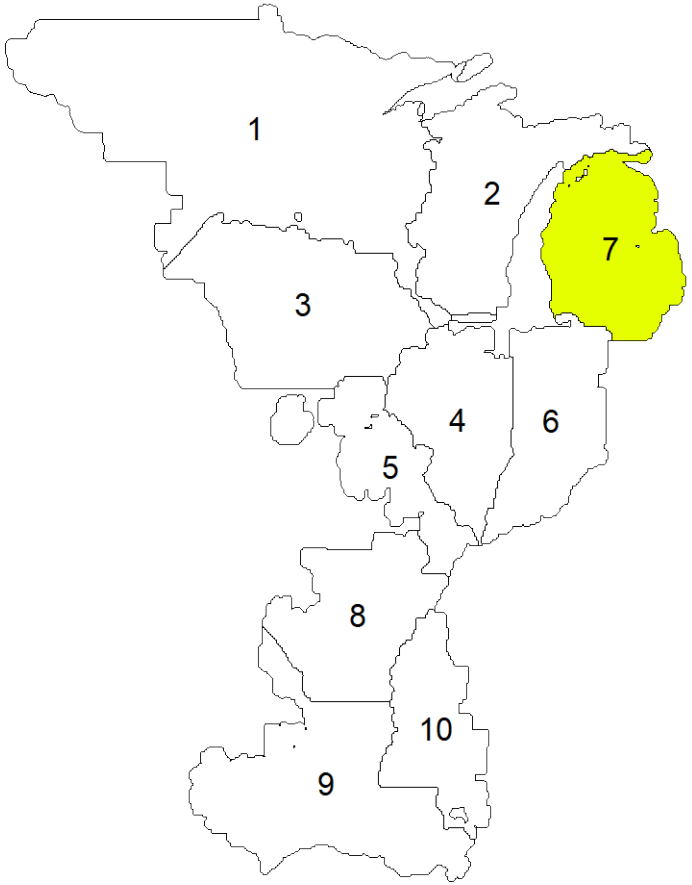


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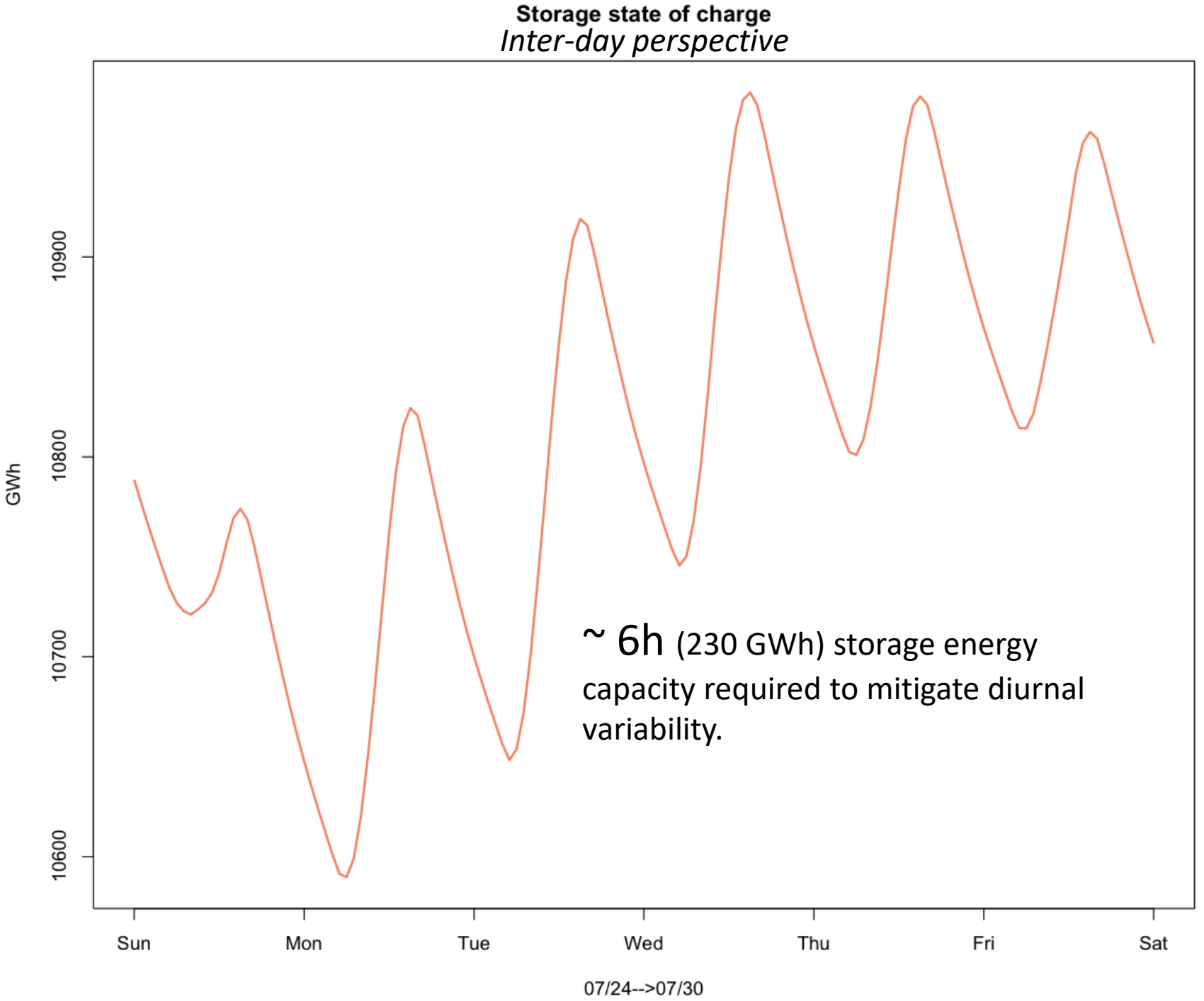

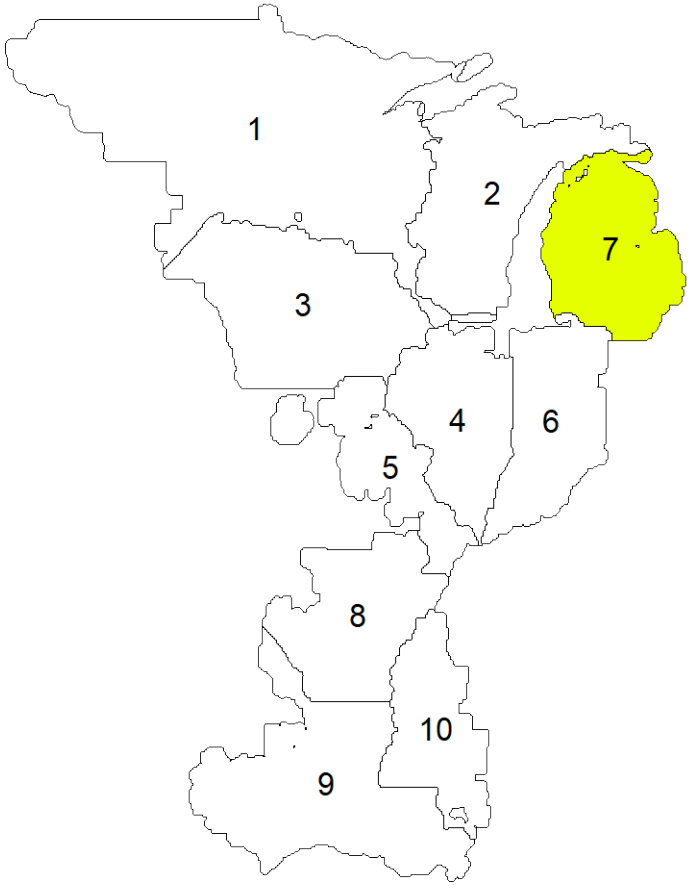


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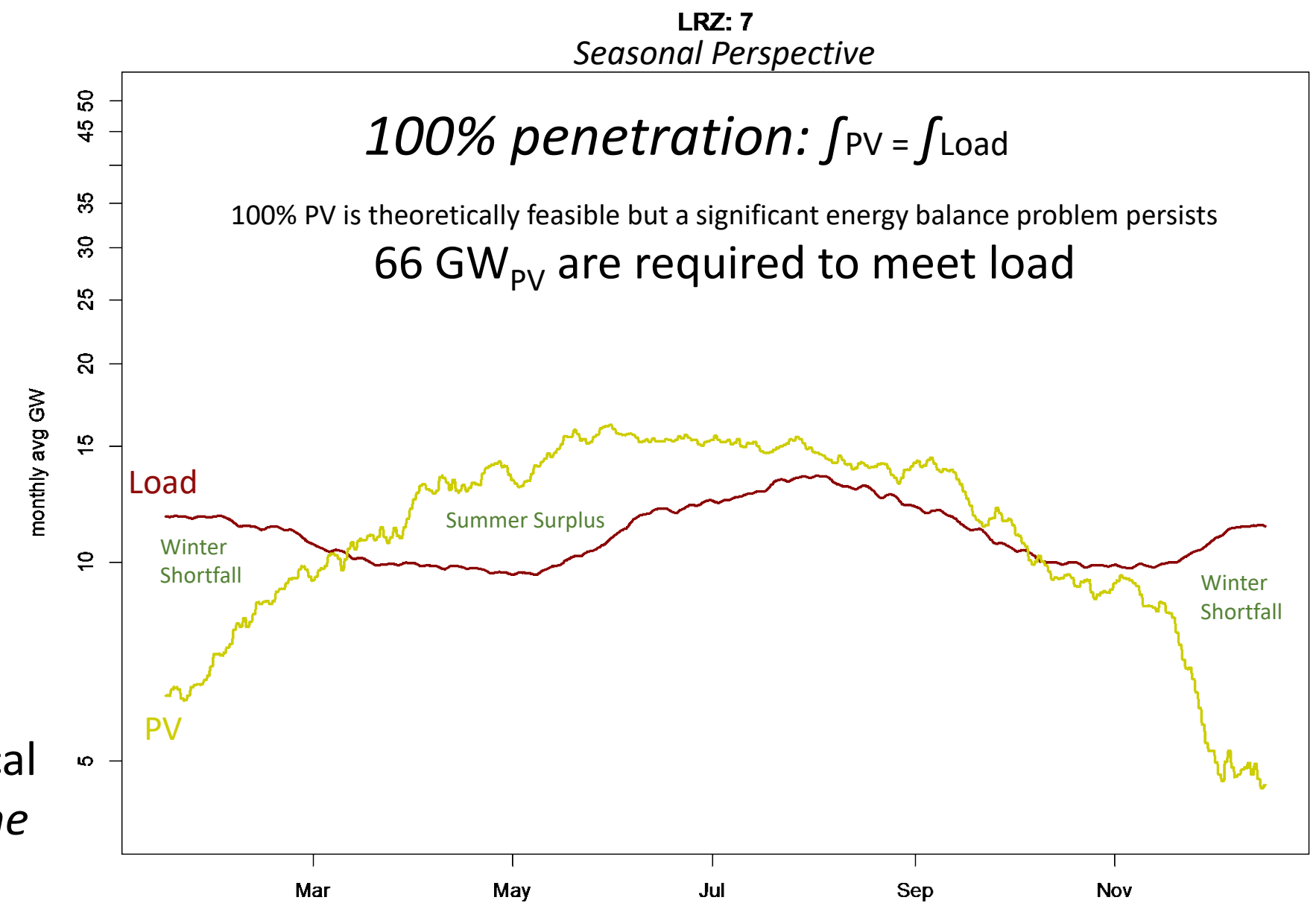

