Barriers to an All (or High) Renewable Energy Grid

Michael Davidson
Postdoctoral Fellow, Harvard University

MIT Global Change Forum
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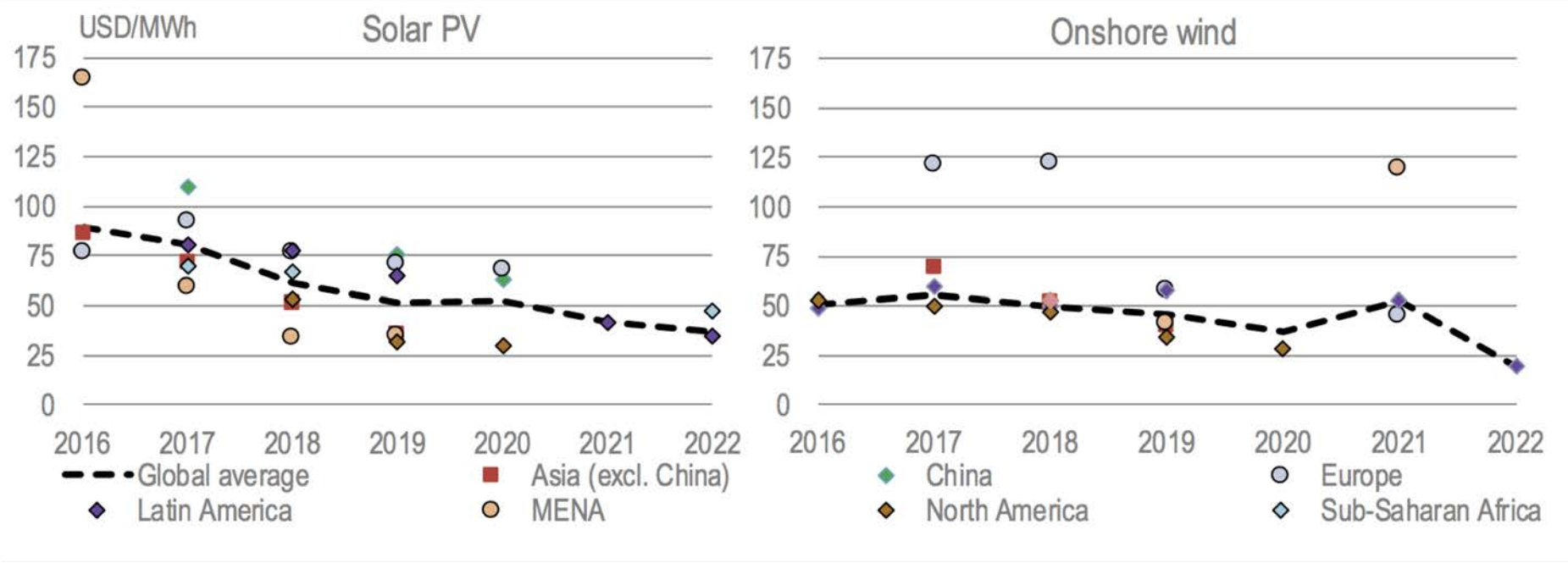
Recent renewable cost trends



Average auction prices*

*Only 15% of commissioned capacity through competitive mechanisms. Also does not include large administratively-set prices (e.g., feed-in-tariffs).

