Electricity Balancing in High Renewable Scenarios

EVOLVED ENERGY RESEARCH

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About Evolved Energy Research

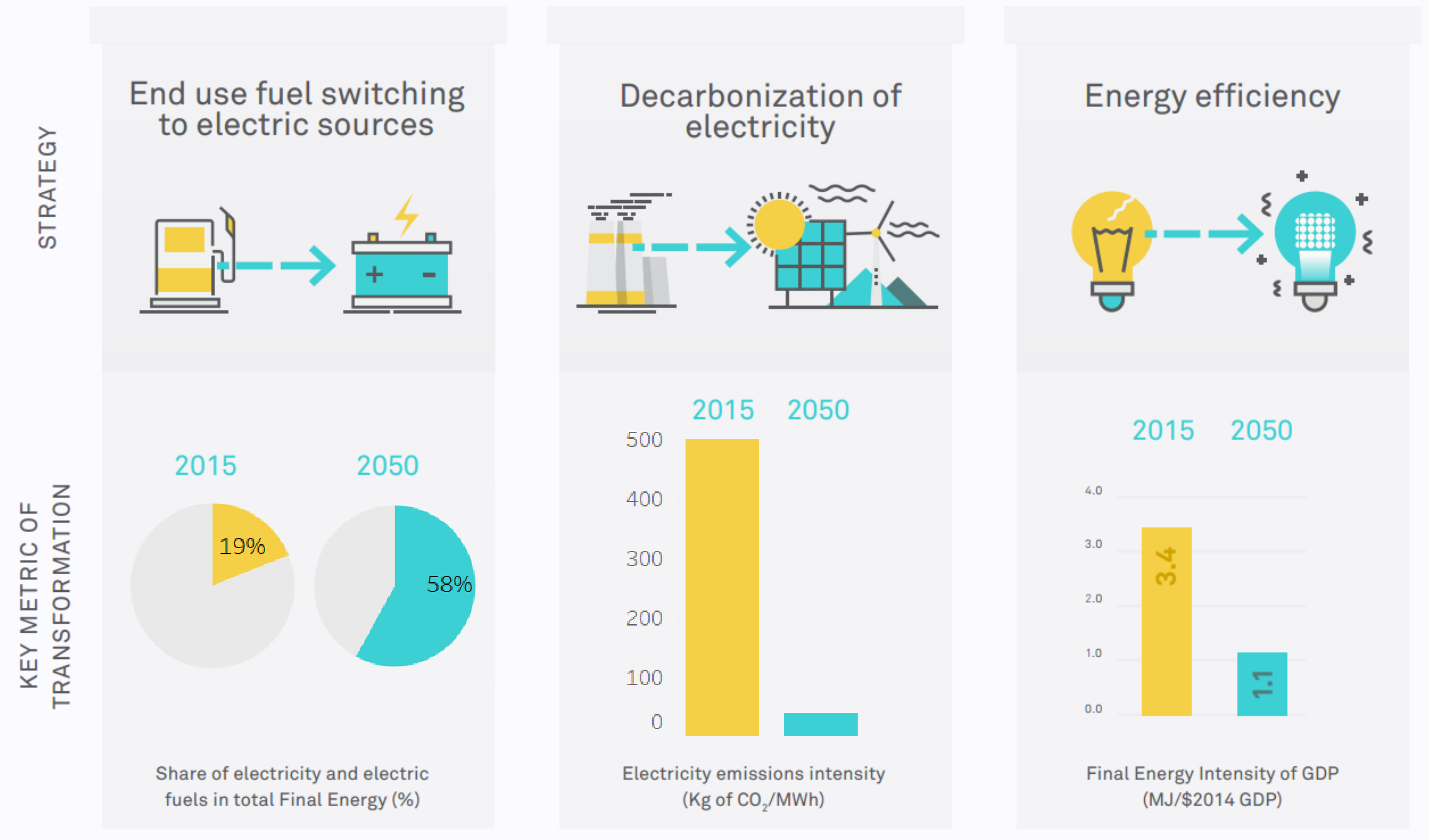
- Energy consulting firm focused on addressing key energy sector challenges posed by energy system transformation
- Lead developers of EnergyPATHWAYS and RIO, two models used to investigate pathways to deep decarbonization
- We advise clients on issues of policy implementation and target-setting, infrastructure investments, R&D strategy, technology competitiveness, and asset valuation

Three pillars of a low carbon energy system transition

United States

2050 U.S. Benchmarks

- 3x increase in the share of energy from electricity or electrically derived fuels
- 90% decrease in the emissions intensity of electricity generation
- 3x drop in energy use per unit GDP



Options for building a low-carbon grid

- Three opportunities for decarbonizing the electricity system
  1. **Fossil with carbon capture and sequestration** – theoretically operates much like today's grid, though with a bit less generator flexibility
  2. **Nuclear** – inflexible, but France demonstrates that excellent service can be provided with a predominantly nuclear electricity supply
  3. **Renewables (wind & solar)** – different characteristics of wind and solar present unique challenges for balancing the electricity system and significant research has gone into investigating these dynamics

Wind cost < gas < coal

In areas with good resources, renewables are the cheapest new source of energy

- Additional factors leading to growth of wind:
  - Is easier to permit than new thermal
  - Can be built in a range of sizes
  - Gives stable PPA prices
  - Offers hedging against policy unknowns

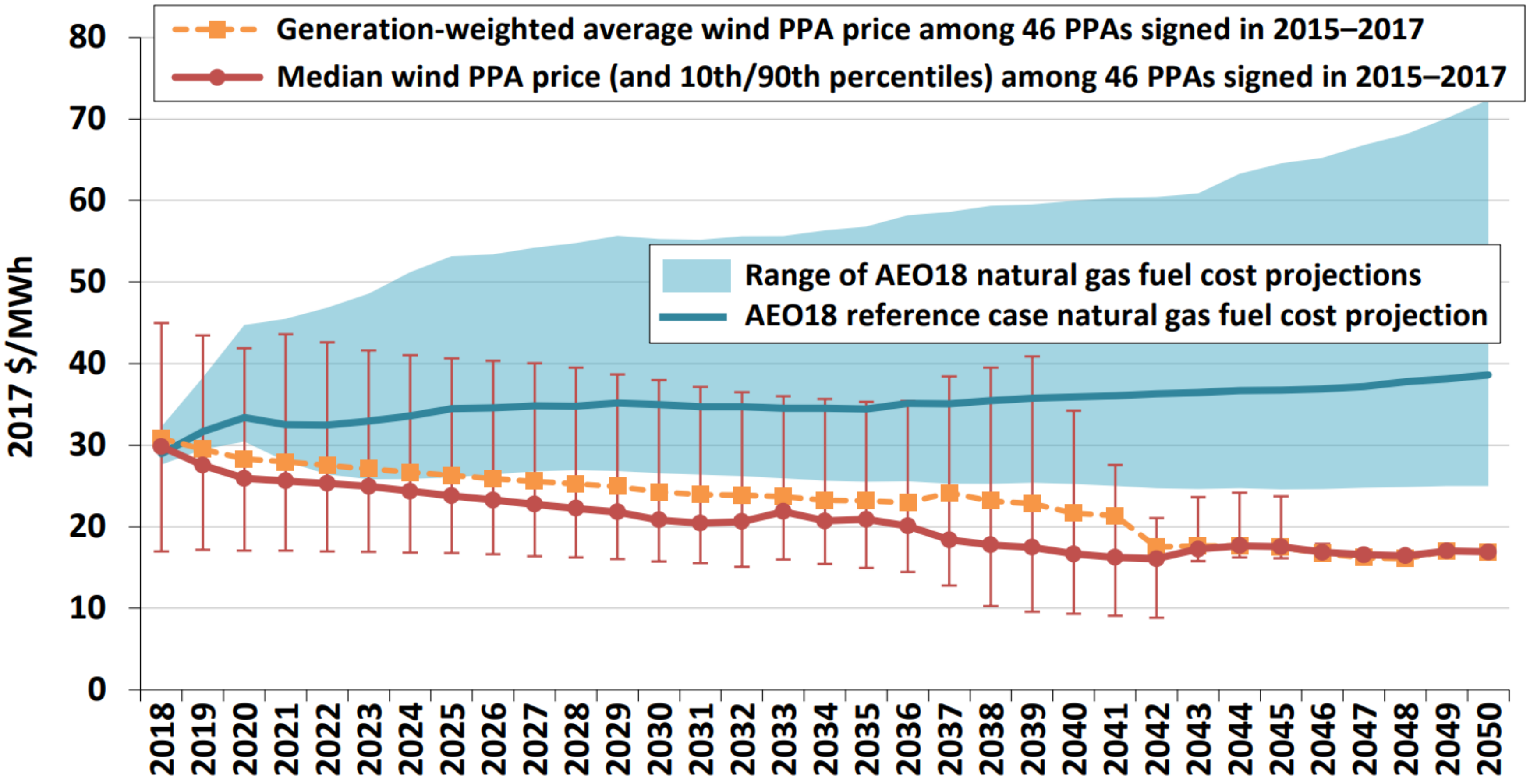


Figure Source: https://emp.lbl.gov/sites/default/files/2017_wind_technologies_market_report.pdf

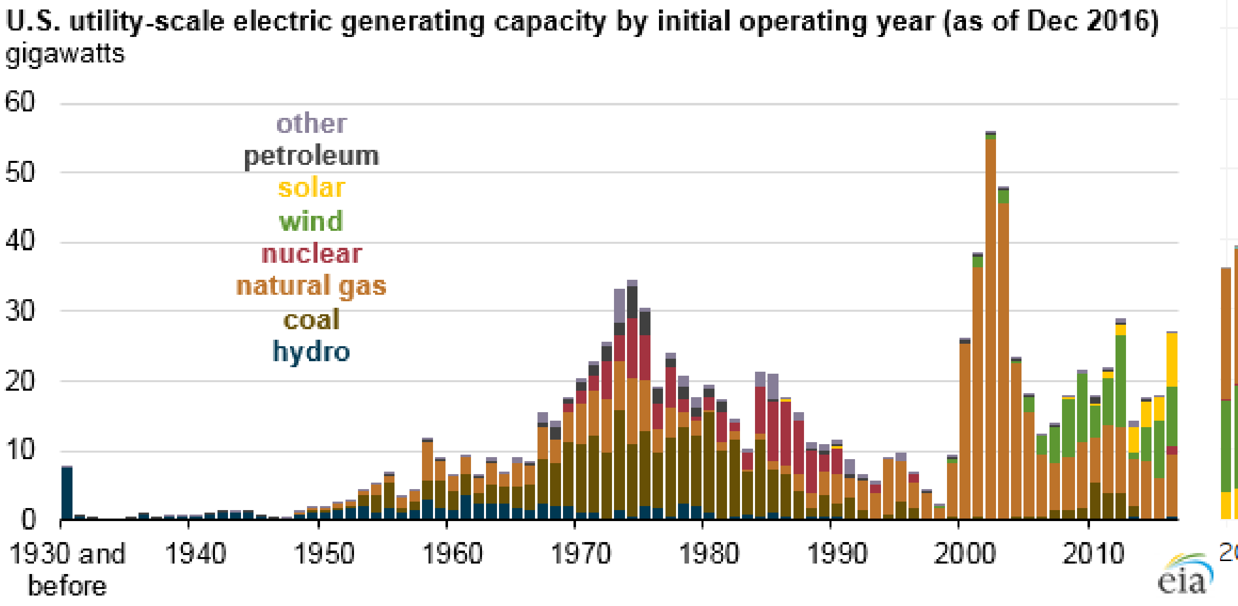
Note: The 10th/90th percentile range narrows considerably in later years as the PPA sample dwindles