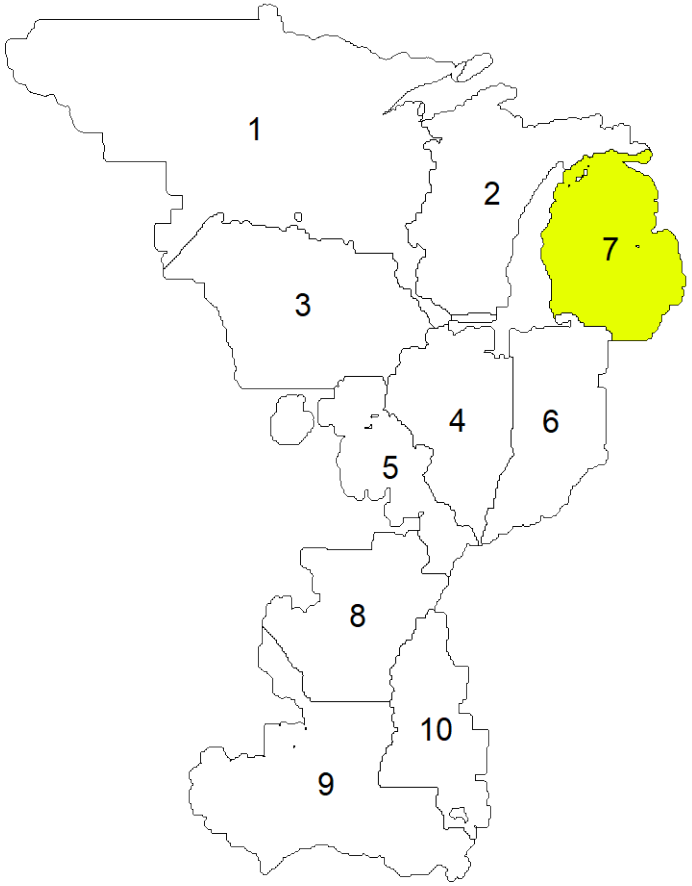


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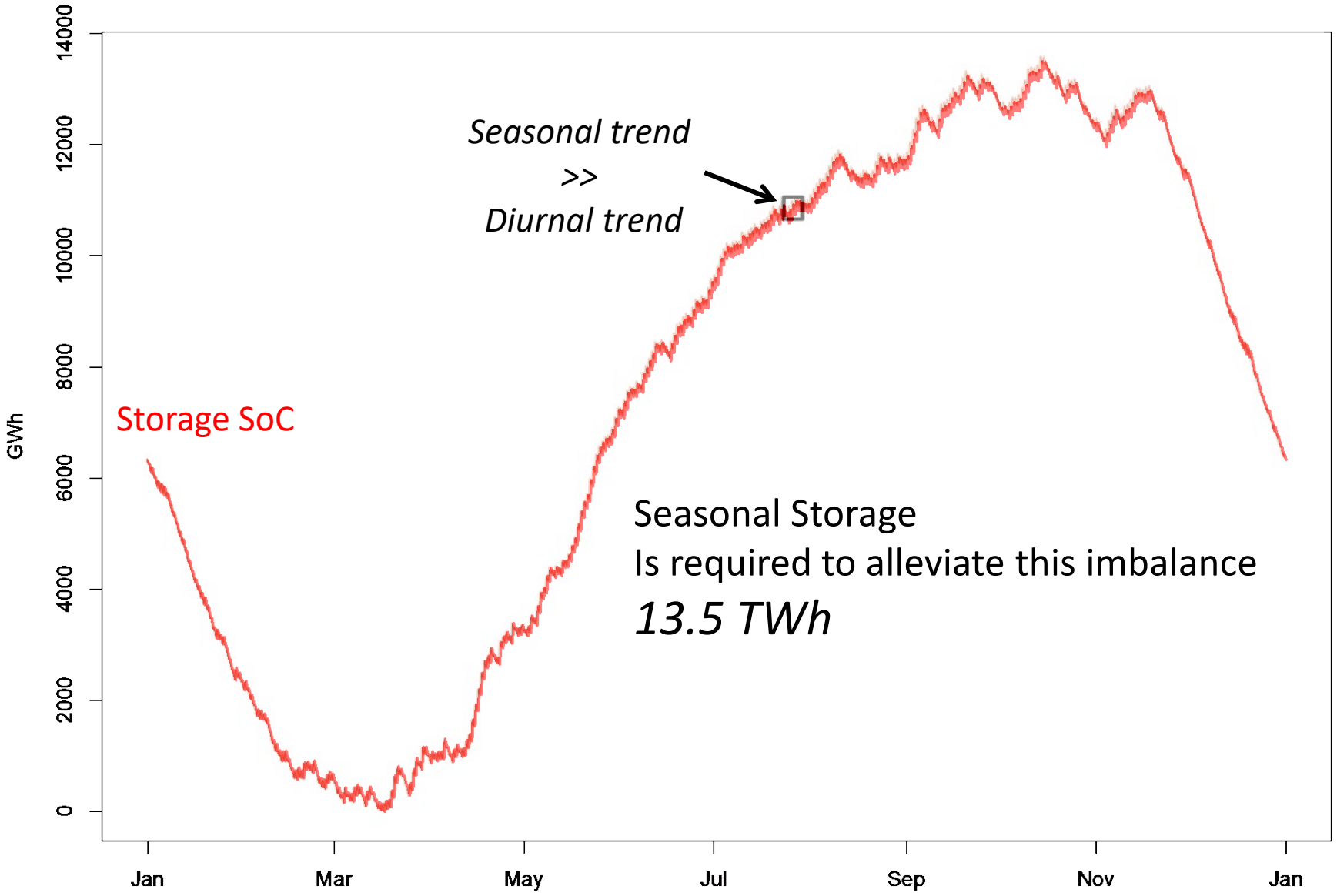

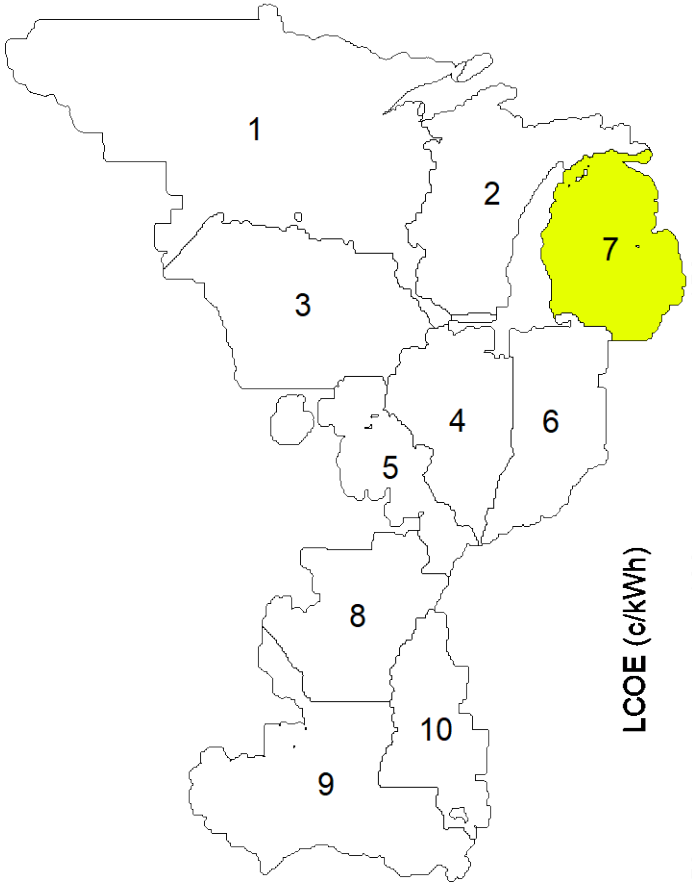


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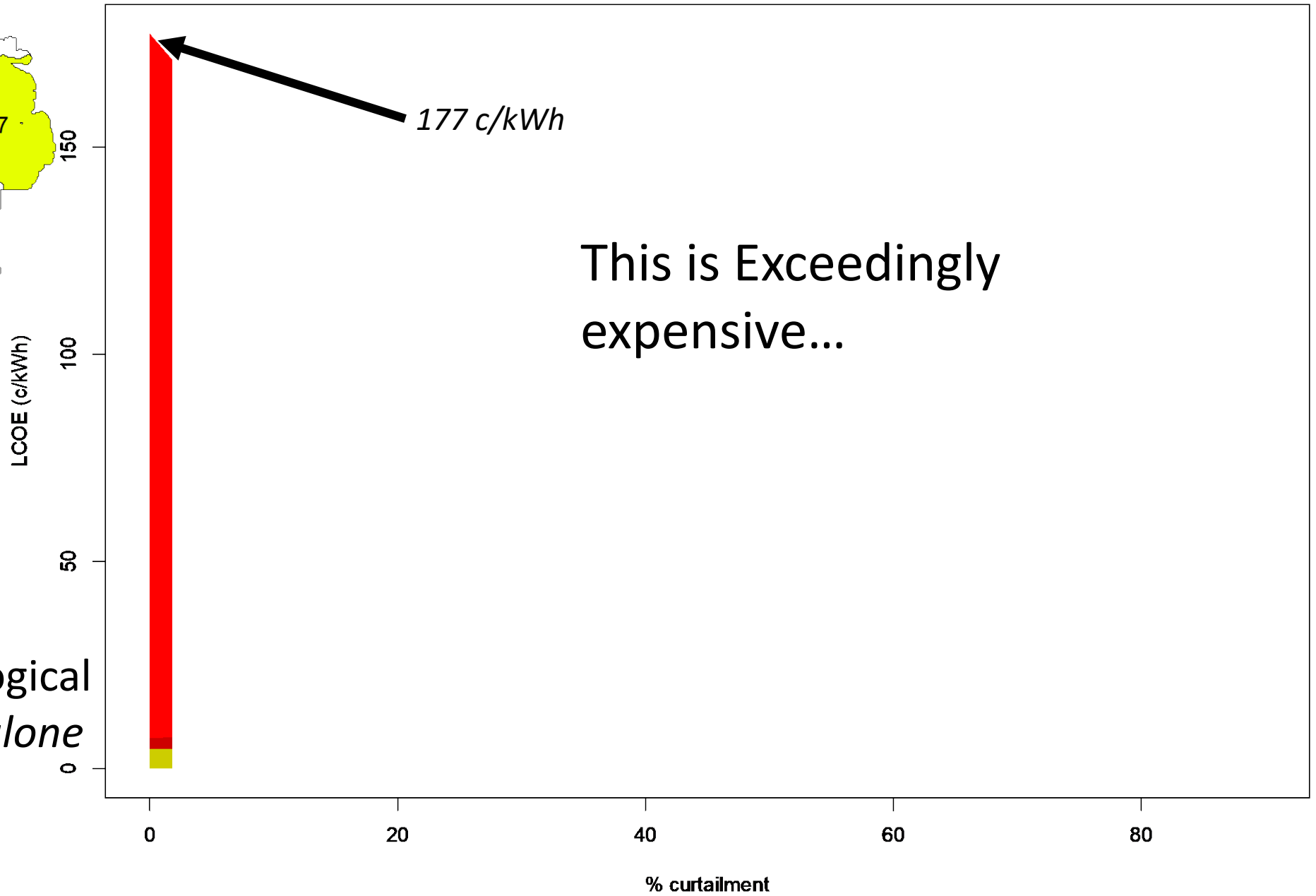