IEA (2019) *Renewables 2018*

ENERGY

California Sets Goal Of 100 Percent Clean Electric Power By 2045

September 10, 2018 · 3:59 PM ET

New York Gov. Cuomo pledges 100% carbon-free electricity by 2040

PUBLISHED
Dec. 18, 2018

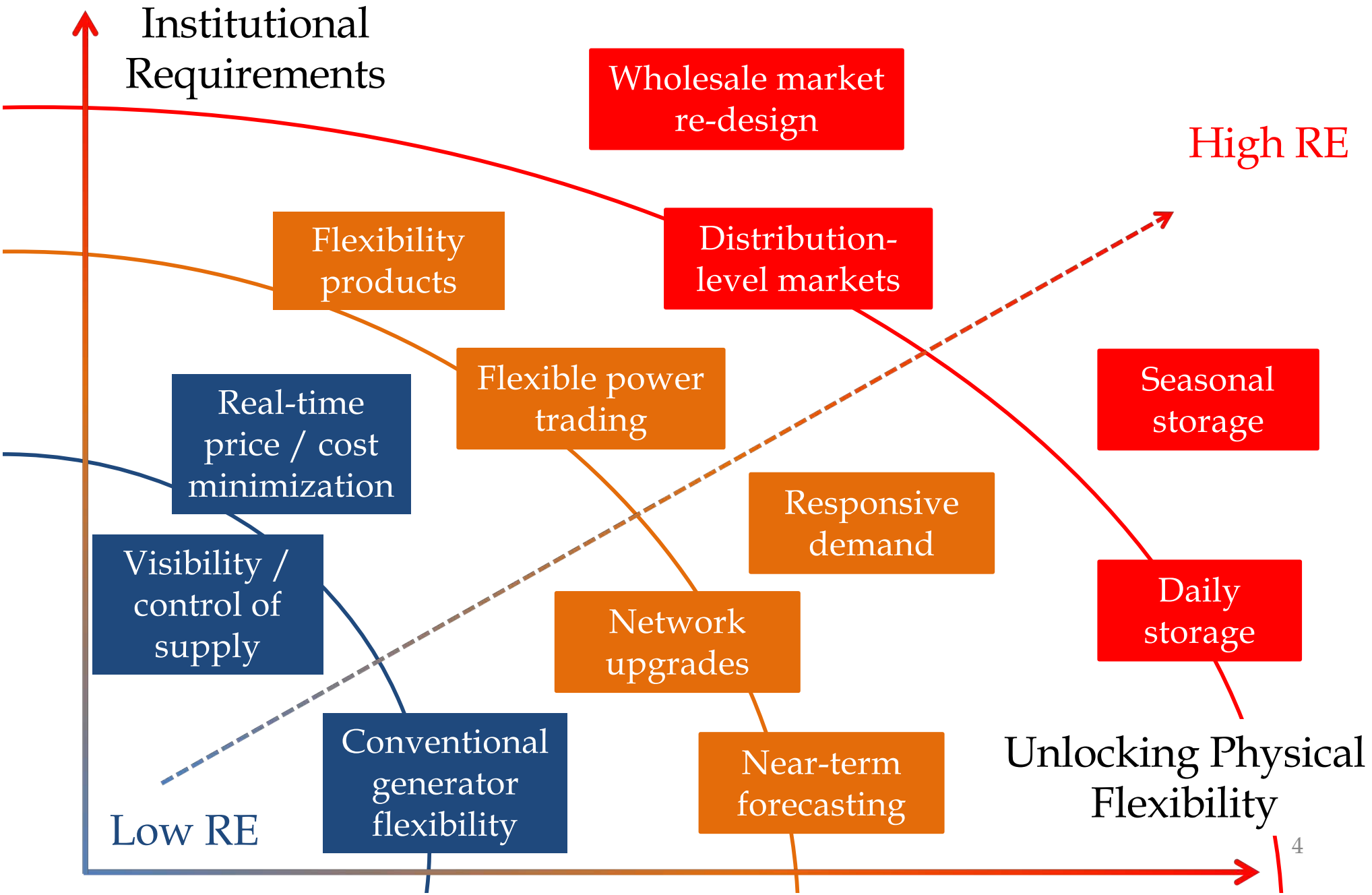
30 Nov 2018, 15:10 Benjamin Wehrmann

Germany's government coalition wrangles over feasibility of 65 percent renewables goal for 2030