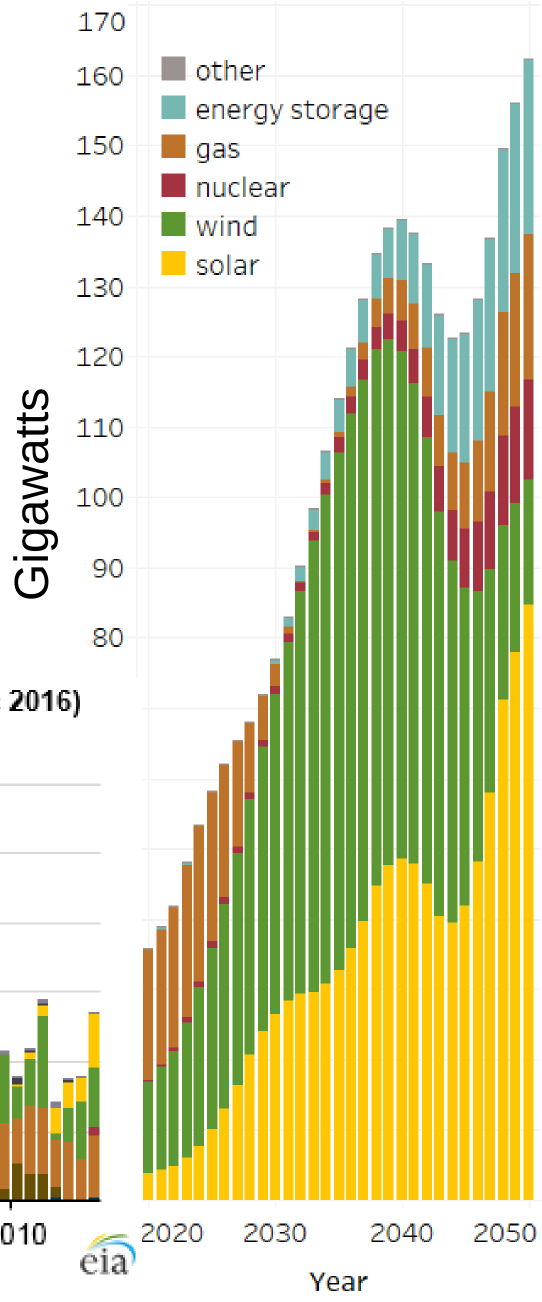
Sources: Berkeley Lab, Energy Information Administration's Annual Energy Outlook 2018 (AEO18)

Rapid growth of renewables possible

Carbon legislation and favorable economics could drive unprecedented growth

Historical Build (EIA)

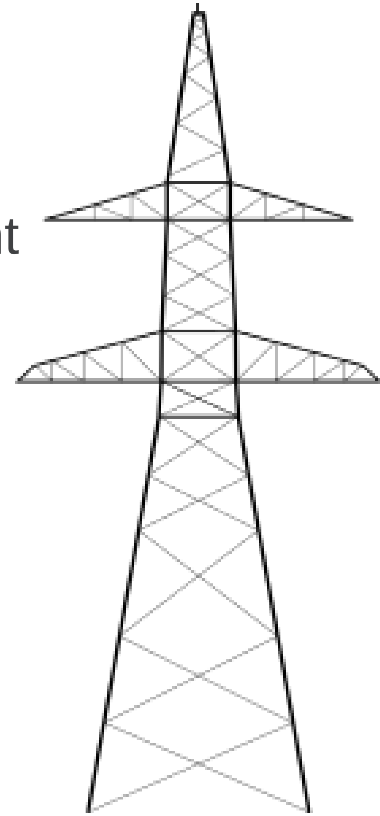




Optimized Electricity Build reaching an 80% Reduction in Energy CO_2 by 2050

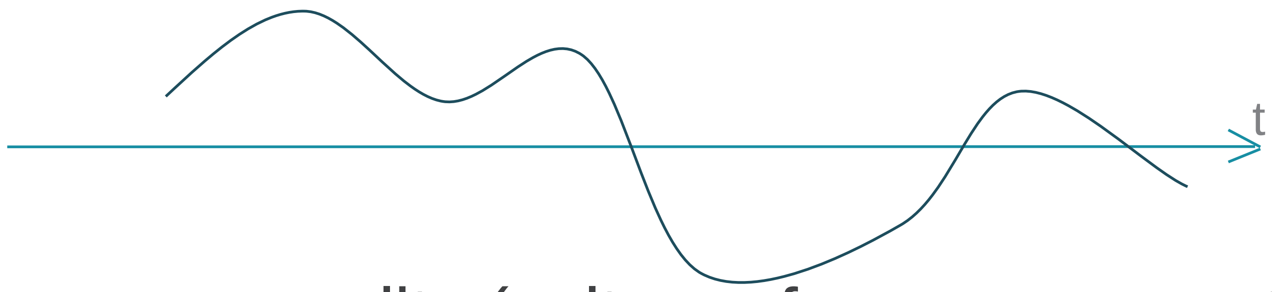
How do renewables present unique challenges for balancing?

- Renewables have certain characteristics that make them difficult to manage in the context of today's electricity system
  - **Variability** – output is not controllable and can change rapidly
  - **Uncertainty** – future output can be difficult to predict
  - **New locations** – deployment in locations not anticipated when the grid was built
  - **Inverters vs. synchronous motors** – technical character of inverters are different

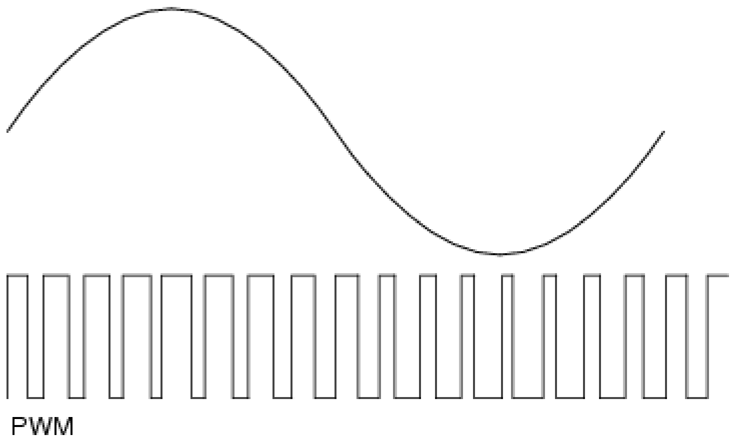


Electricity balancing has two components

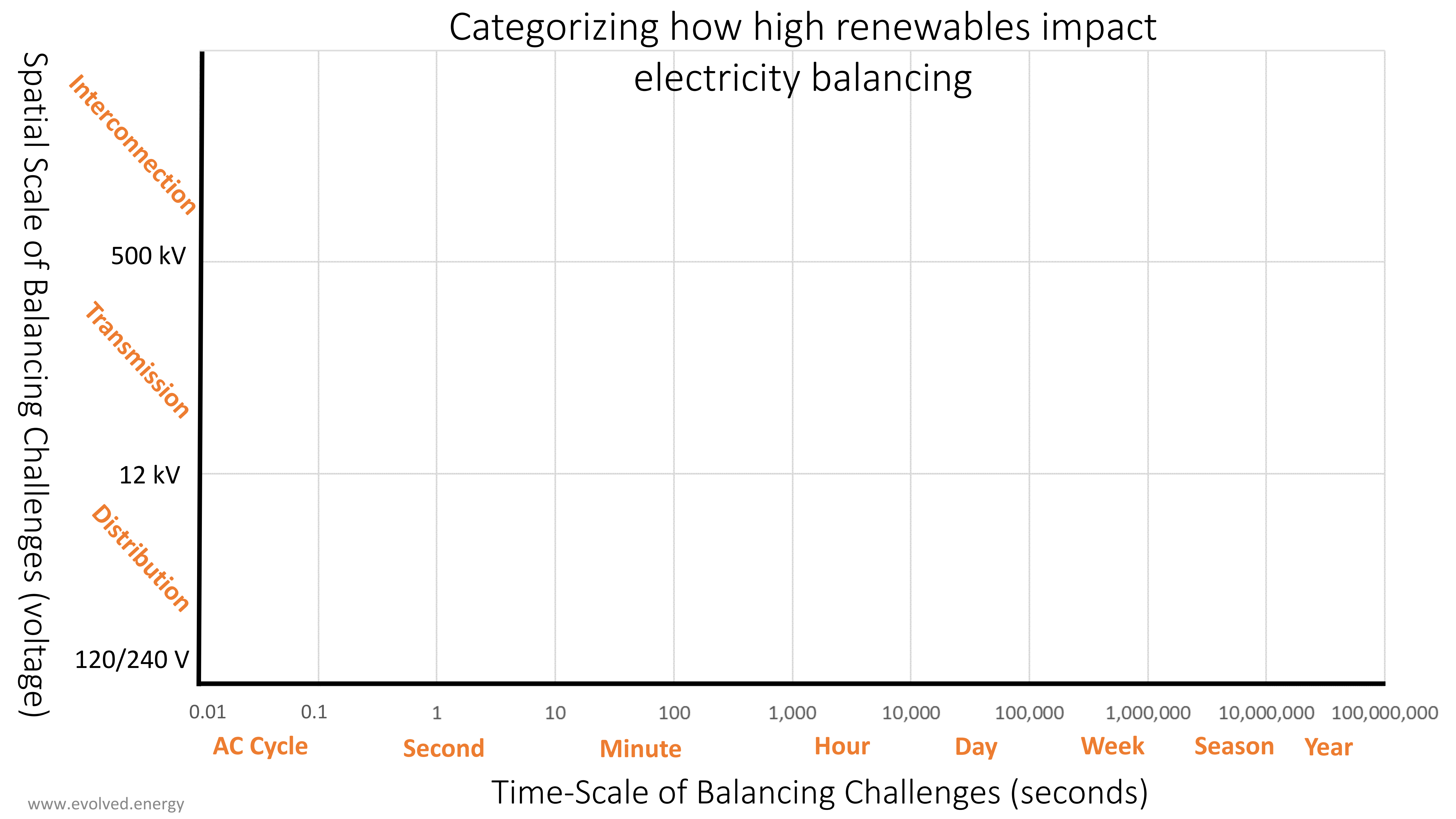
1. Ensuring electricity supply matches demand through time



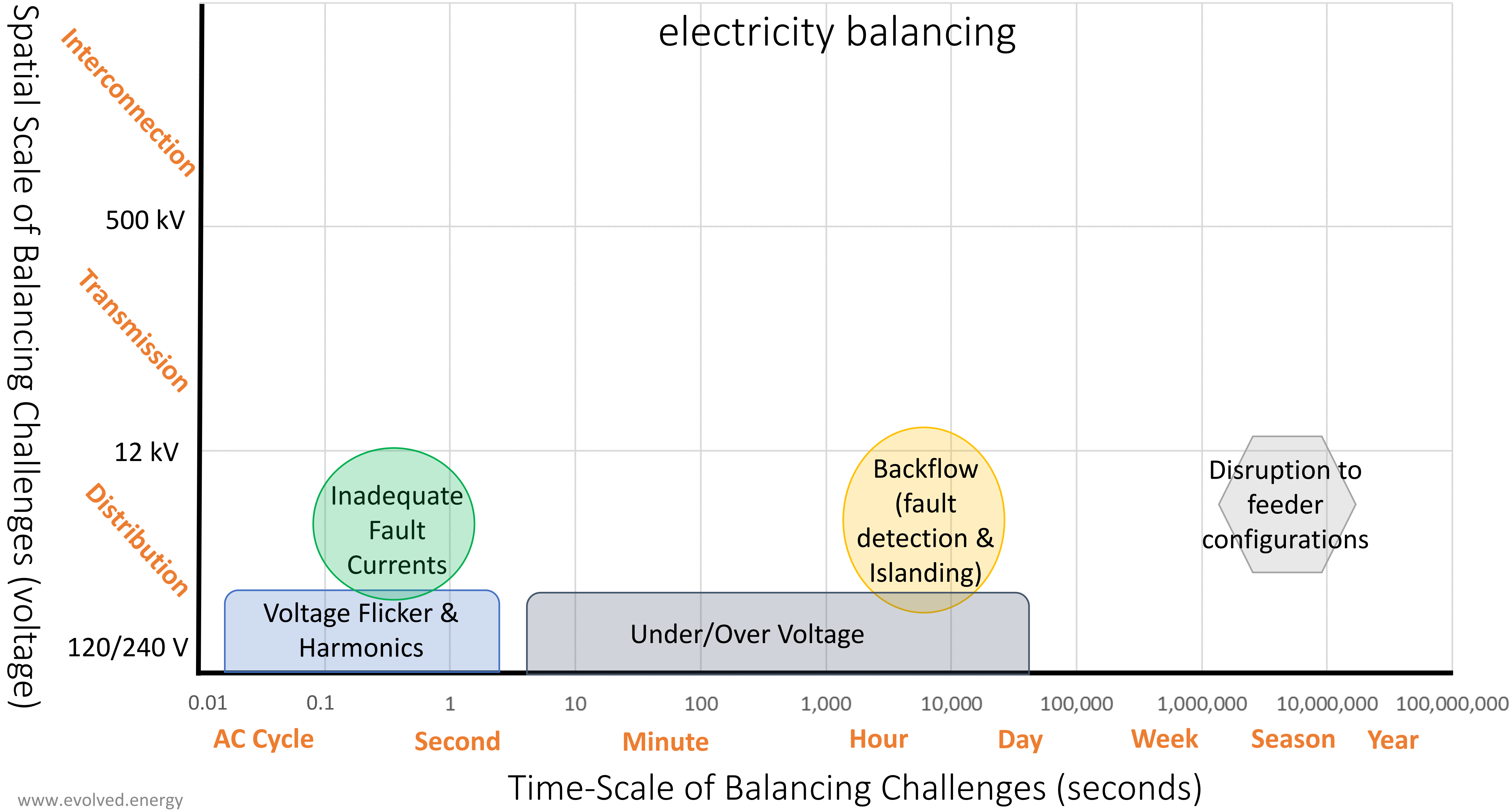
2. Ensuring power quality (voltage, frequency, reactive power)



https://www.allaboutcircuits.com/textbook/alternating-current/chpt-13/synchronous-motors/