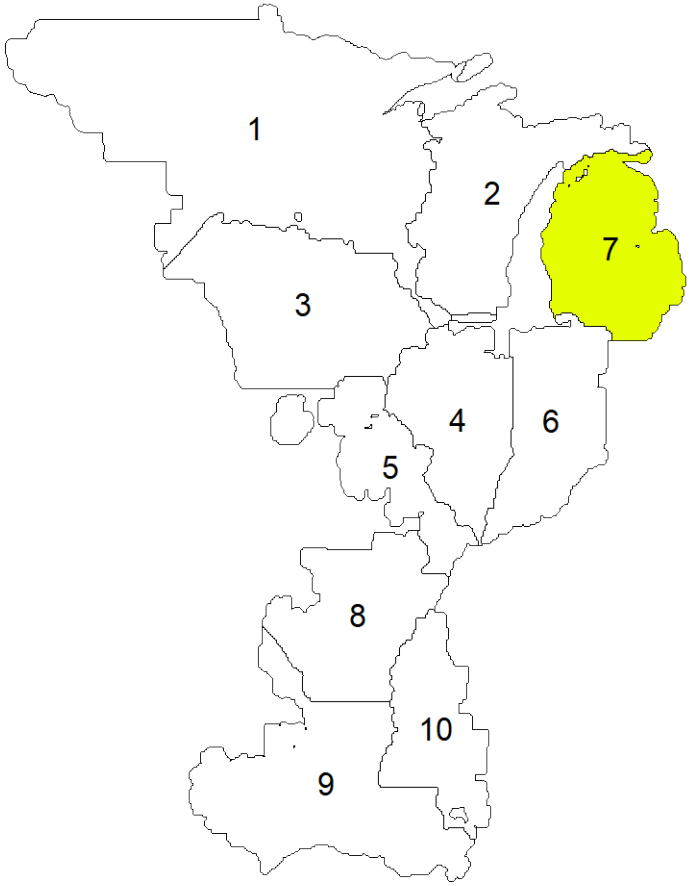


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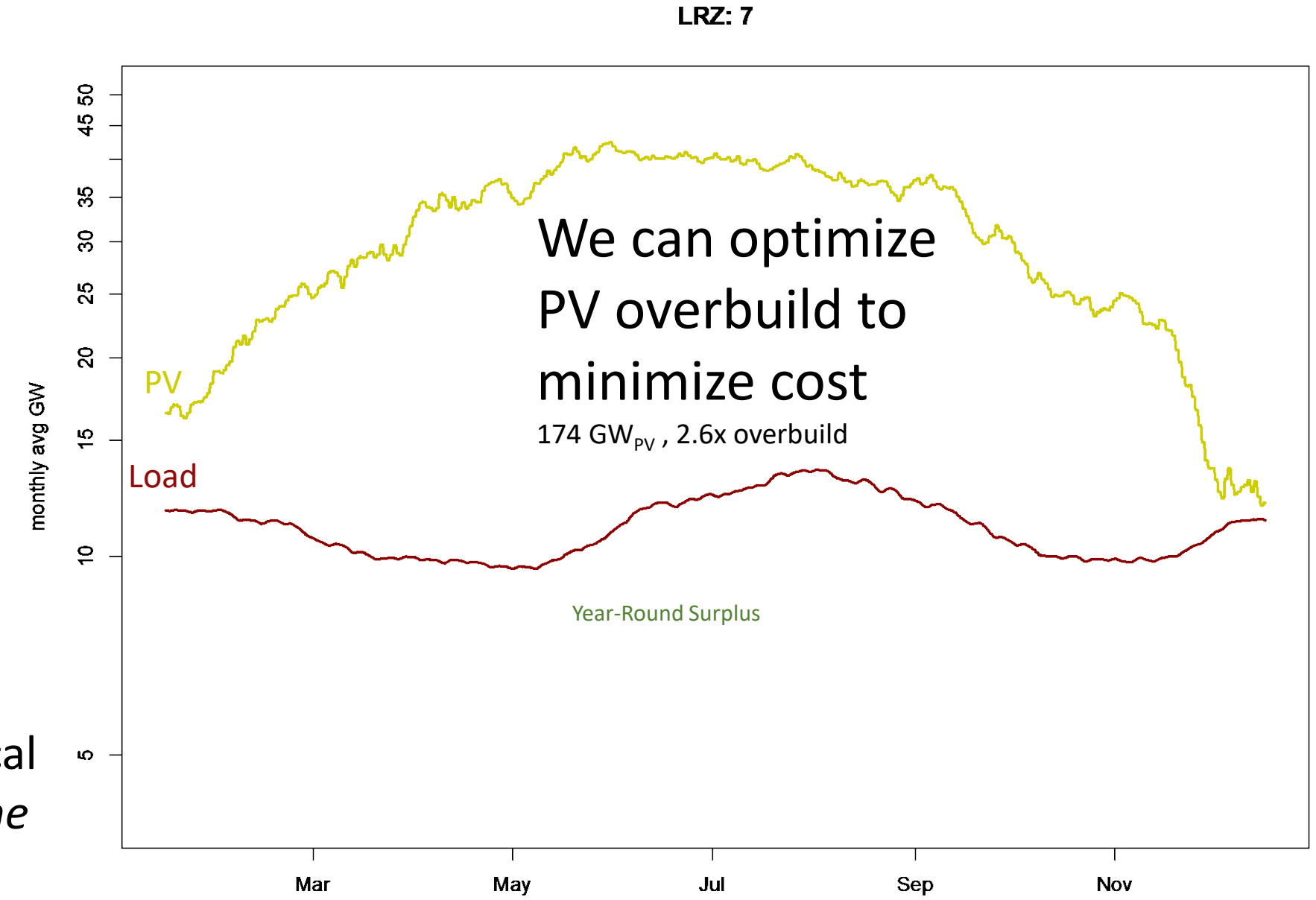

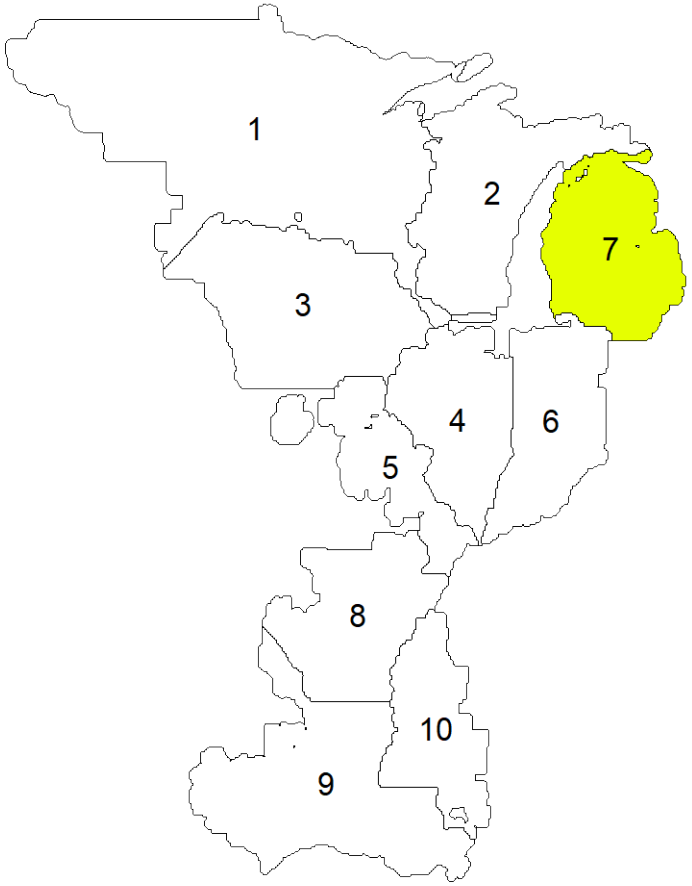


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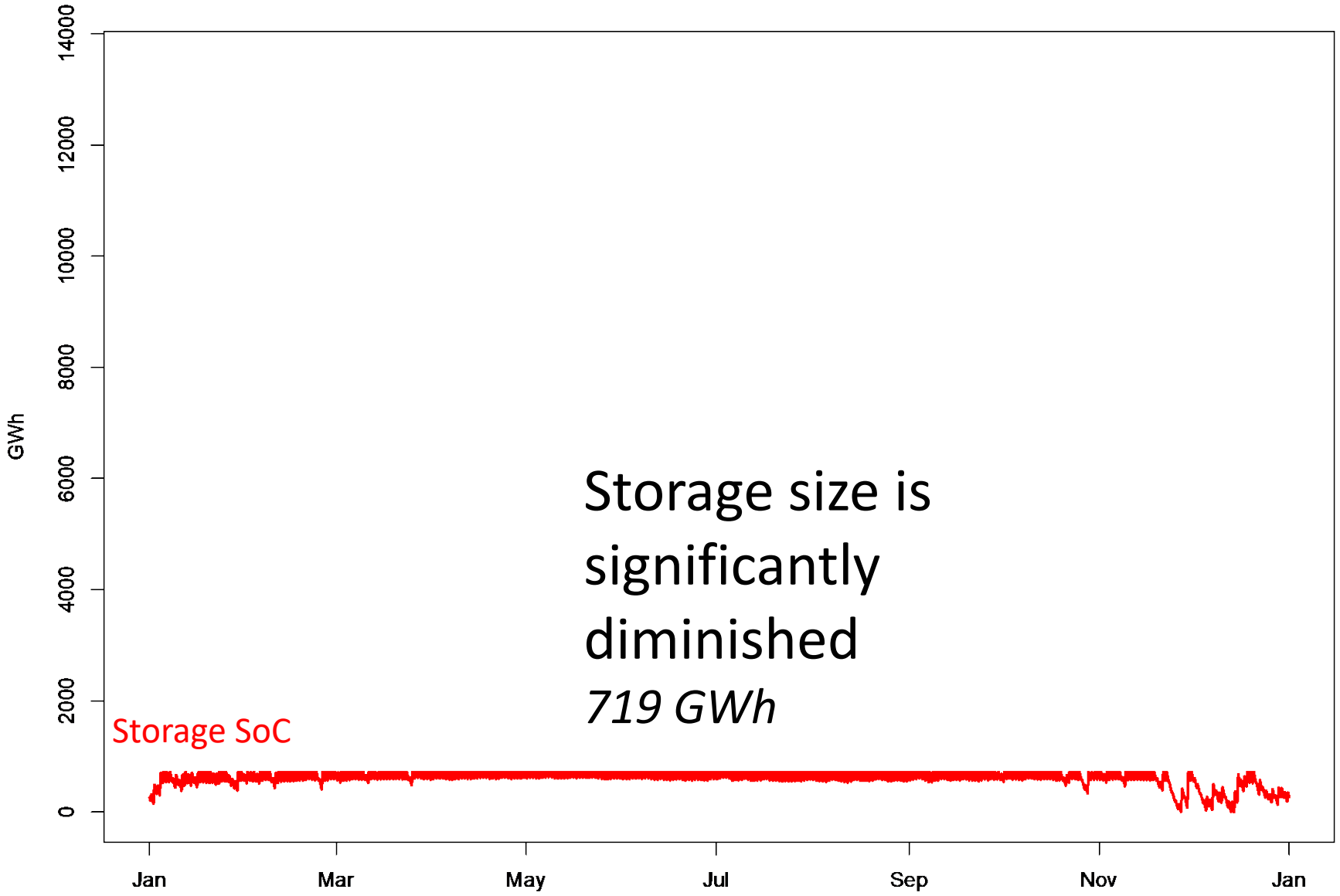