Categorizing how high renewables impact electricity balancing
Spatial Scale of Balancing Challenges (voltage)
Interconnection
500 kV
Transmission
12 kV
Distribution
120/240 V
0.01
0.1
1
10
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
AC Cycle
Second
Minute
Hour
Day
Week
Season
Year
Time-Scale of Balancing Challenges (seconds)
www.evolved.energy

Categorizing how high renewables impact electricity balancing



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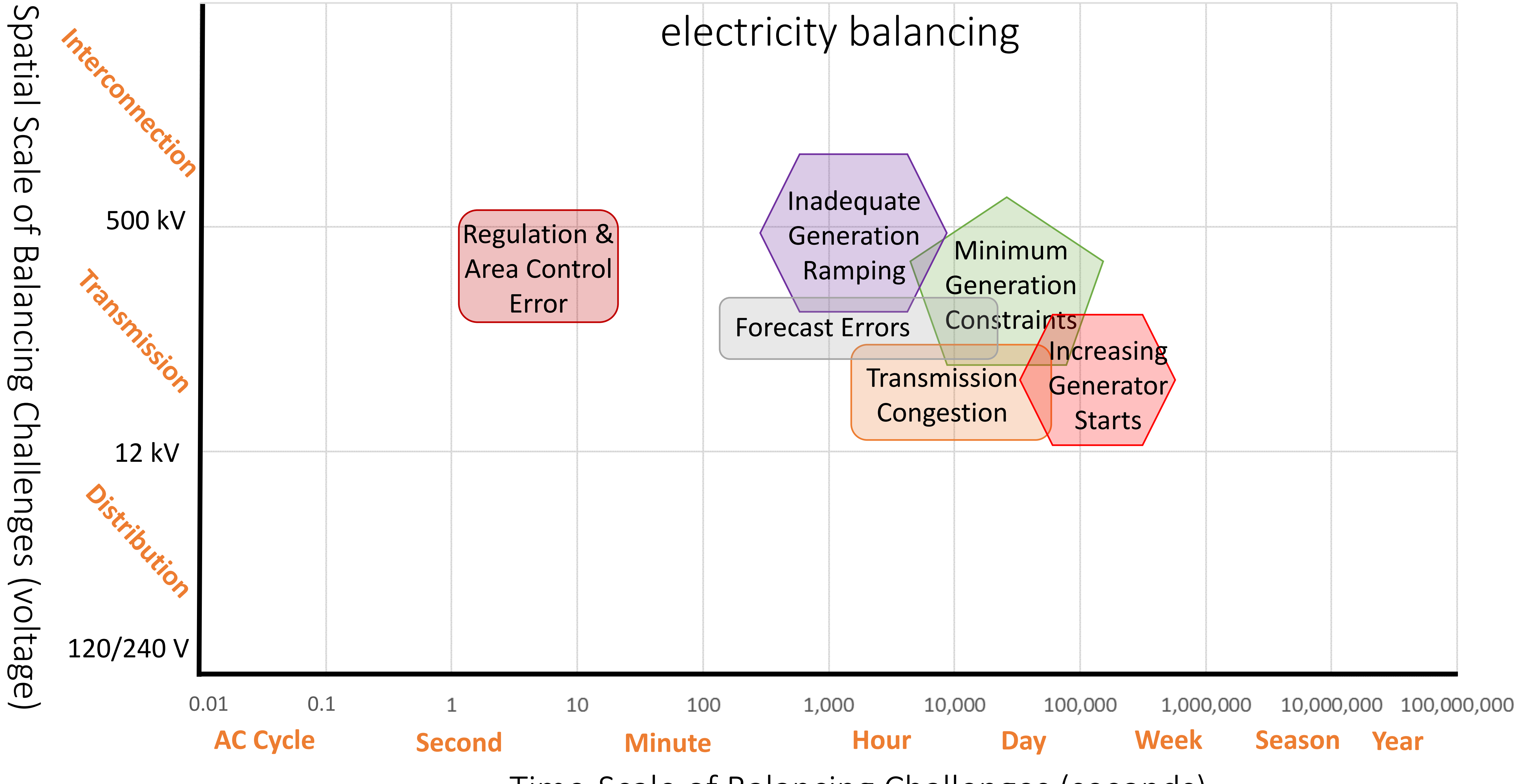

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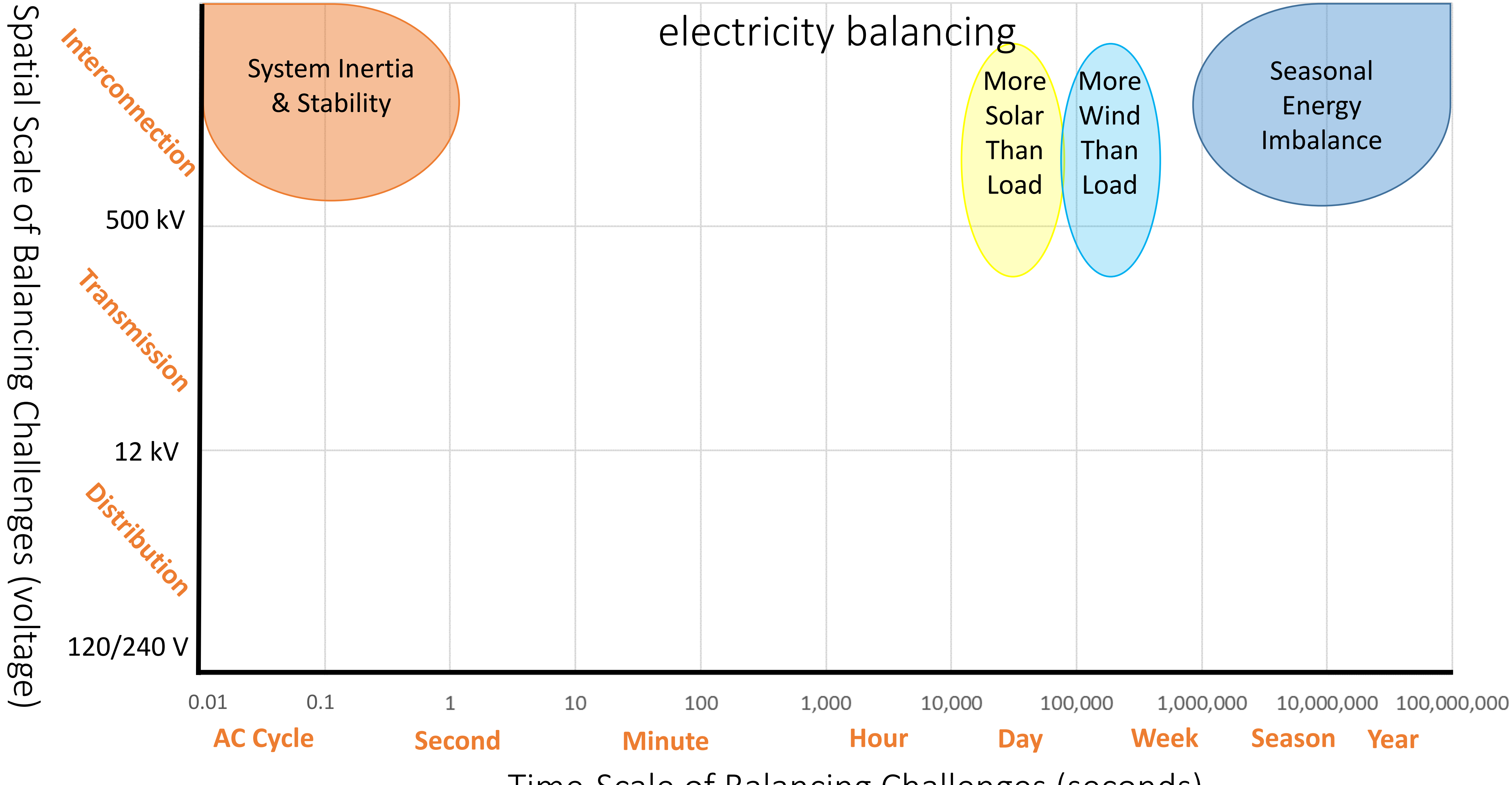
Categorizing how high renewables impact electricity balancing



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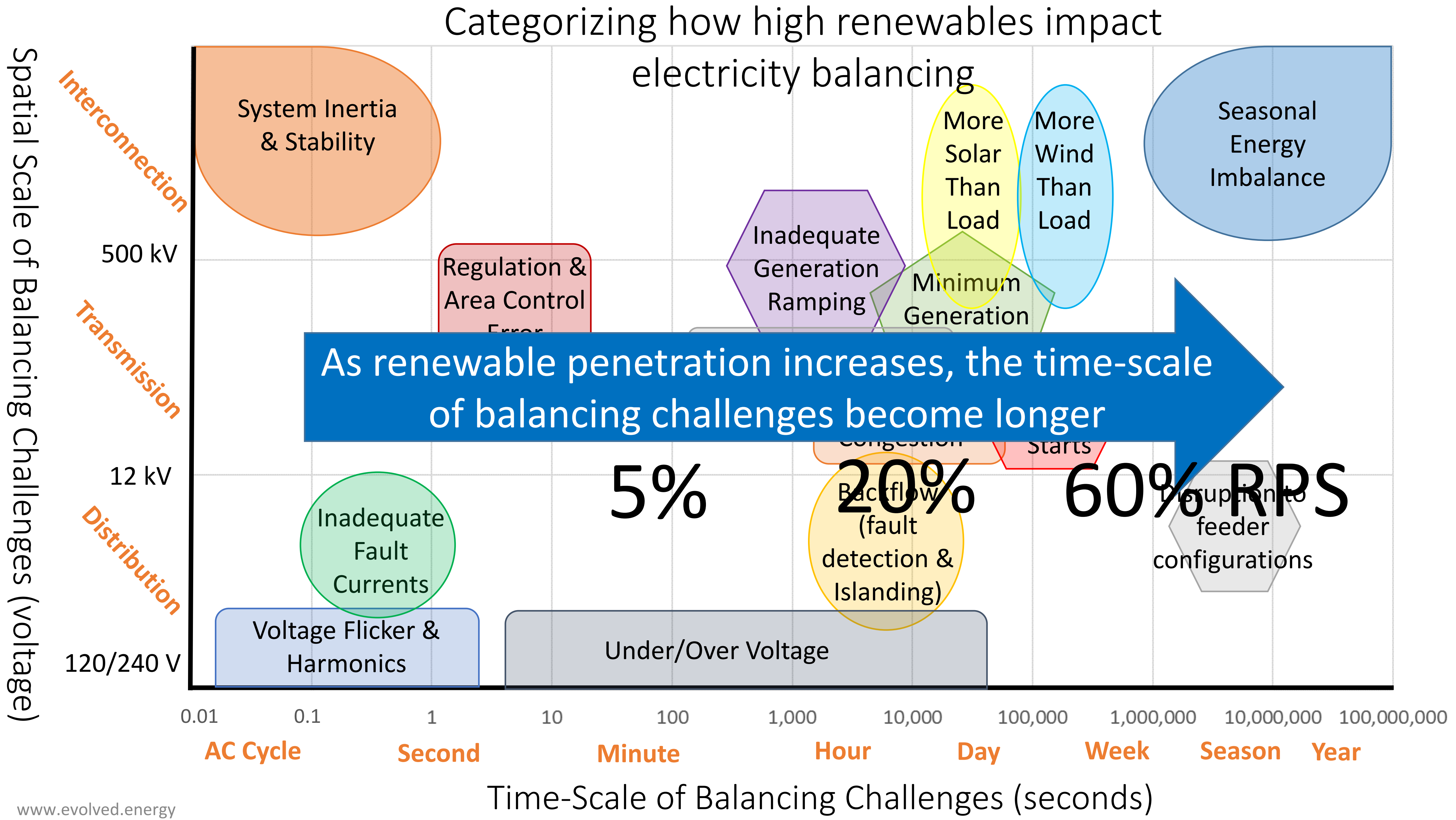

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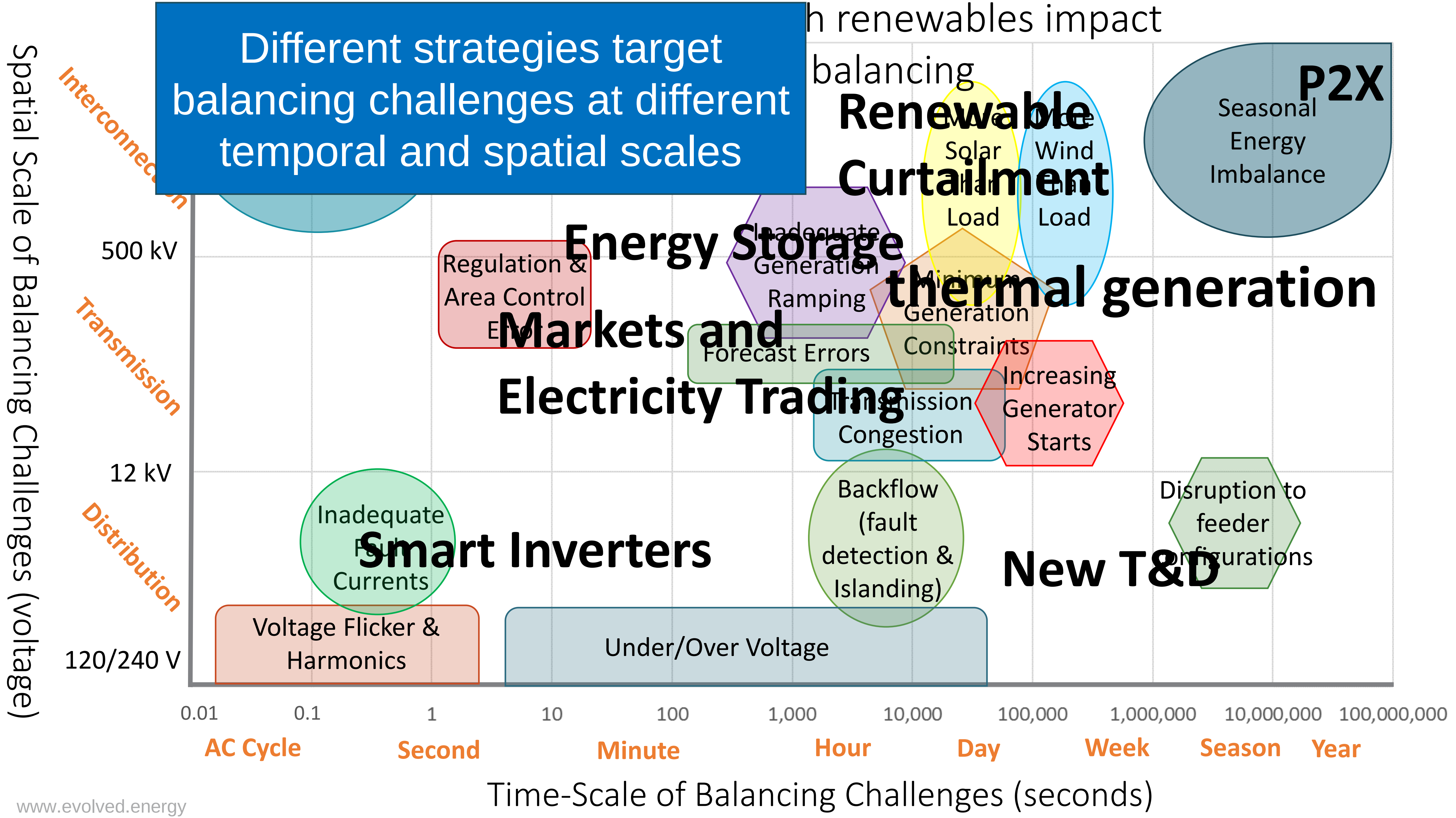
Different strategies target balancing challenges at different temporal and spatial scales

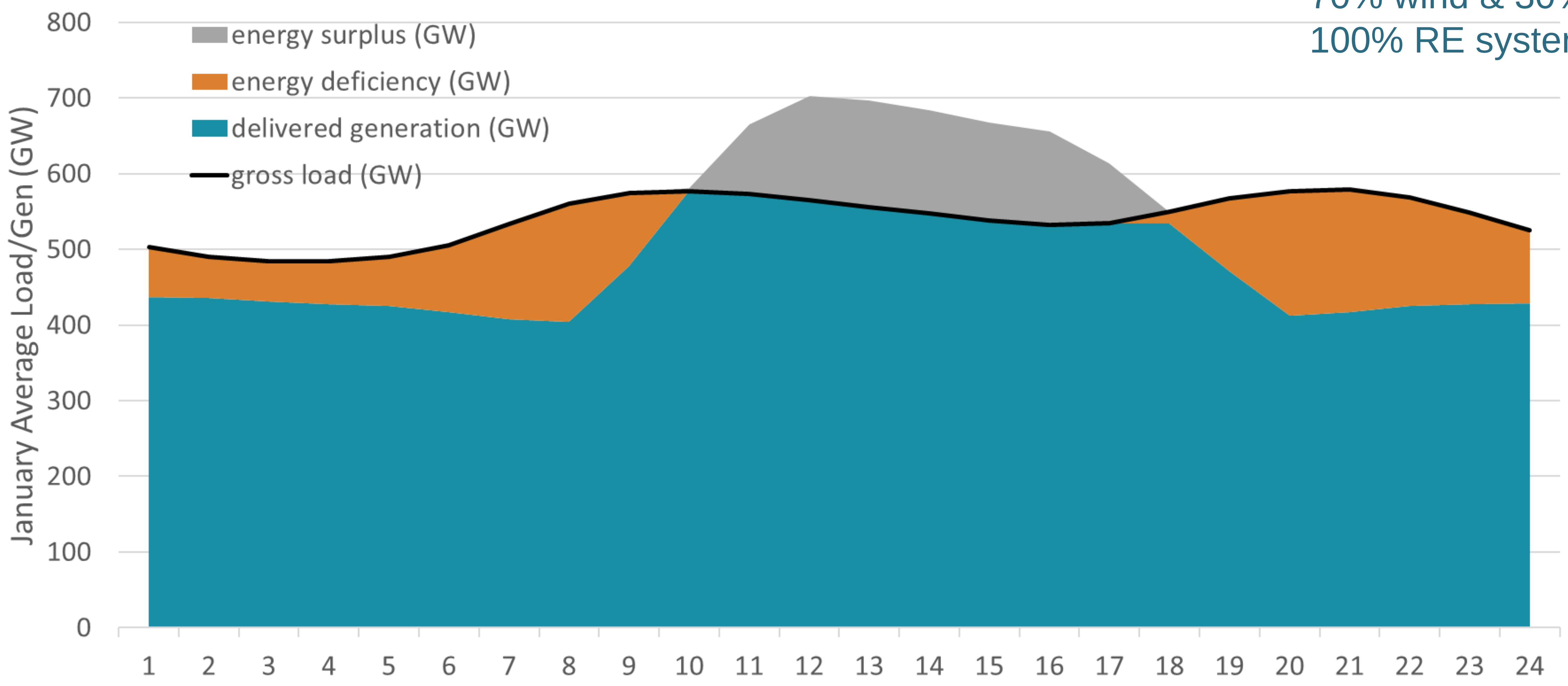


Understanding energy imbalance in a high renewables system

Defining energy imbalance

Eastern interconnection using load and renewable profiles from January, 2011

70% wind & 30% solar
100% RE system



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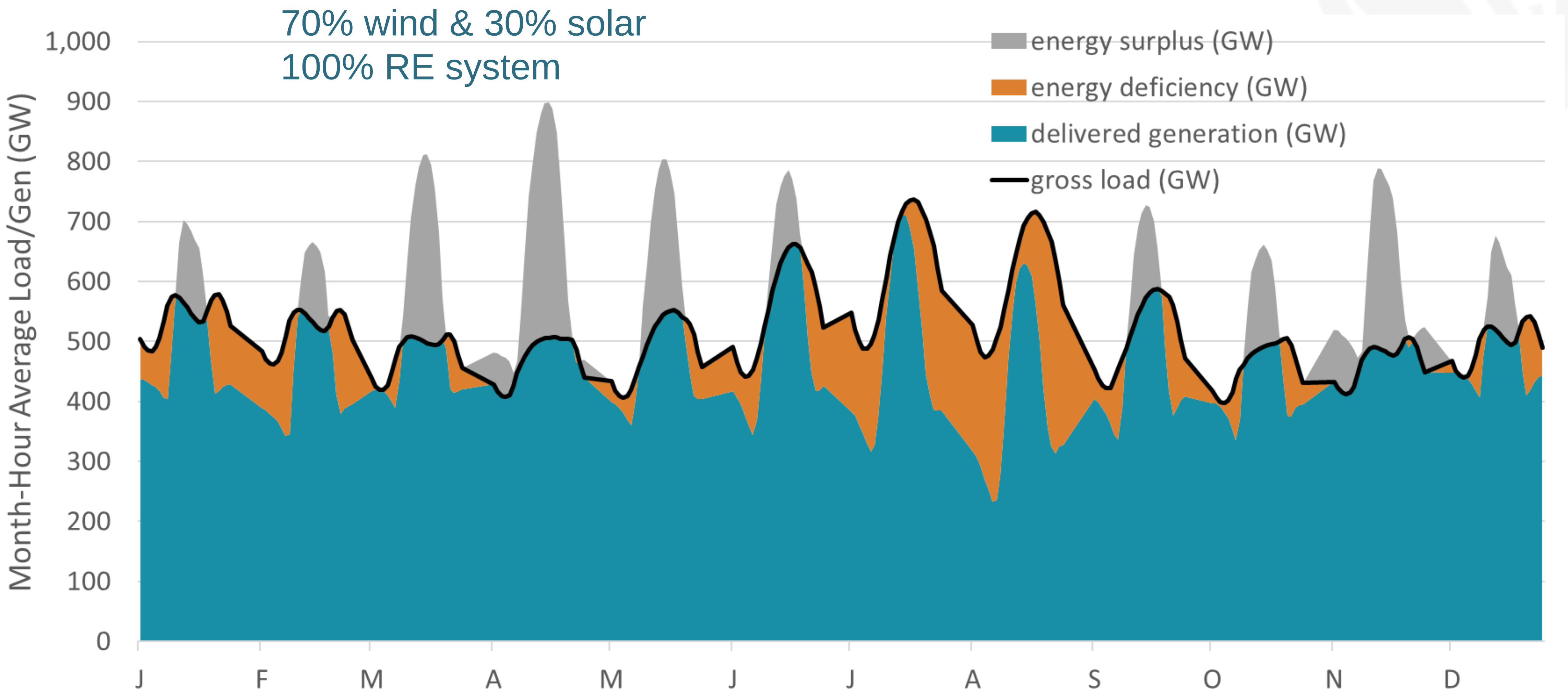
Average energy imbalance by month-hour