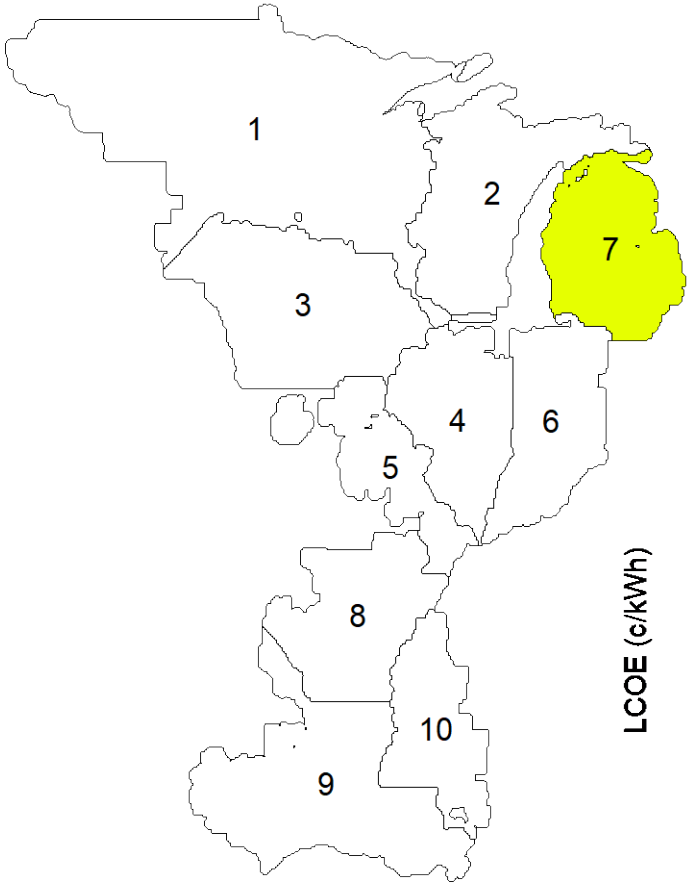


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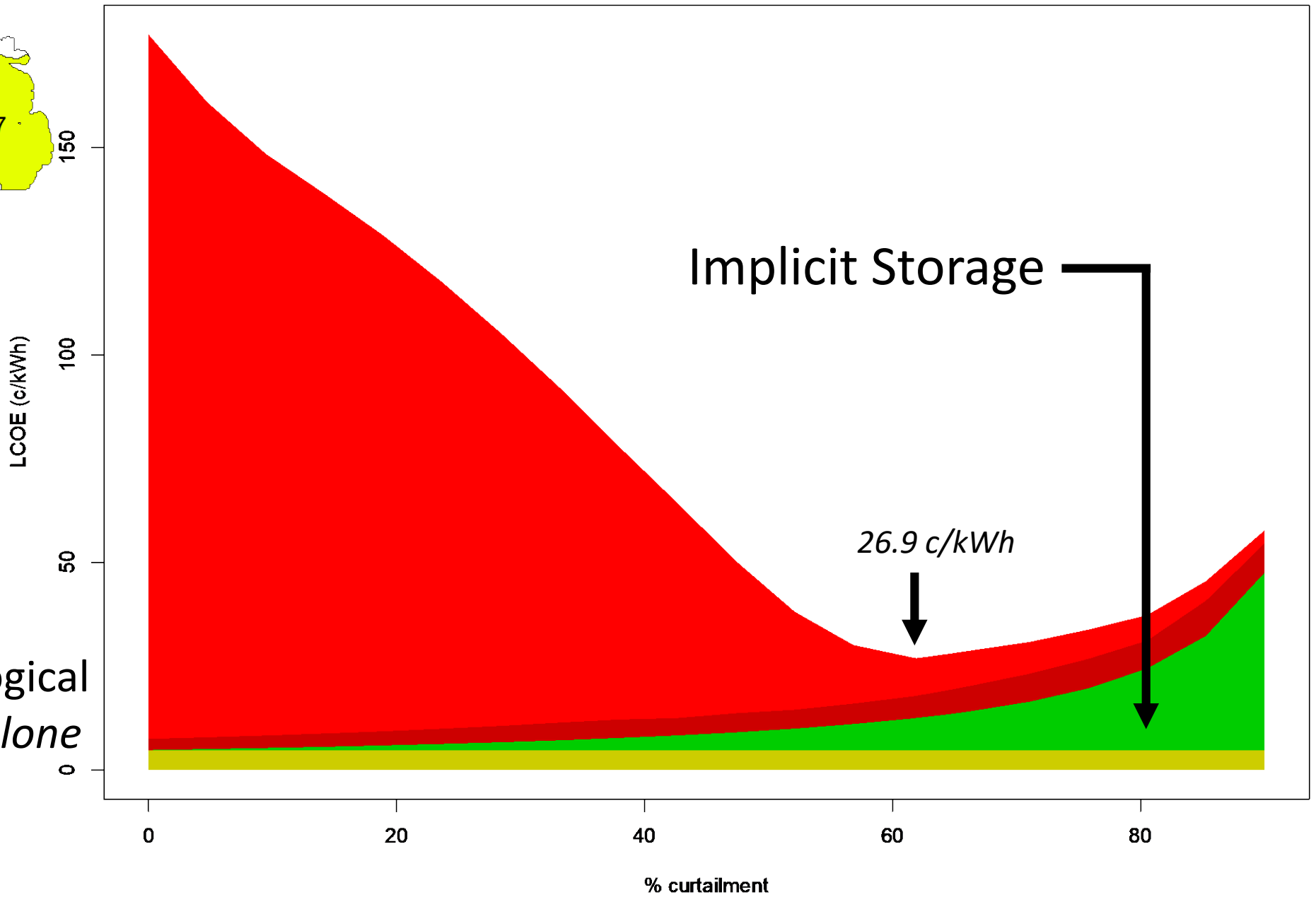