Eastern interconnection using load and renewable profiles from 2011



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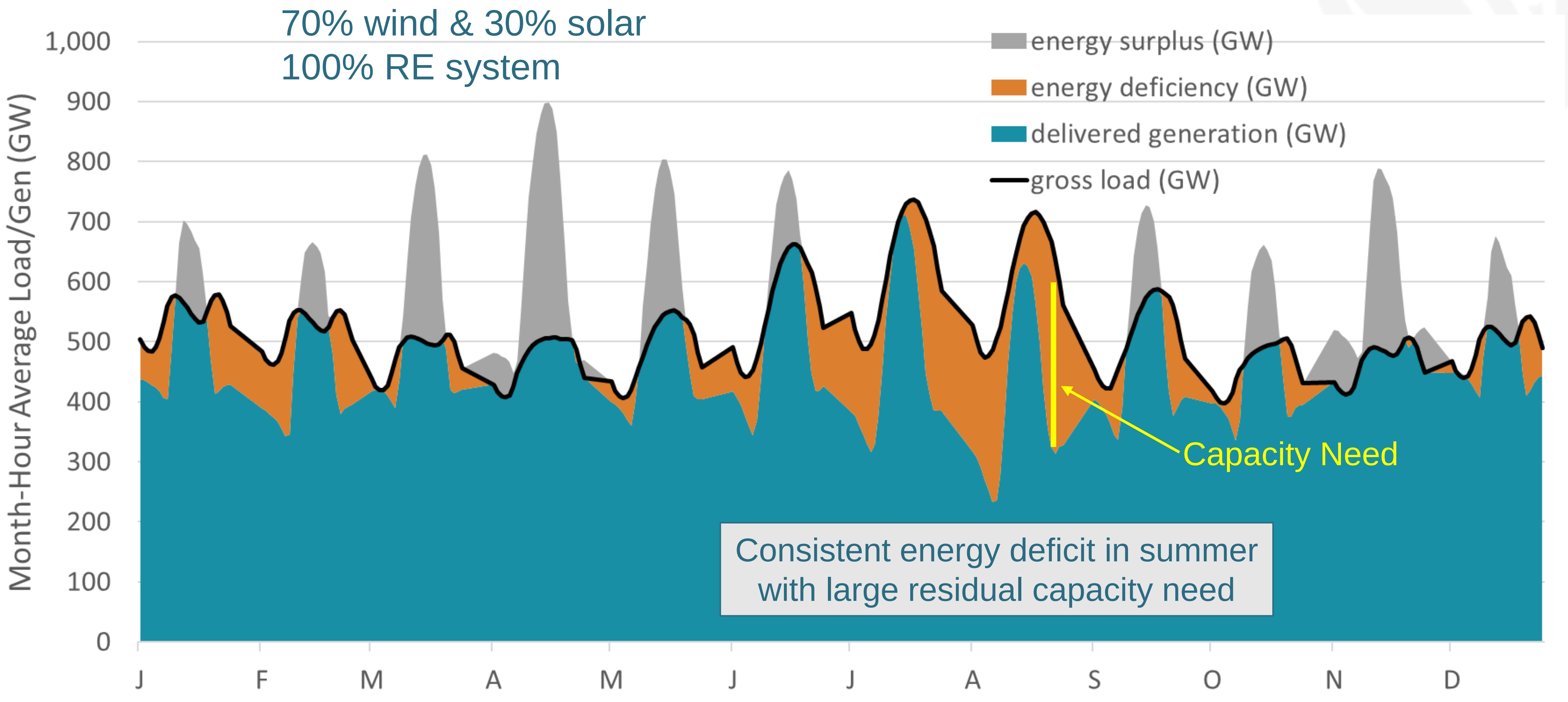
Seasonal energy storage challenge in 100% renewables system

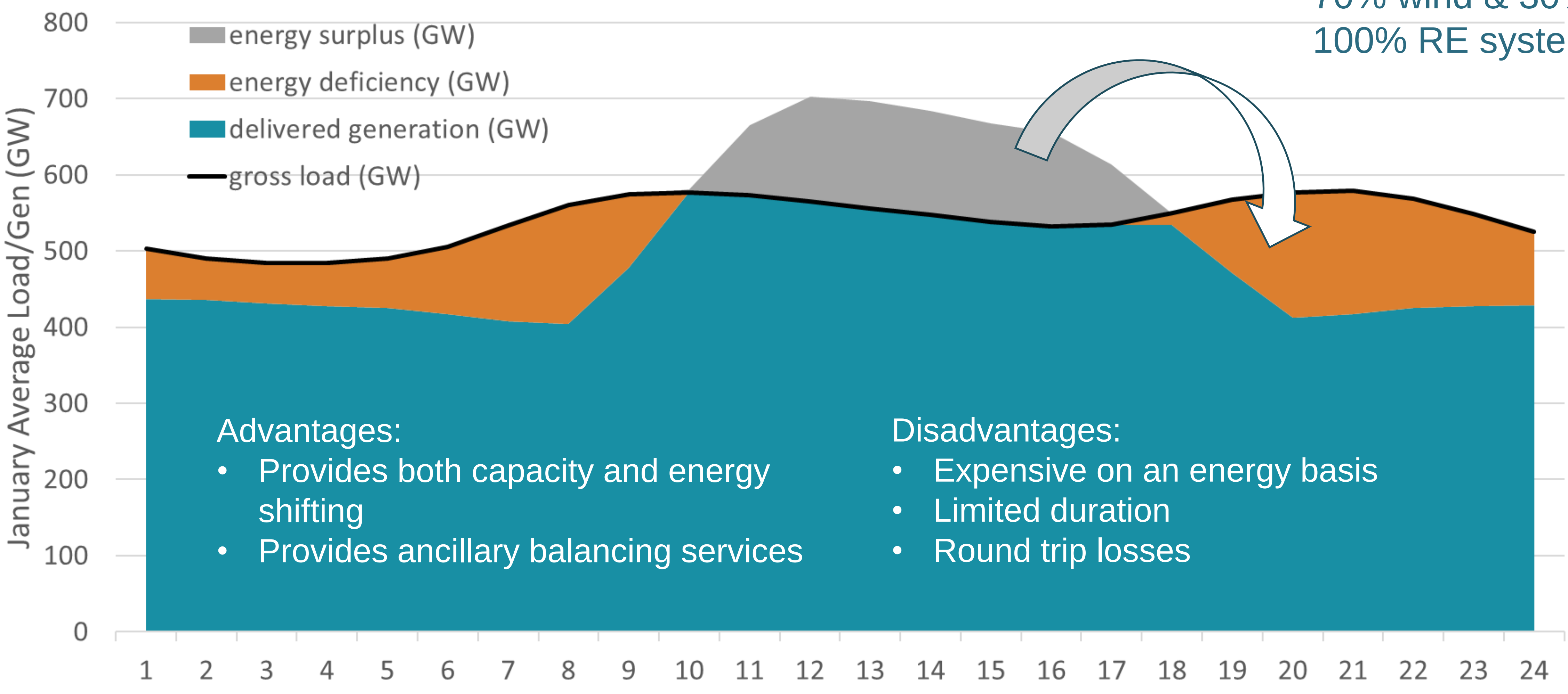
Eastern interconnection using load and renewable profiles from 2011



Option 1: Use storage to shift the grey to the orange

Eastern interconnection using load and renewable profiles from January, 2011

70% wind & 30% solar
100% RE system



Advantages:

- Provides both capacity and energy shifting
- Provides ancillary balancing services

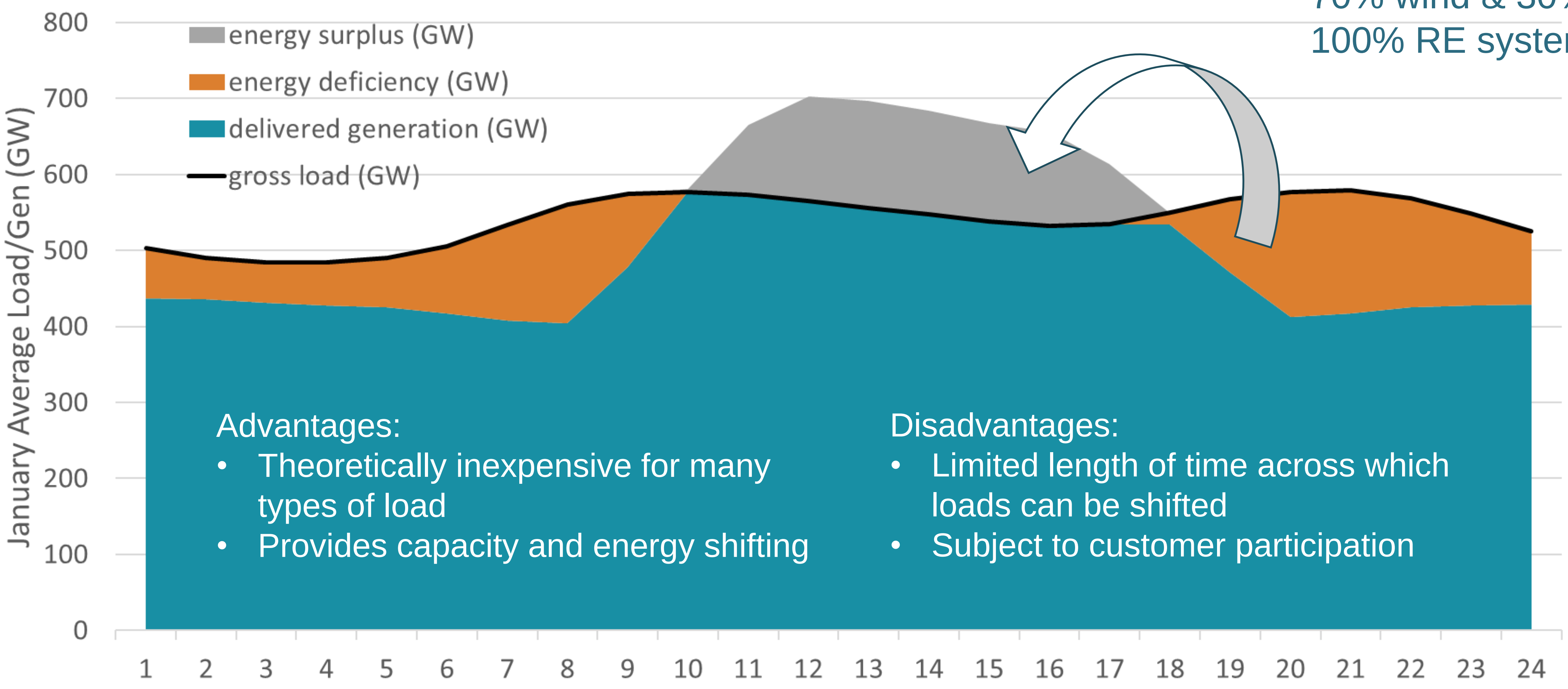
Disadvantages:

- Expensive on an energy basis
- Limited duration
- Round trip losses

Option 2: Use flexible load to shift the orange to the grey

Eastern interconnection using load and renewable profiles from January, 2011

70% wind & 30% solar
100% RE system



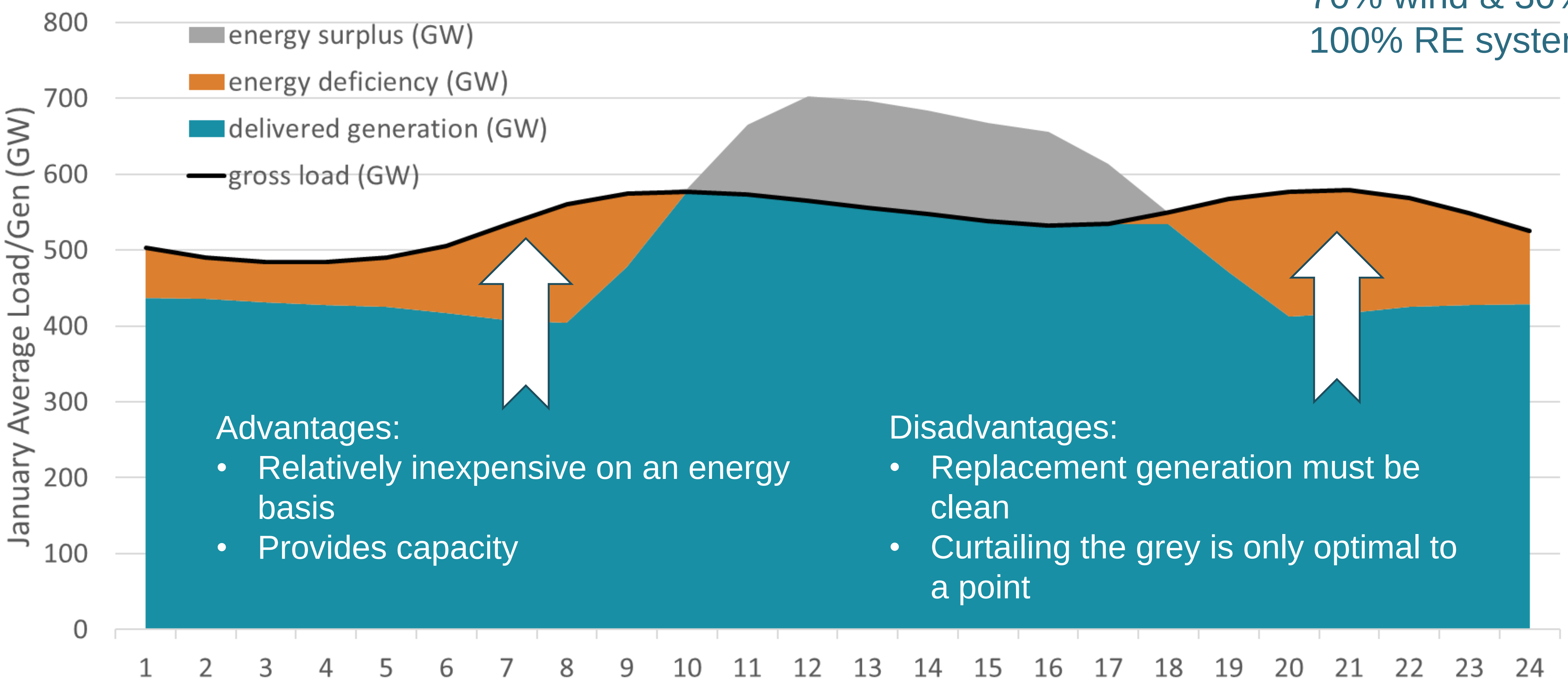
Advantages:
- Theoretically inexpensive for many types of load
- Provides capacity and energy shifting

Disadvantages:
- Limited length of time across which loads can be shifted
- Subject to customer participation

Option 3: Use other generation to fill the orange

Eastern interconnection using load and renewable profiles from January, 2011

70% wind & 30% solar
100% RE system



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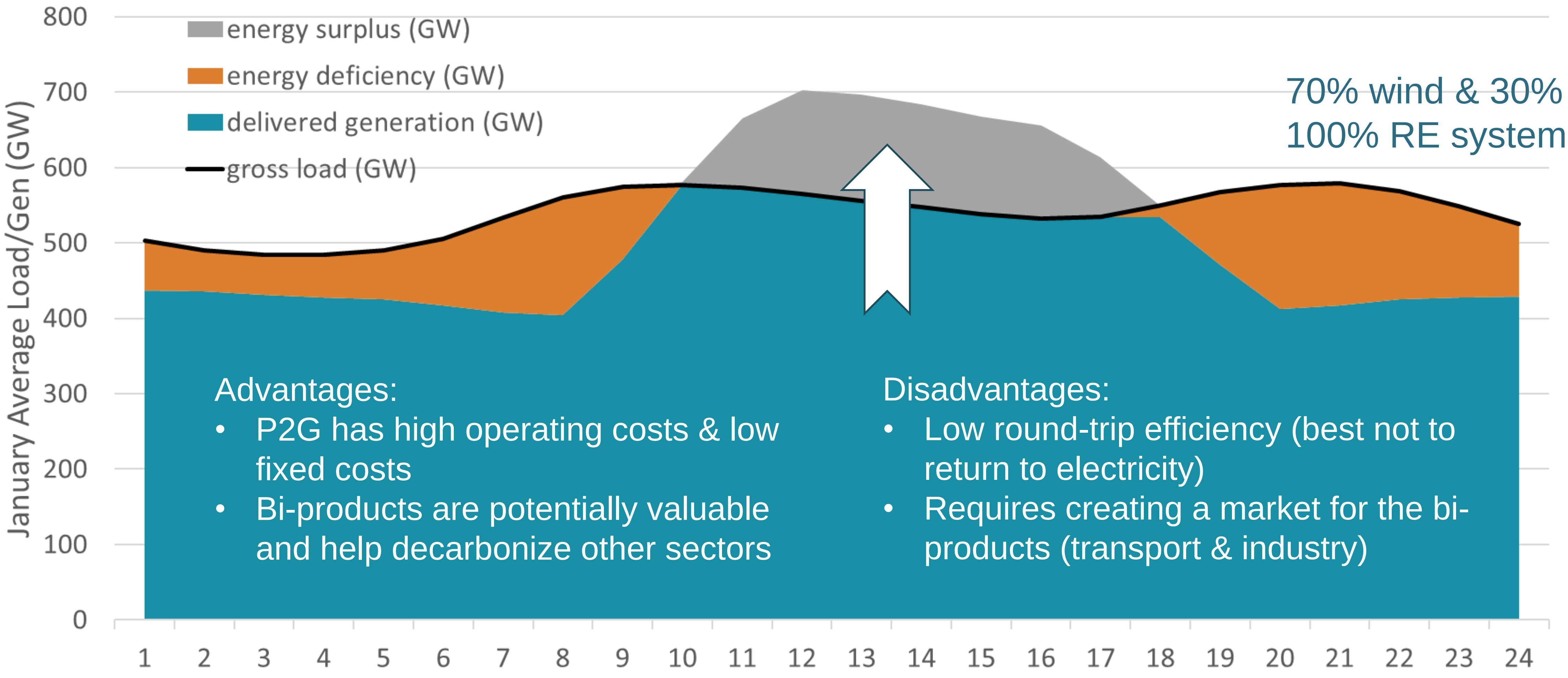
Option 4: Build load into the grey and build more renewables

Eastern interconnection using load and renewable profiles from January, 2011



70% wind & 30% solar
100% RE system

Advantages:

- P2G has high operating costs & low fixed costs
- Bi-products are potentially valuable and help decarbonize other sectors

Disadvantages:

- Low round-trip efficiency (best not to return to electricity)
- Requires creating a market for the bi-products (transport & industry)

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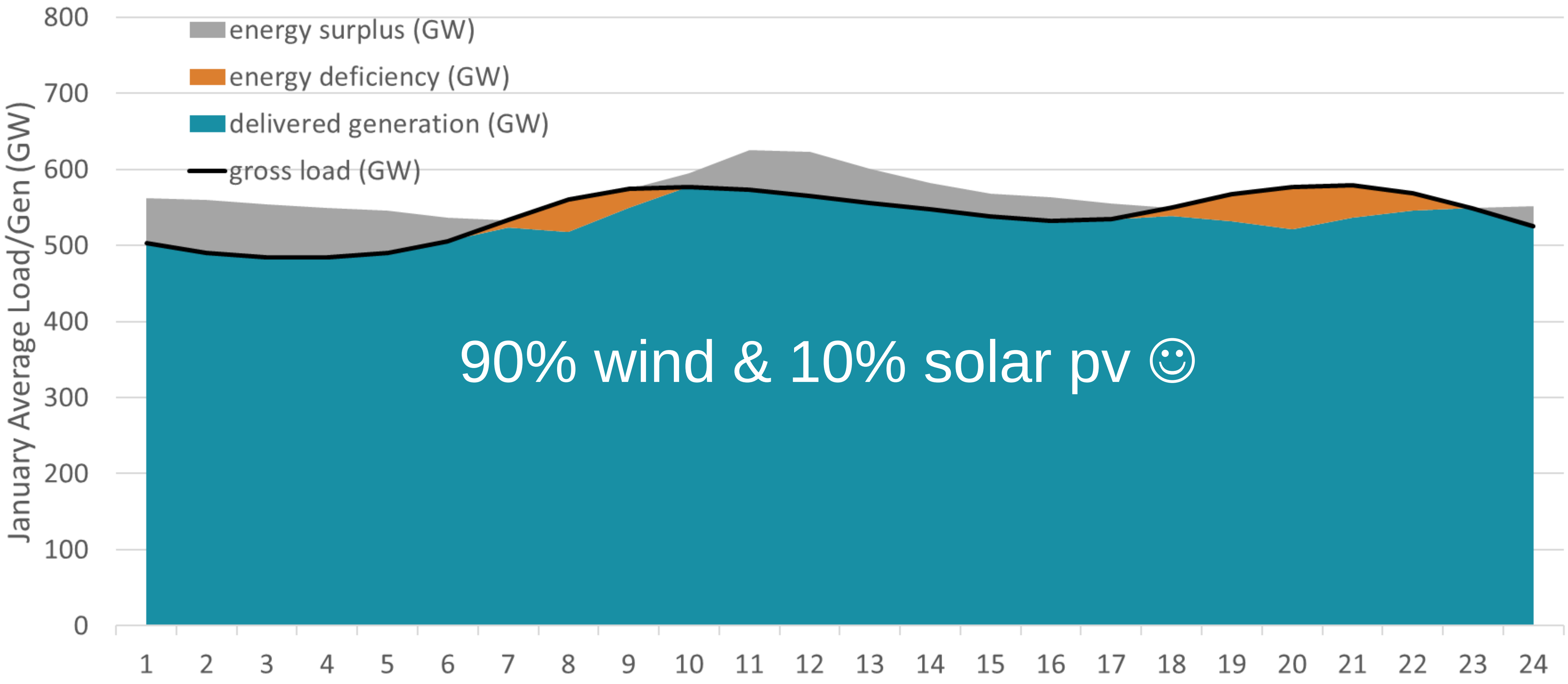
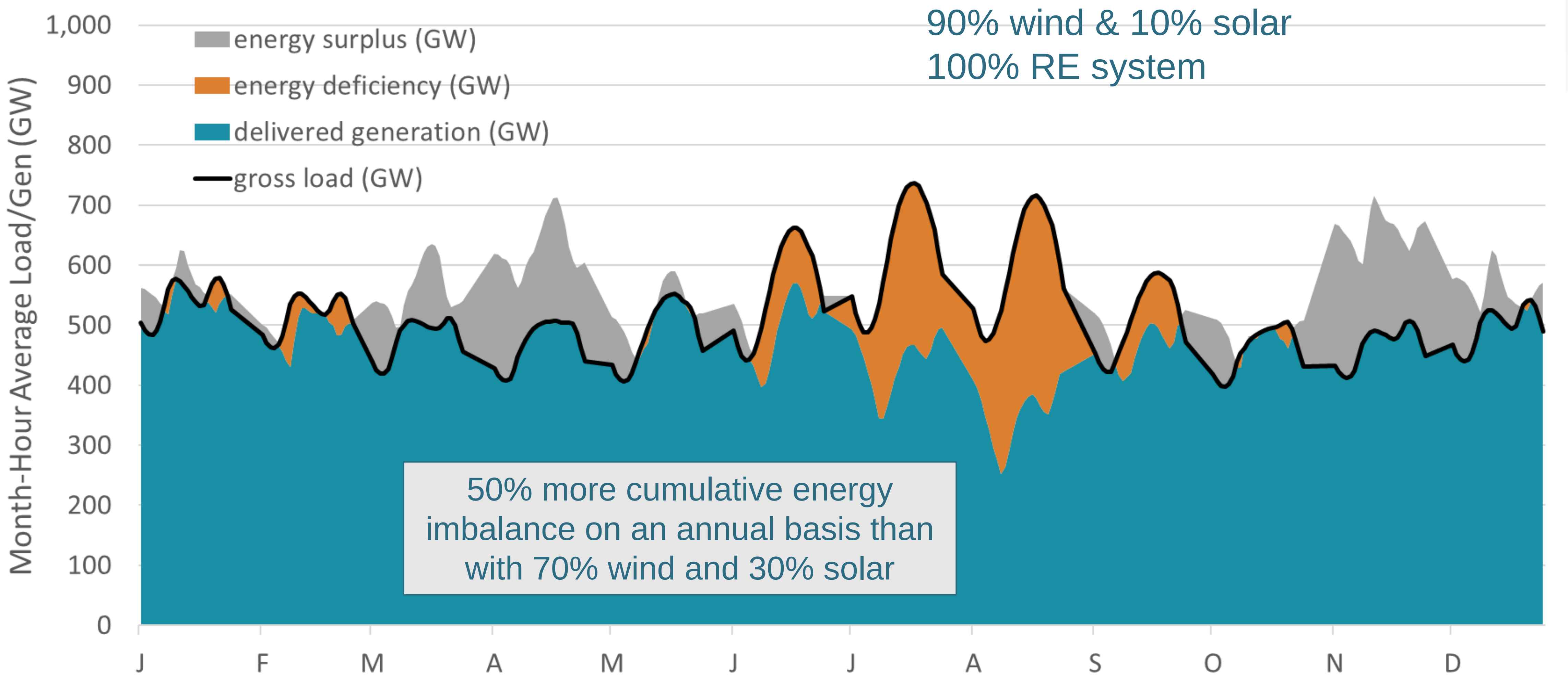
Option 5: Change the mix between renewables