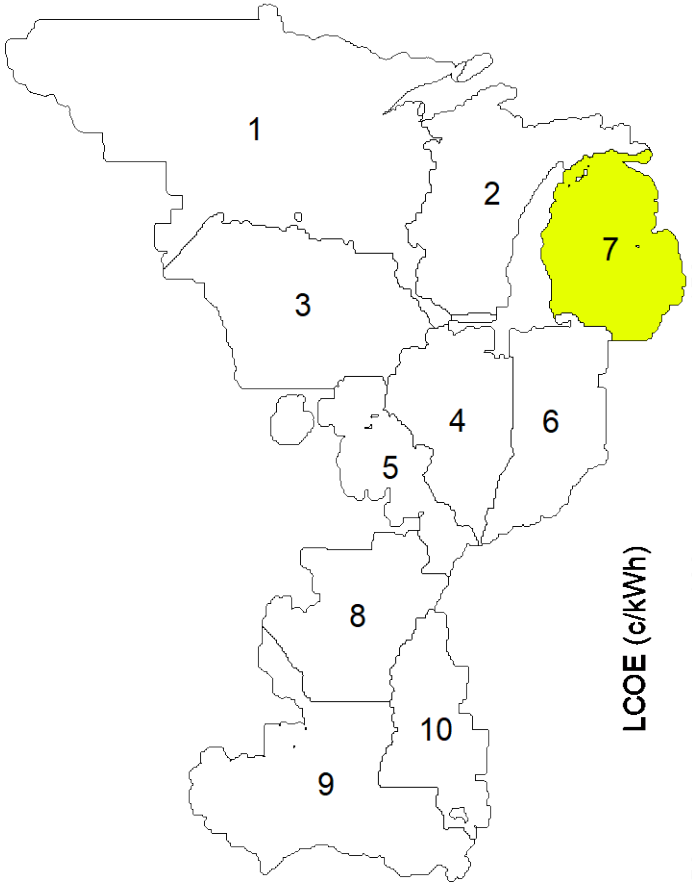
2050 , High

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

**26.9 c/kWh**

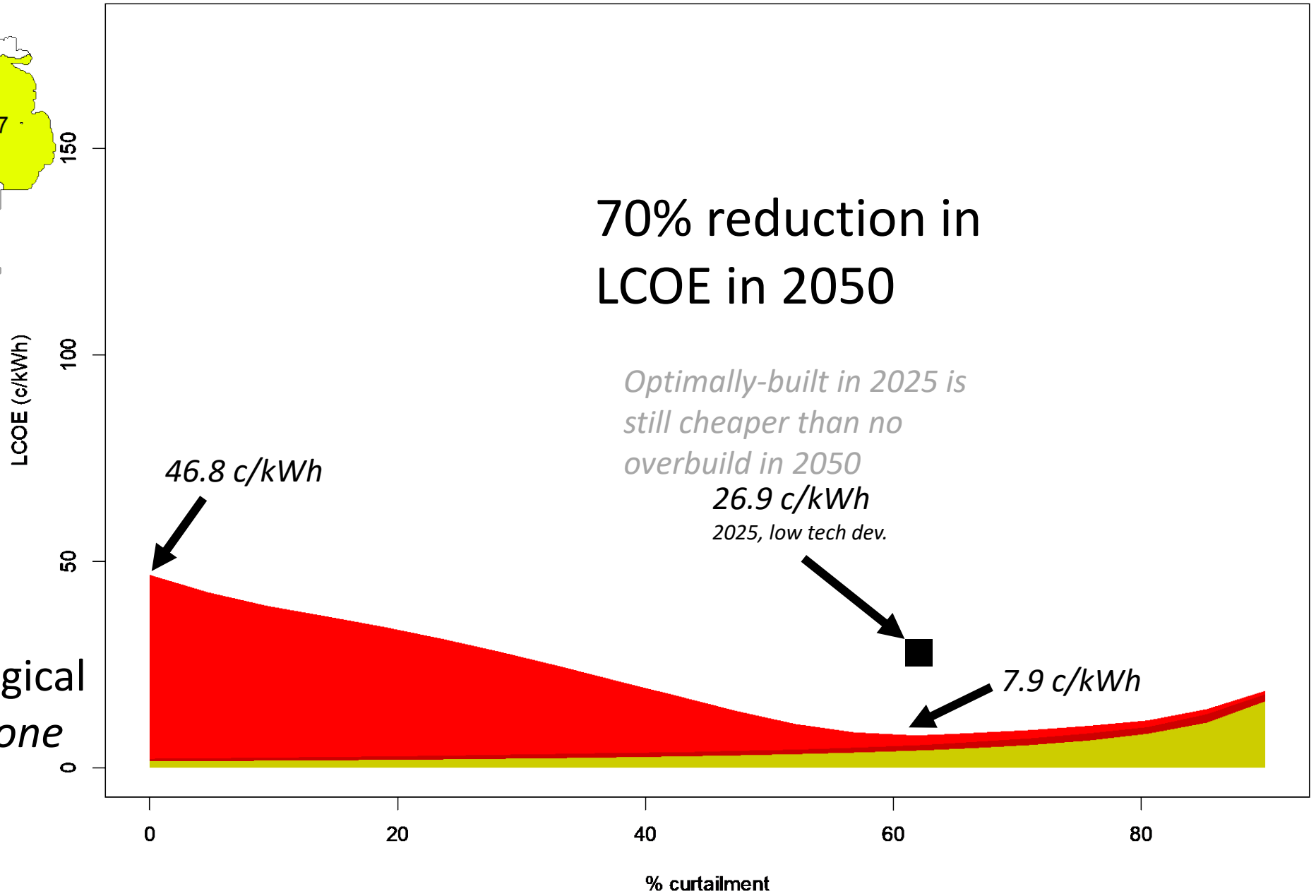
*174 $GW_{PV}$ 719 GWh Storage*

Let’s look at the impact of price




# Consider LRZ 7

2050, *high* technological development, PV *alone*



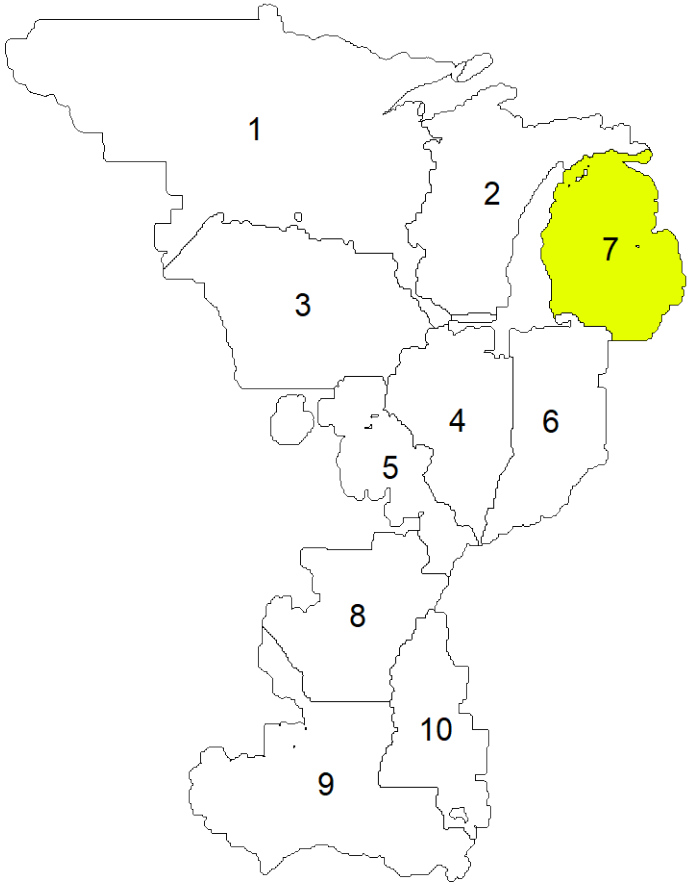
Wind

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

**7.9 c/kWh**

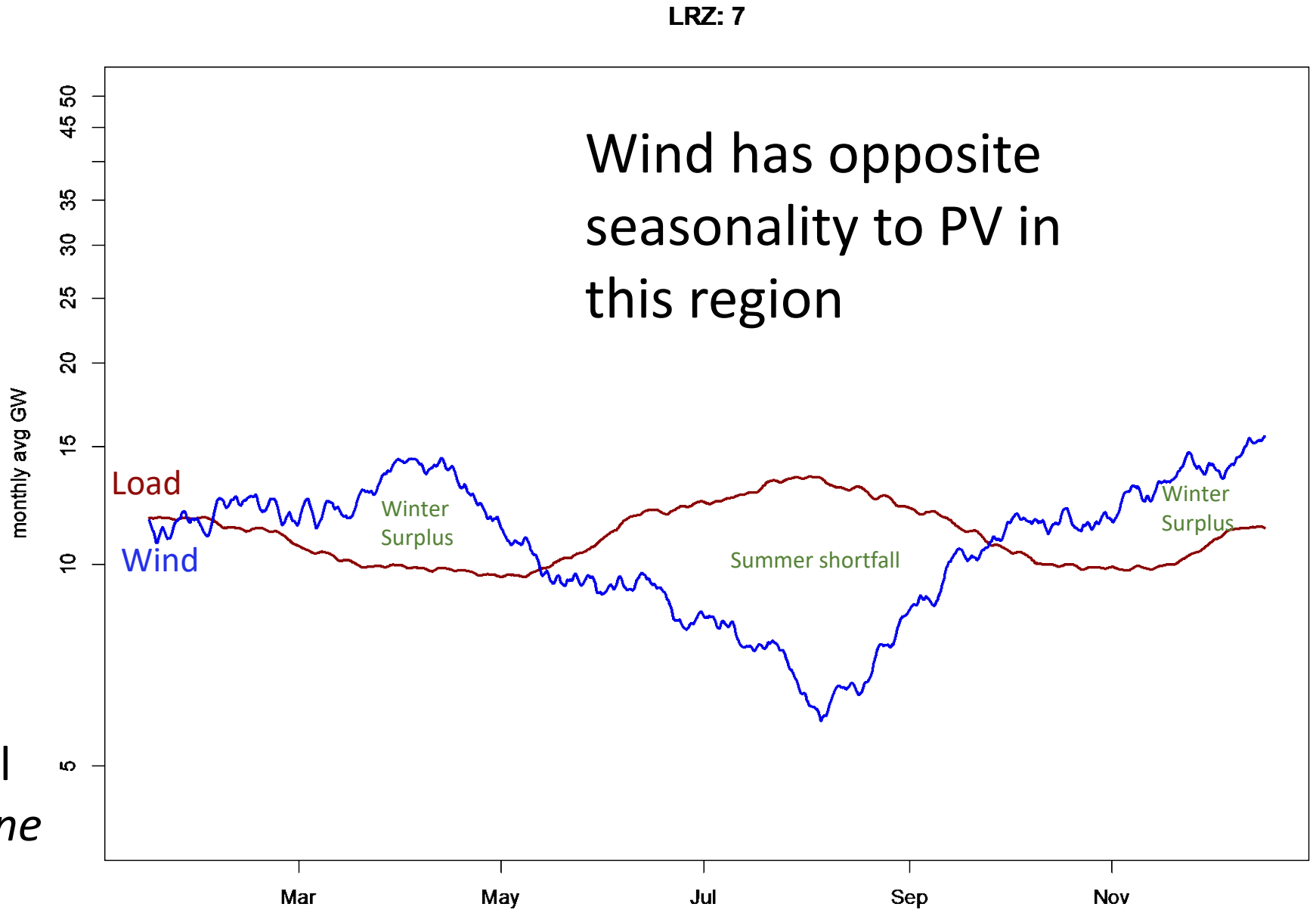
*174 $GW_{PV}$ 719 GWh Storage*

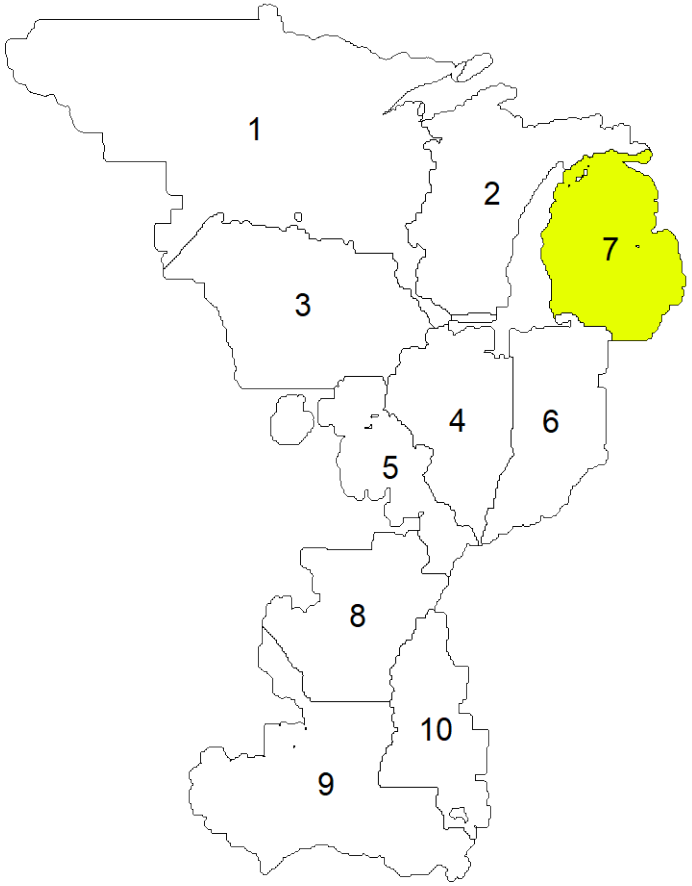
What about wind? Does the same hold true?




# Consider LRZ 7

2050, *high* technological development, Wind *alone*



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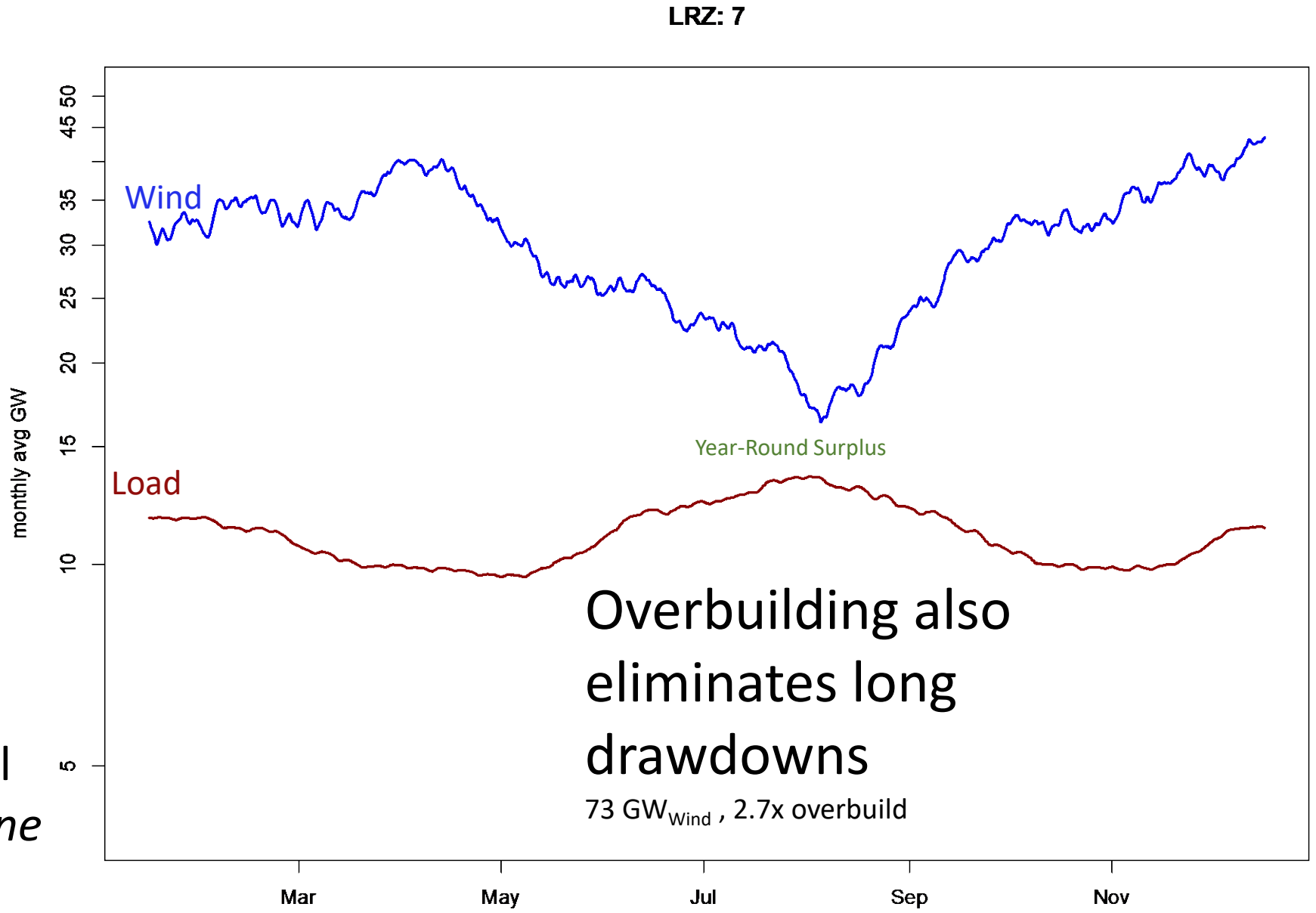
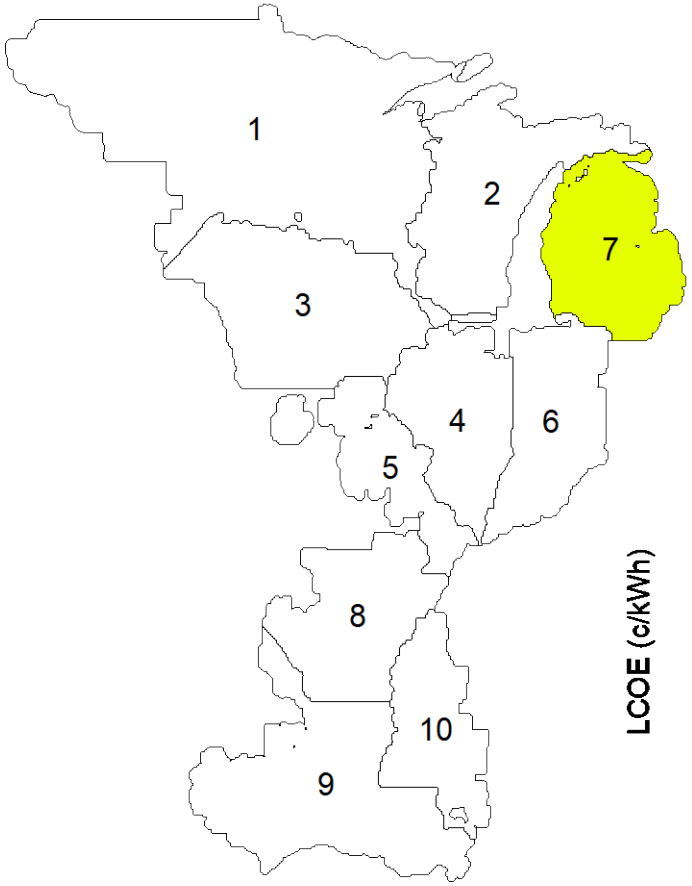
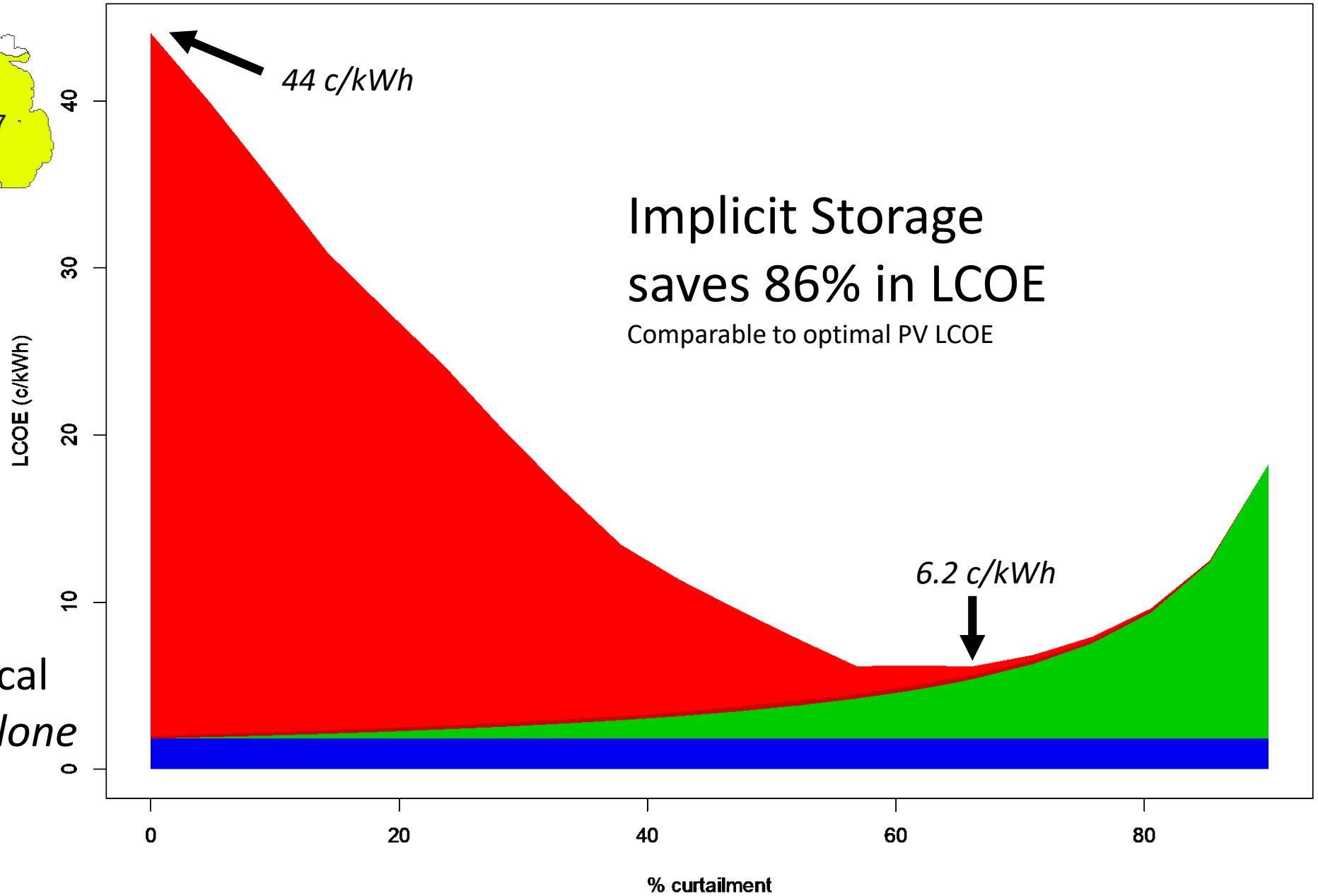
2050, *high* technological development, Wind *alone*






# Consider LRZ 7

2050, *high* technological development, Wind *alone*



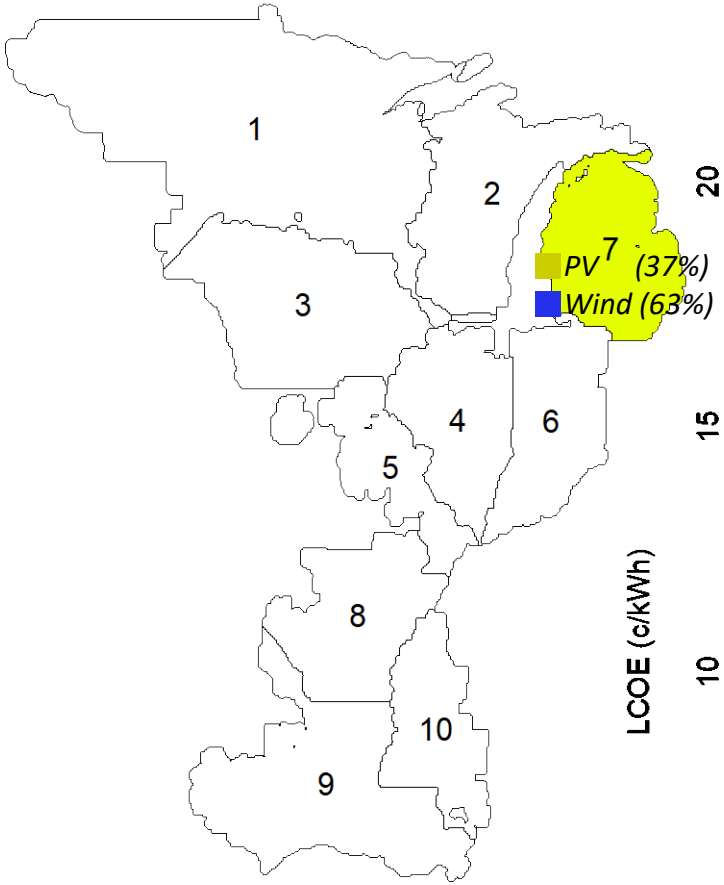
Wind + PV

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

**6.2 c/kWh**

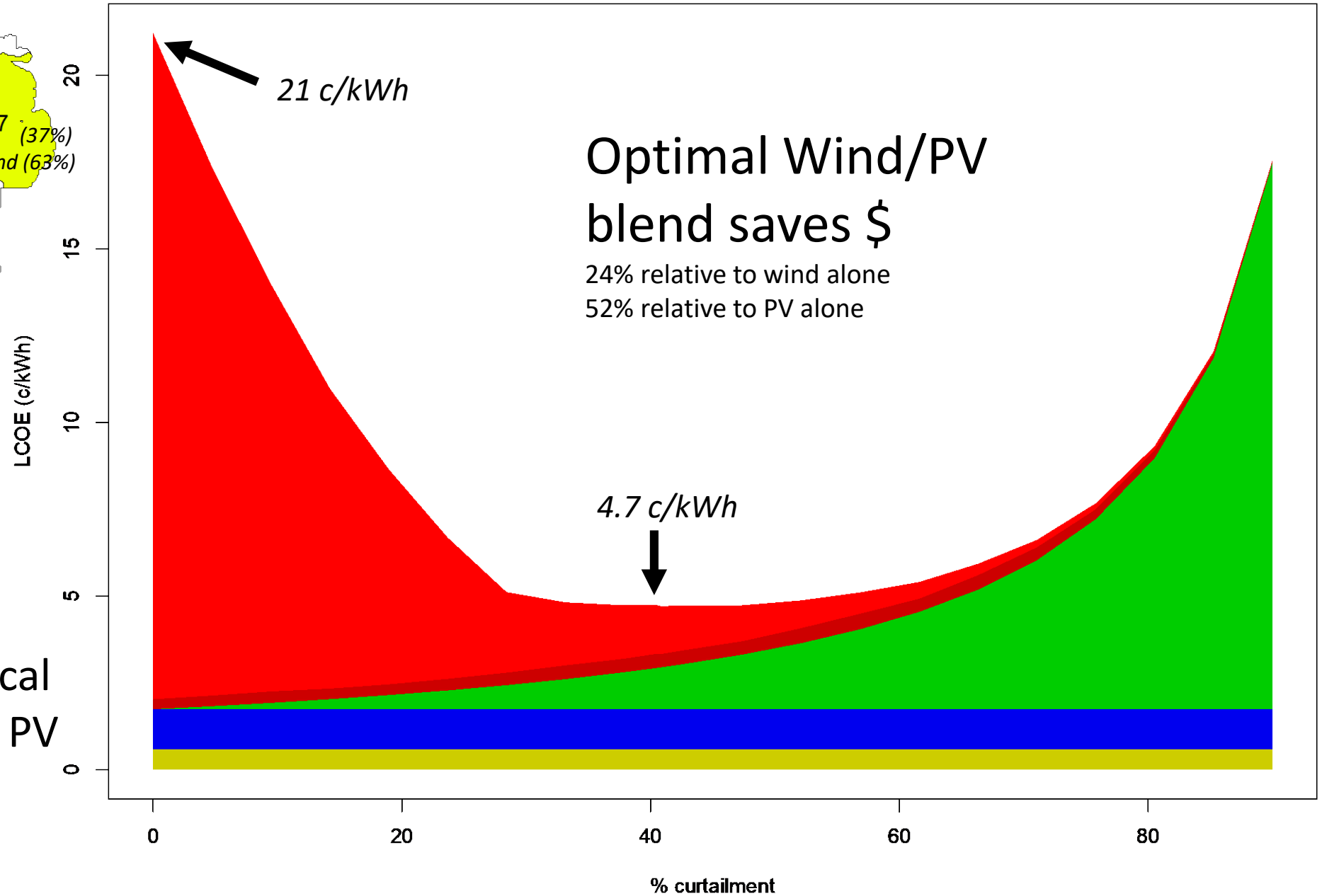
*73 $GW_{Wind}$ 239 GWh Storage*

How does wind/PV hybridization change price?