Eastern interconnection using load and renewable profiles from January, 2011



… but this can create more imbalance in other months ☹

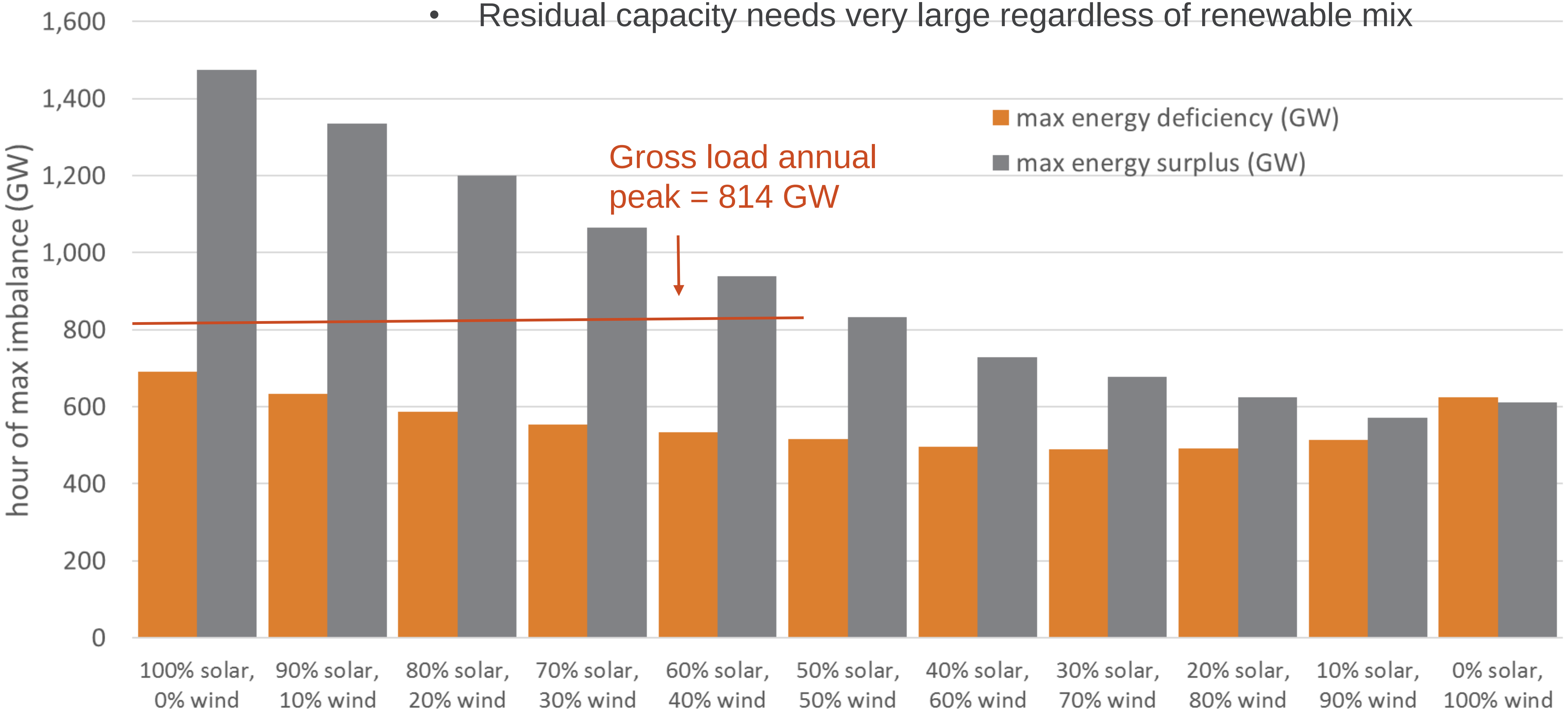
Eastern interconnection using load and renewable profiles from 2011



Capacity needs to cover all energy imbalance

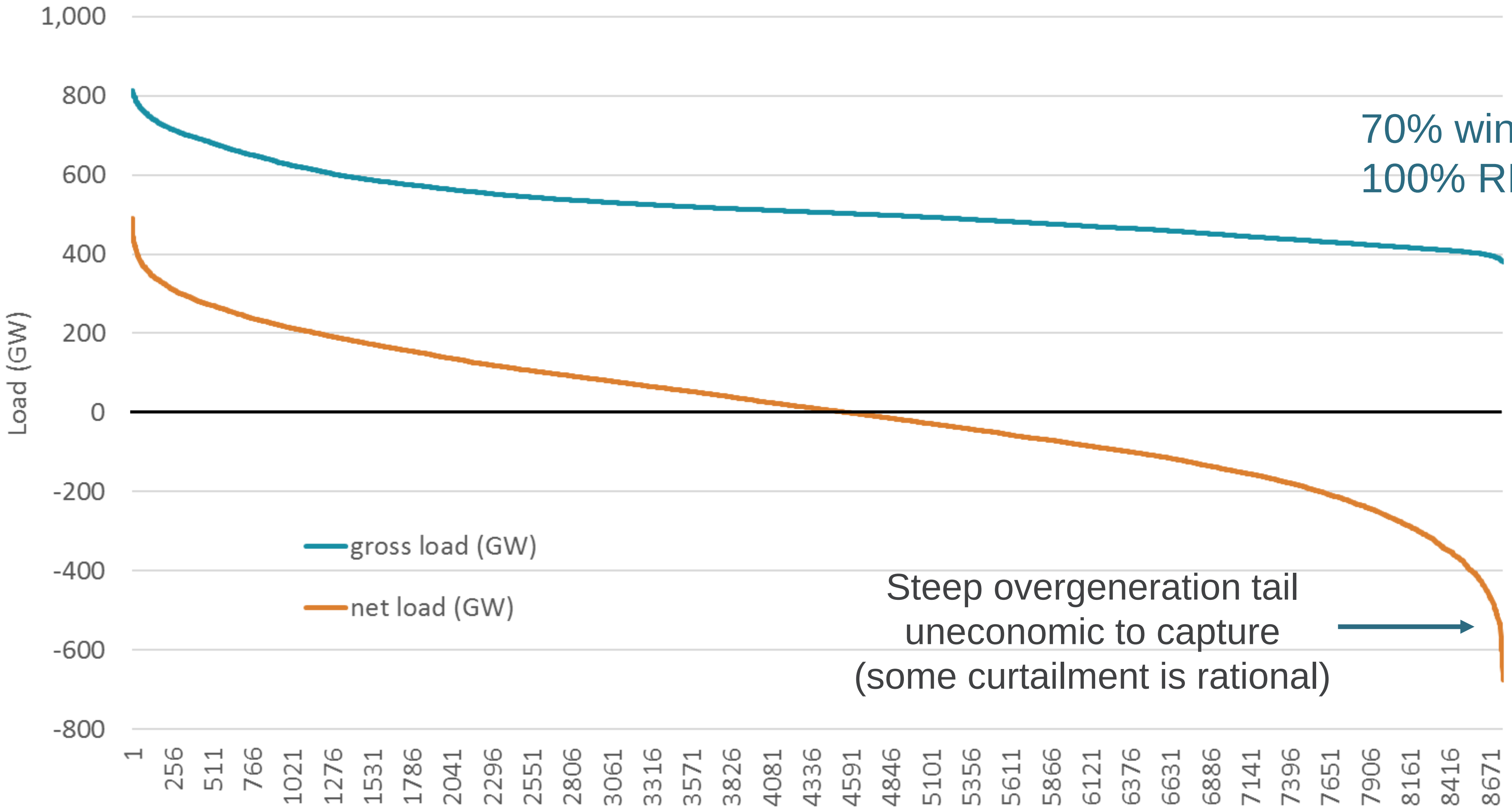
Eastern interconnection using load and renewable profiles from 2011

- Residual capacity needs very large regardless of renewable mix



Load duration curves

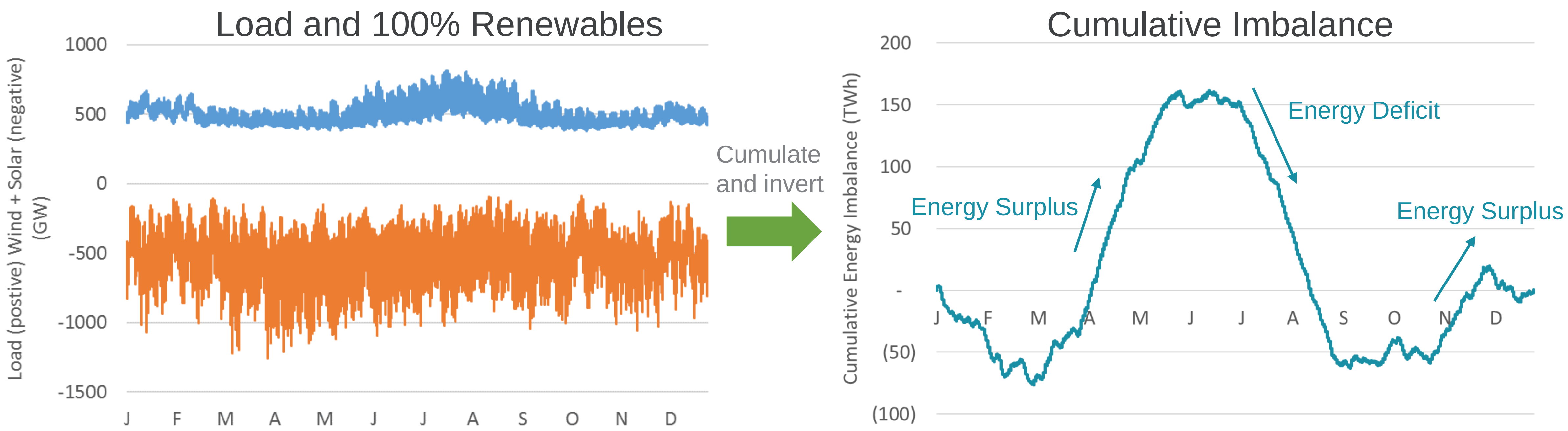
Eastern interconnection using load and renewable profiles from 2011



70% wind & 30% solar
100% RE system

Seasonal energy imbalance

- Increasing the penetration of wind & solar beyond 60% in temperate climates results in seasonal energy imbalances that become the dominate challenge for achieving deep decarbonization in electricity