# Consider LRZ 7

2050, *high* technological development, Wind + PV



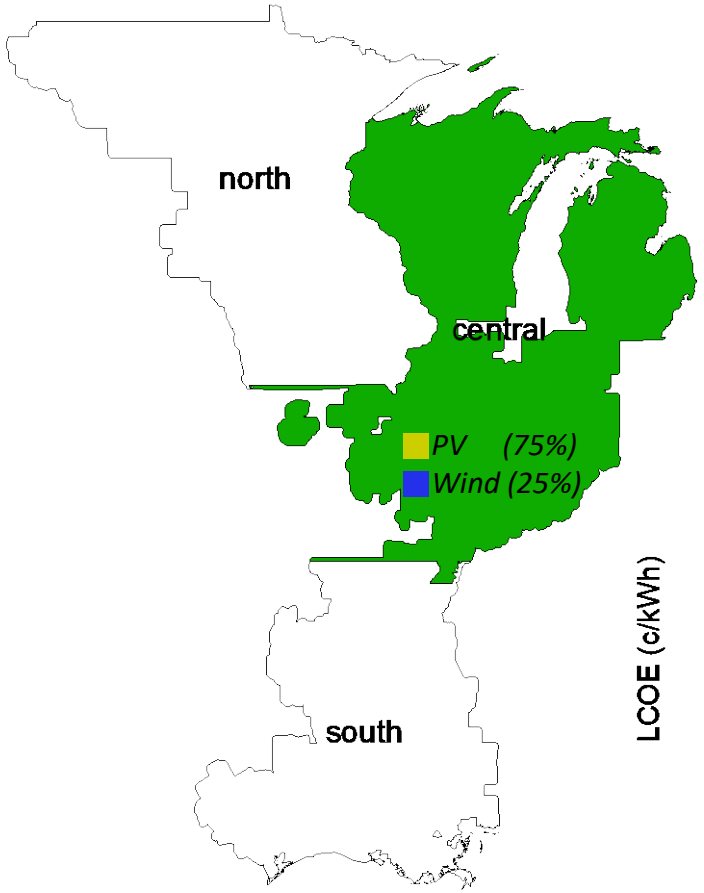
MISO Central Region

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

**4.7 c/kWh**

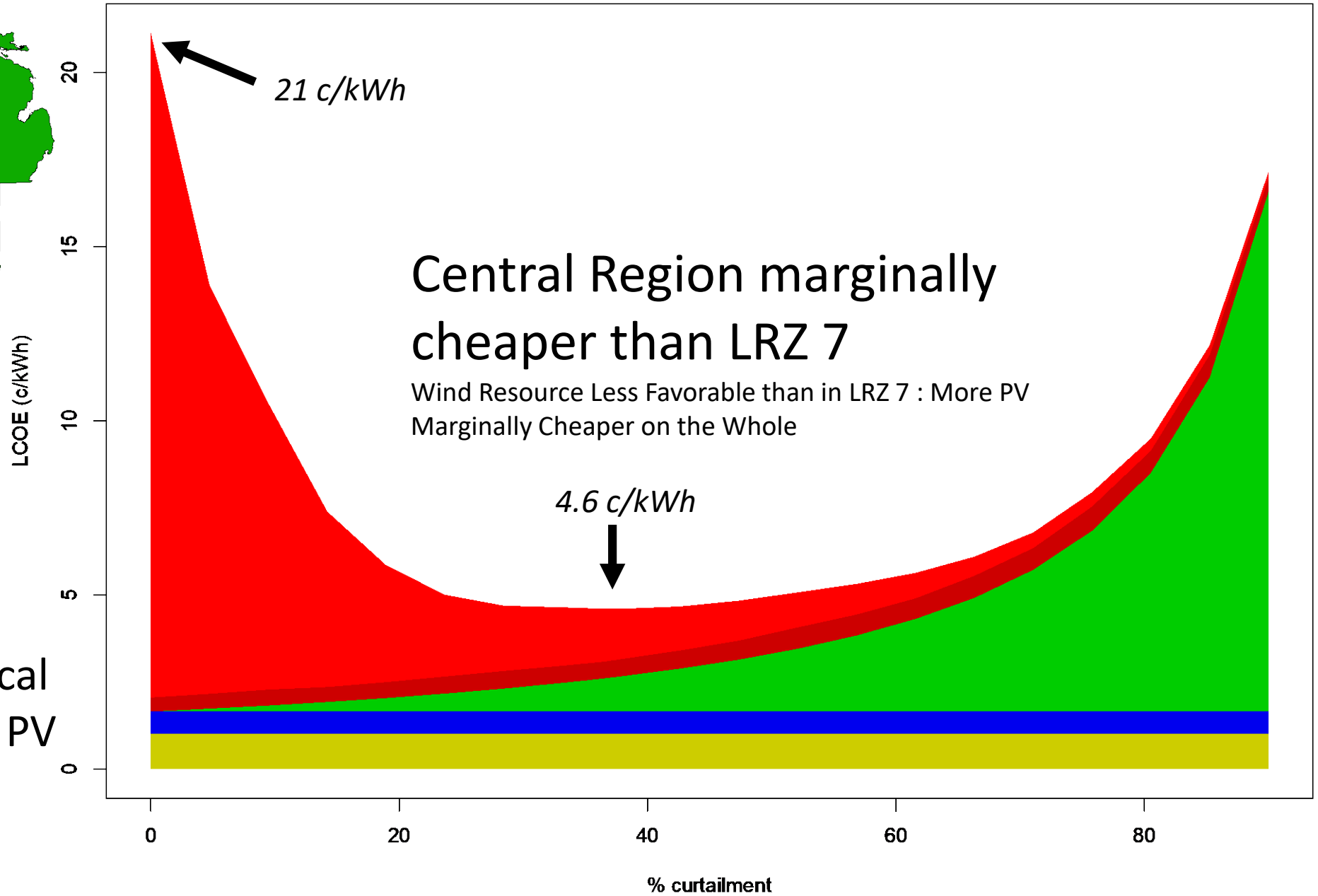
*28 $GW_{Wind}$, 42 $GW_{PV}$, 419 $GWh_{Storage}$*

How does region size impact LCOE?




# Consider *Central*

2050, *high* technological development, Wind + PV



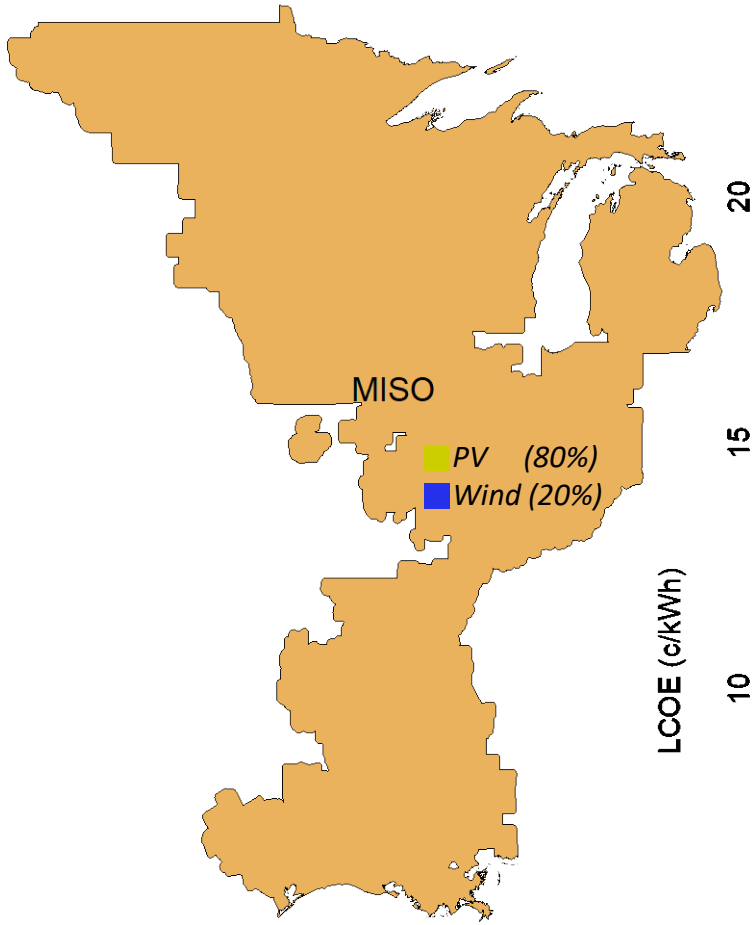
All of MISO

2050, high Technological Development, MISO ~~Central Region, 100%~~ Wind + PV + storage

**4.6 c/kWh**

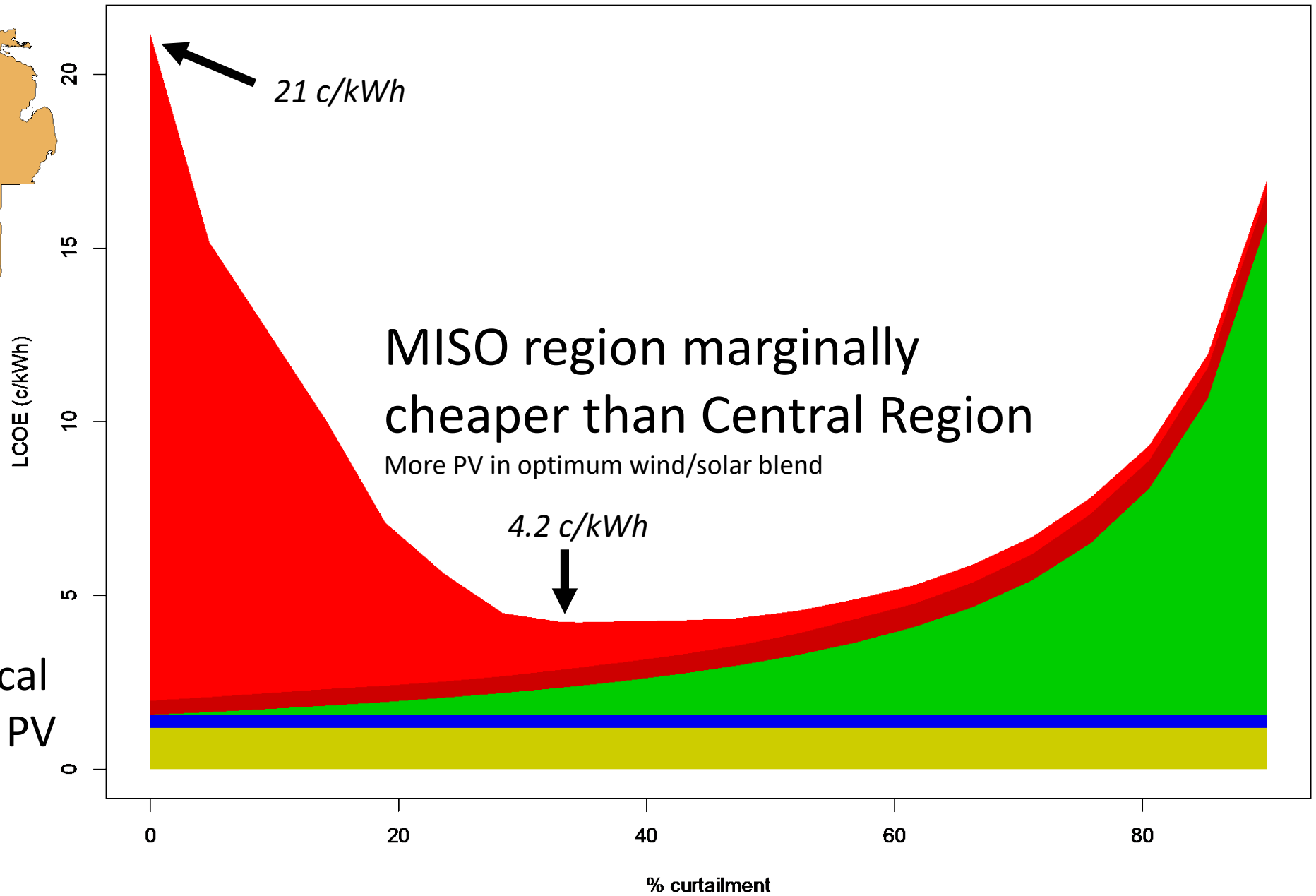
*52 $GW_{Wind}$, 243 $GW_{PV}$, 1.6 $TWh_{Storage}$*

What about all of MISO?




# Consider *MISO*

2050, *high* technological development, Wind + PV



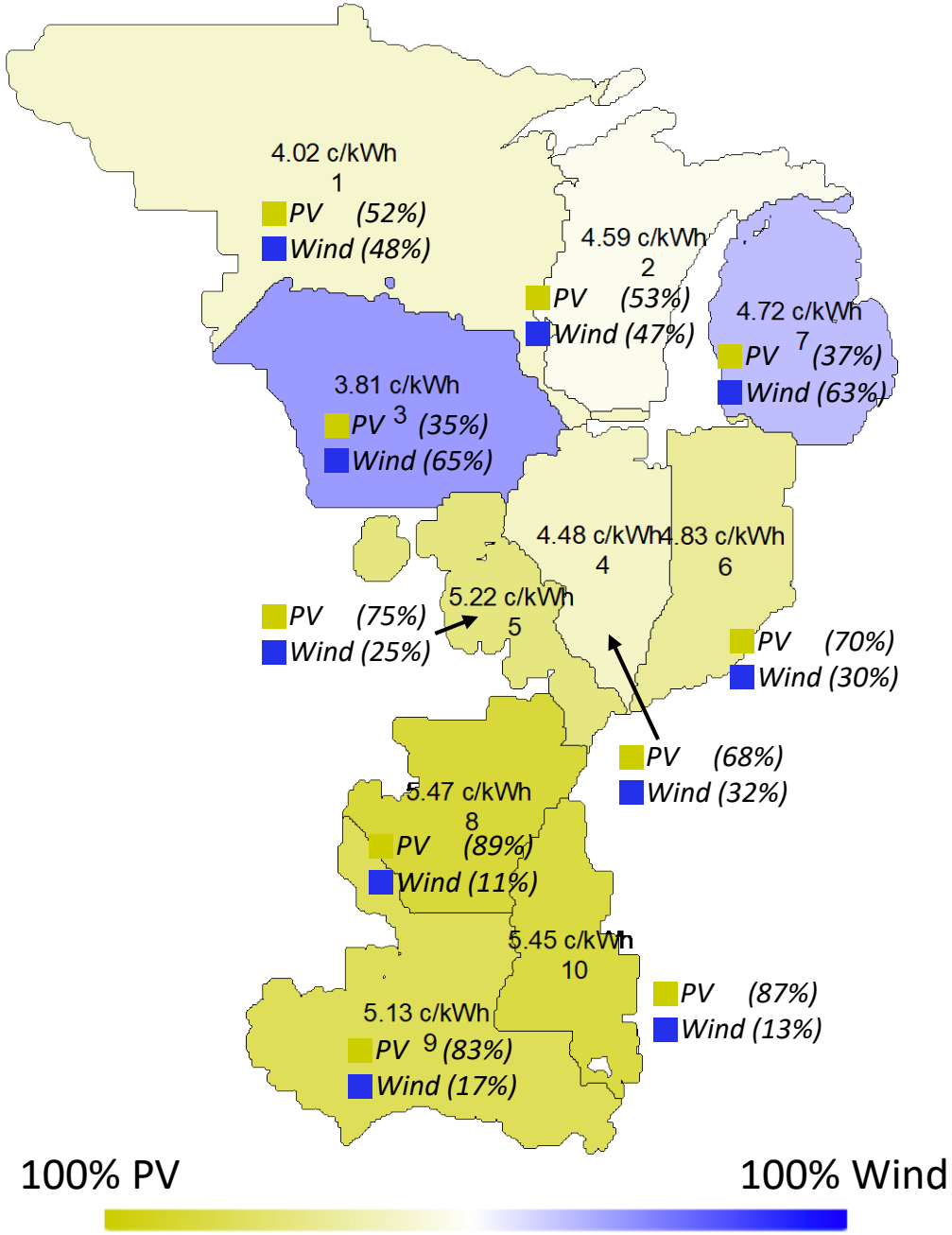
2050, high Technological Development, All of MISO, 100% Wind + PV + storage

**4.2 c/kWh**

$57\ GW_{Wind}$, $511\ GW_{PV}$, $2.7\ TWh_{Storage}$

With 667 TWh of annual usage, this equates to $28 Bn of annual expenditures

What if each LRZ optimized for themselves?



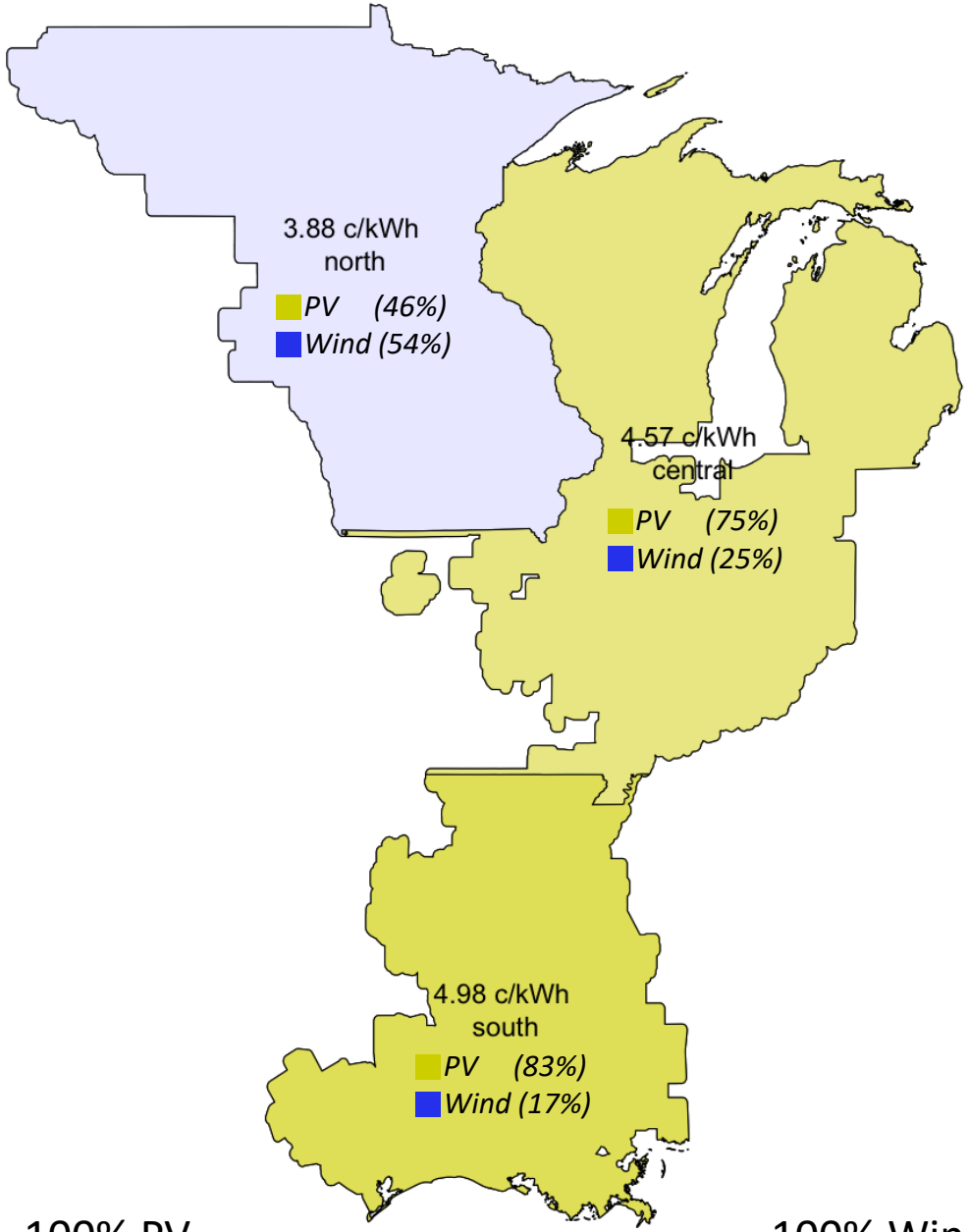

*If each LRZ islanded themselves and optimized their resource blends, the electricity price would be:*

**4.65 c/kWh**

*weighted average cost*

This equates to $31 Bn/yr

<u>The MISO-region interconnection will save ratepayers $3 Bn/yr</u>




*The picture is similar if each MISO Region Islanded themselves*

**4.53 c/kWh**

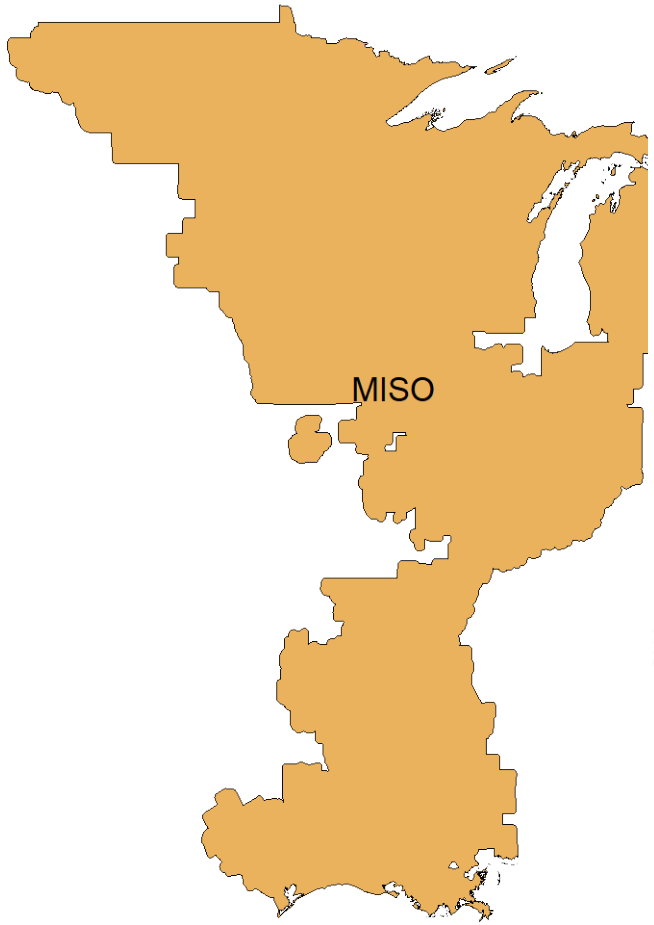
*weighted average cost*

This equates to $30 Bn/yr

<u>The MISO-region interconnection will save ratepayers $2 Bn/yr</u>

The larger the interconnection region, the lower the cost

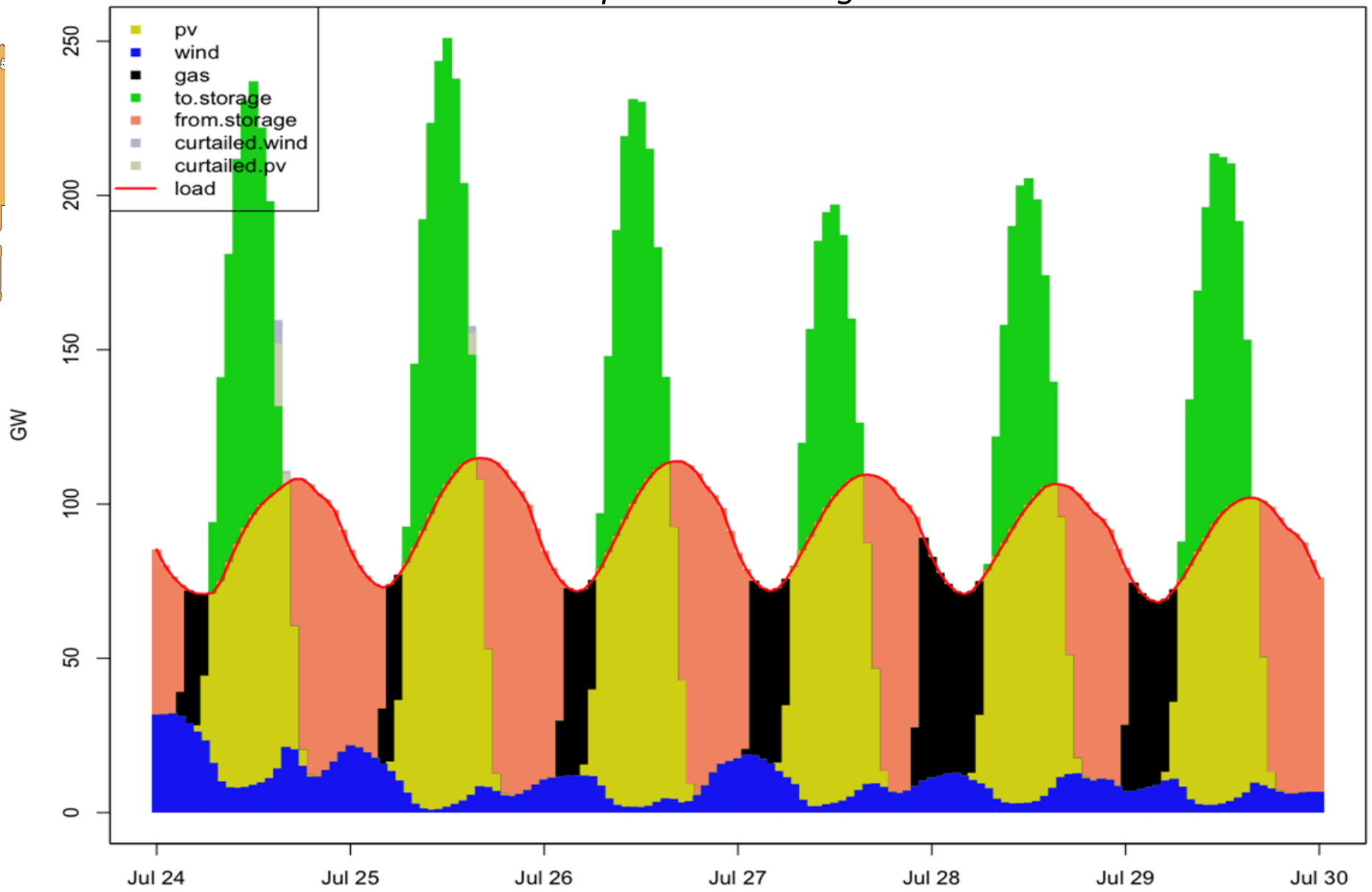
*Finally, what about adding 5% new-build gas as we did for MN?*




# Consider *MISO*

2050, *high* technologica development, Wind, PV +gas

*Dispatch with 5% gas*



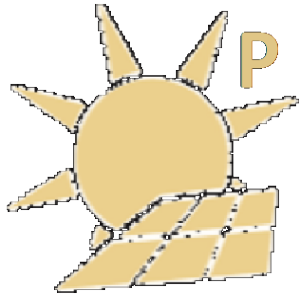

% curtailment

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

# Key takeaways

- **Implicit Storage Value** Overbuilding + Curtailment is highly cost-effective in every case
- **Wind/PV value** Wind + PV hybrid resourcing is significantly cheaper than either alone due to seasonal resource anticorrelations, even in areas that have a dominant resource. (i.e. MISO North still wound up with 46% PV at the optimal point)
- **Cost matters** Technology costs changing rapidly and correspondingly alter the LCOEs
  - Raise wind cost relative to PV cost, decrease optimal wind percentage
  - Raise storage cost relative to renewables, increase implicit storage use
  - Confidence and consensus surrounding cost will help solidify the planning process
- **PV>Wind**
  - PV is Favored in 2050 In 2050, high technological development scenarios drive PV CapEx so low that even in areas where wind appears dominant, PV is largely favored.
  - This is despite a very strong wind resource in the northern part of MISO territory
  - Exceptions include MISO-North and LRZ 3 and 7 where the very strong wind resource tilts the balance
- **5% flexibility -20%**
  - **95% Renewables is significantly cheaper** Allowing 5% gas or some other dispatchable gas to perform some of the work otherwise done by storage (both implicit and real). It may also be more acceptable as it correspondingly reduces the amount of optimal curtailment.
- **Transmission value**
  - **The Value of MISO** The larger the region we interconnect across, the lower the aggregate cost. On the whole this will save ratepayers billions annually.

# 100% MISO Load


30% Wind 65% Solar 5% Gas

*3.5 c/kWh*

# *Thanks!*

# Pathways to 100% Renewables across the MISO region

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Marc Perez, Ph.D.

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