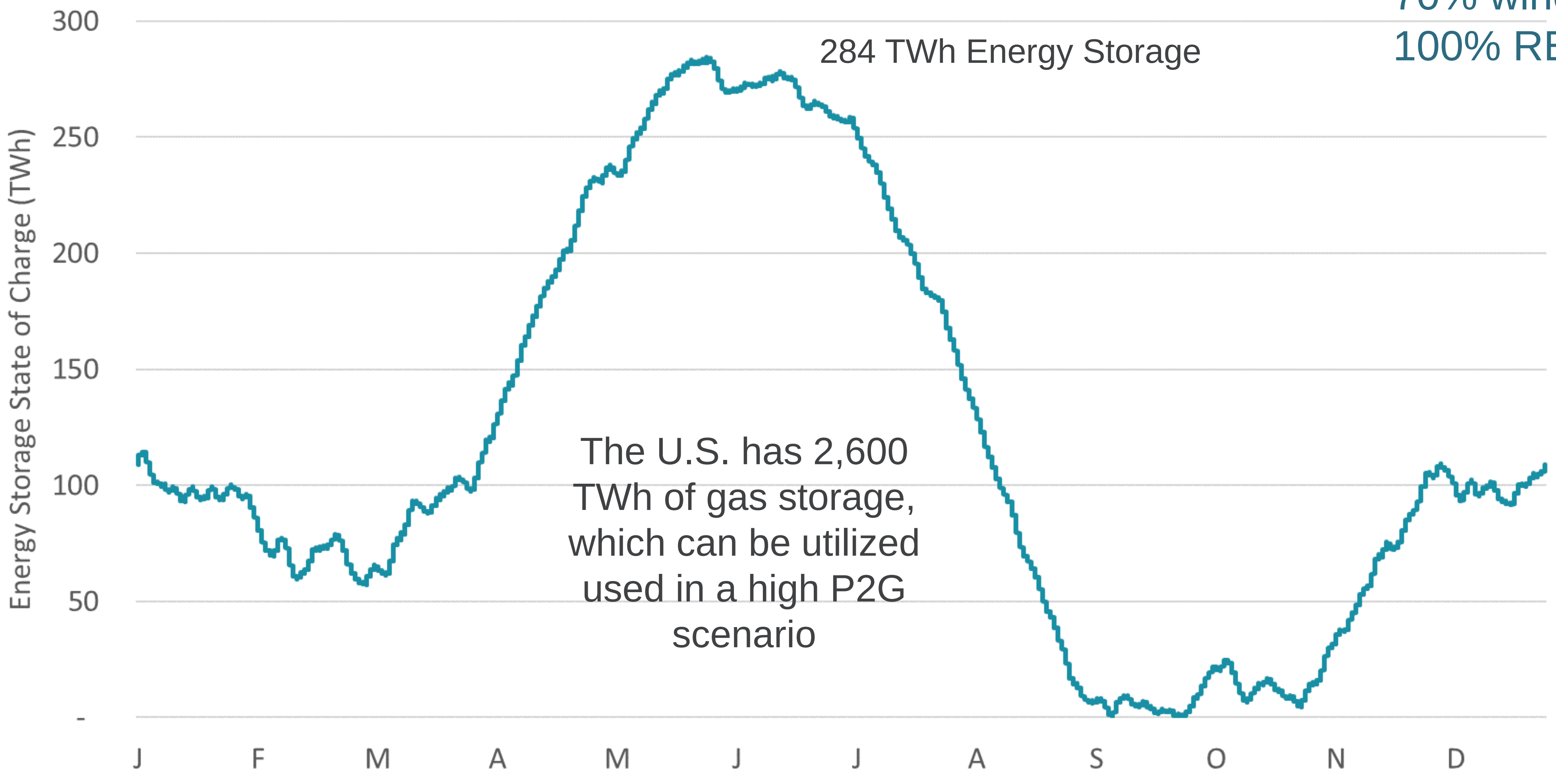


U.S. Eastern Interconnect 2015 Load with simulated 40% Solar & 60% Onshore Wind by Energy

How would the state-of-charge of a perfect storage device change through the year?

Prior chart shifted upward by the maximum cumulative deficit

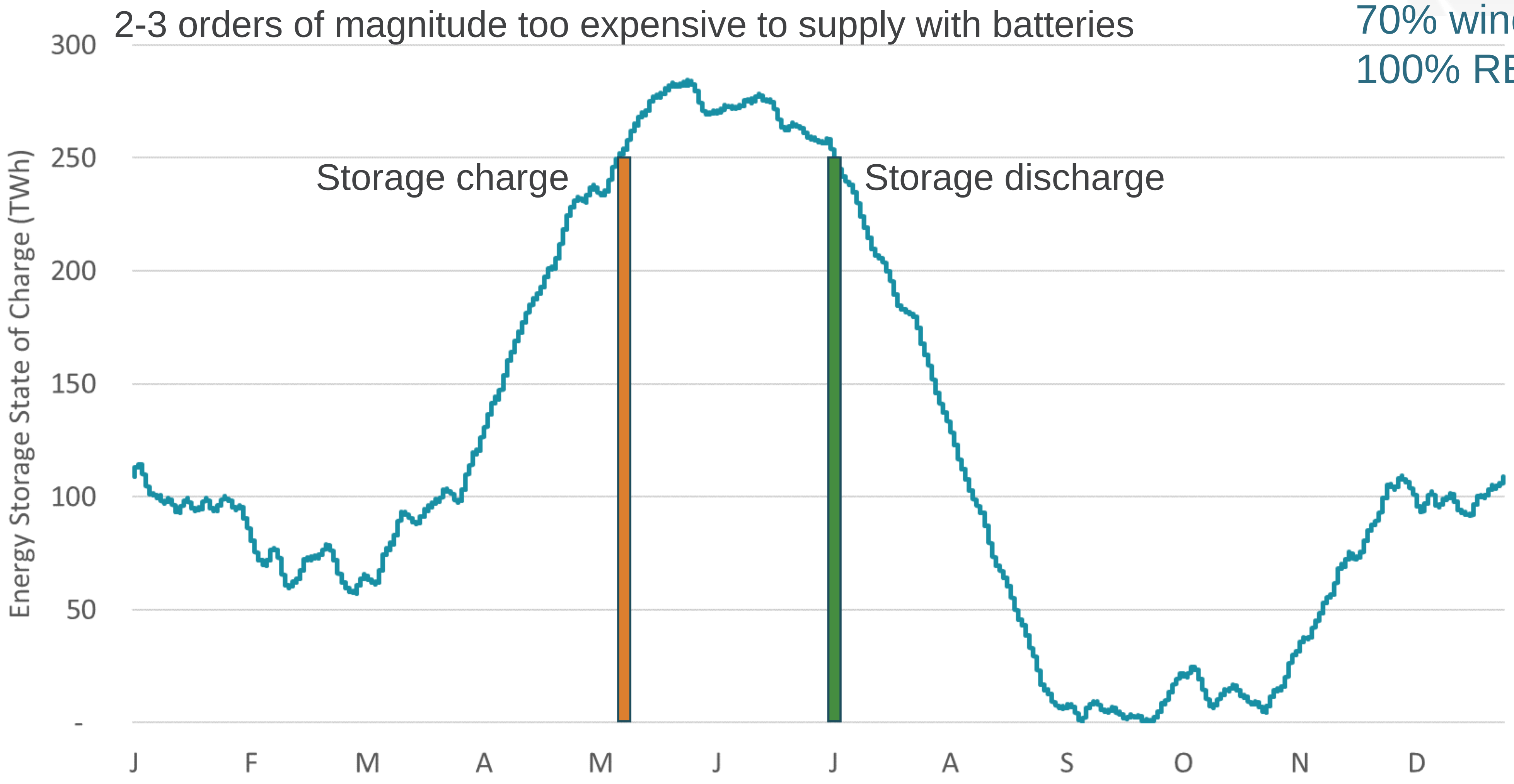
70% wind & 30% solar
100% RE system



The U.S. has 2,600 TWh of gas storage, which can be utilized used in a high P2G scenario

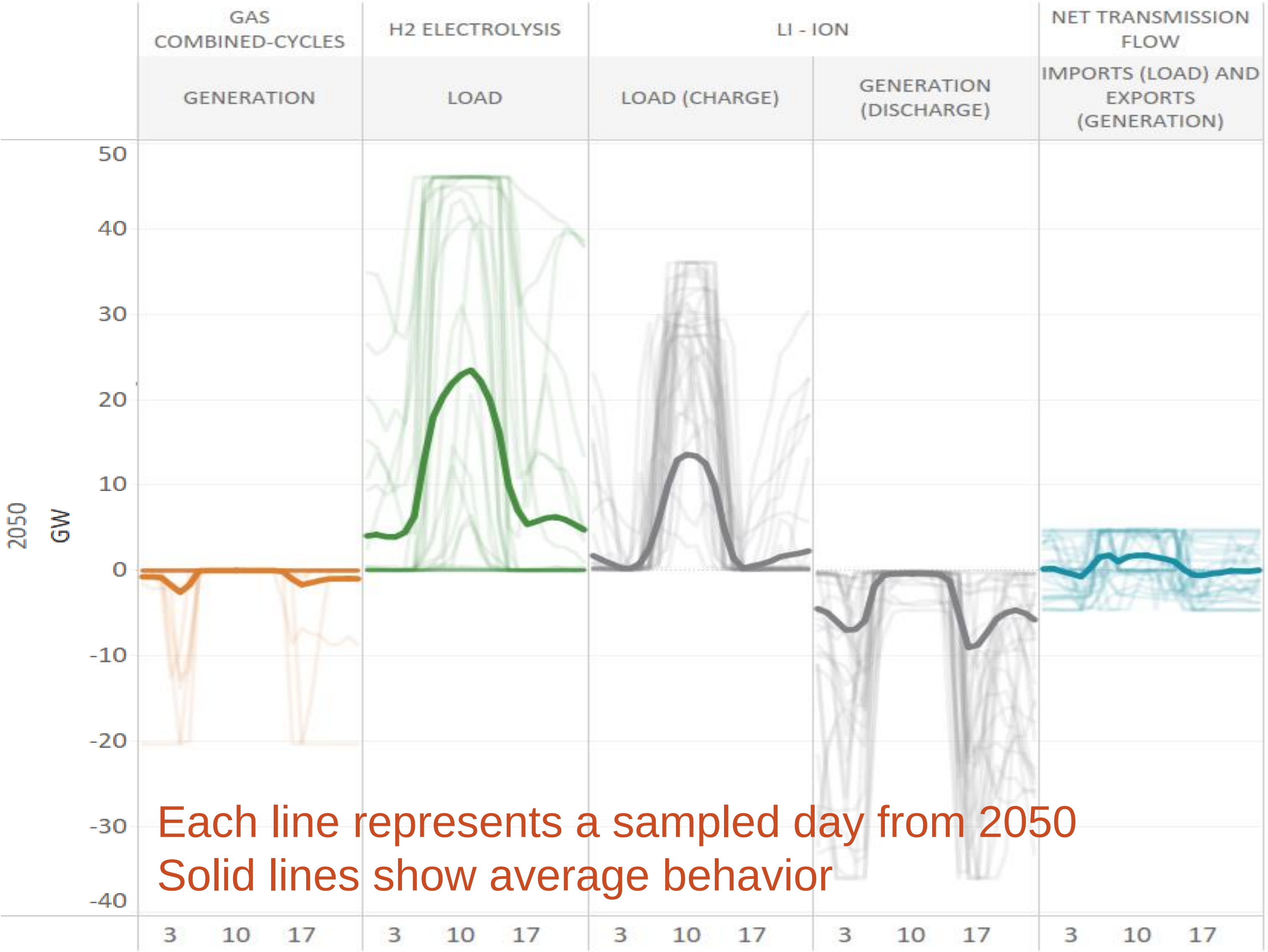
Operation of the 250th TWh of storage

One charge and one discharge cycle per year illustrated in the orange and green bars



70% wind & 30% solar
100% RE system

Electricity balancing simulation in a low carbon grid (2050 ERCOT)



- Managing periods of undergeneration from renewables is primarily accomplished with thermal generation operating infrequently
- Overgeneration is mitigated with the flexible operations of electric fuels, direct air capture facilities, increased utilization of transmission, and the operation of battery storage

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Key takeaways

- Grid balancing issues are diverse, complex, and depend on the particulars of any system
- Integration of high penetrations of renewables is largely an institutional and economic problem.
  - While the technical challenges are real and complex, renewable electricity penetrations have no ceiling because of engineering first-principals
- Storage, transmission expansion, flexible load, and renewable curtailment are each best for solving certain types of balancing problems
  - Using storage alone is prohibitively expensive
  - Using transmission alone won’t solve interconnection level problems
  - Using flexible load alone may degrade service
  - Some renewable curtailment is rational but using it alone is inefficient

THANK YOU

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