RE 100

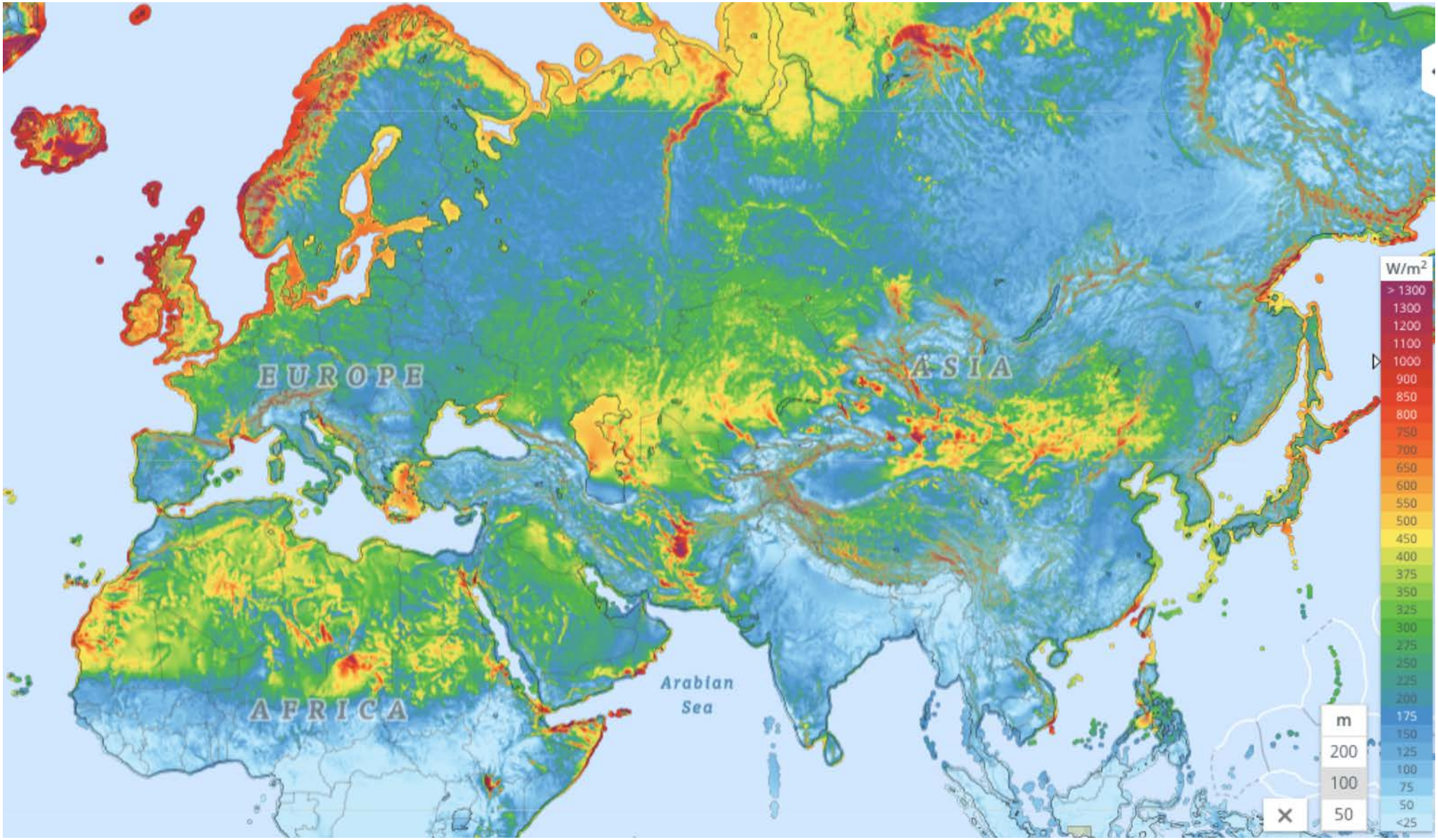
167 RE100 companies have made a commitment to go '100% renewable'. Read about the actions they are taking and why.

Unlocking physical and institutional flexibility



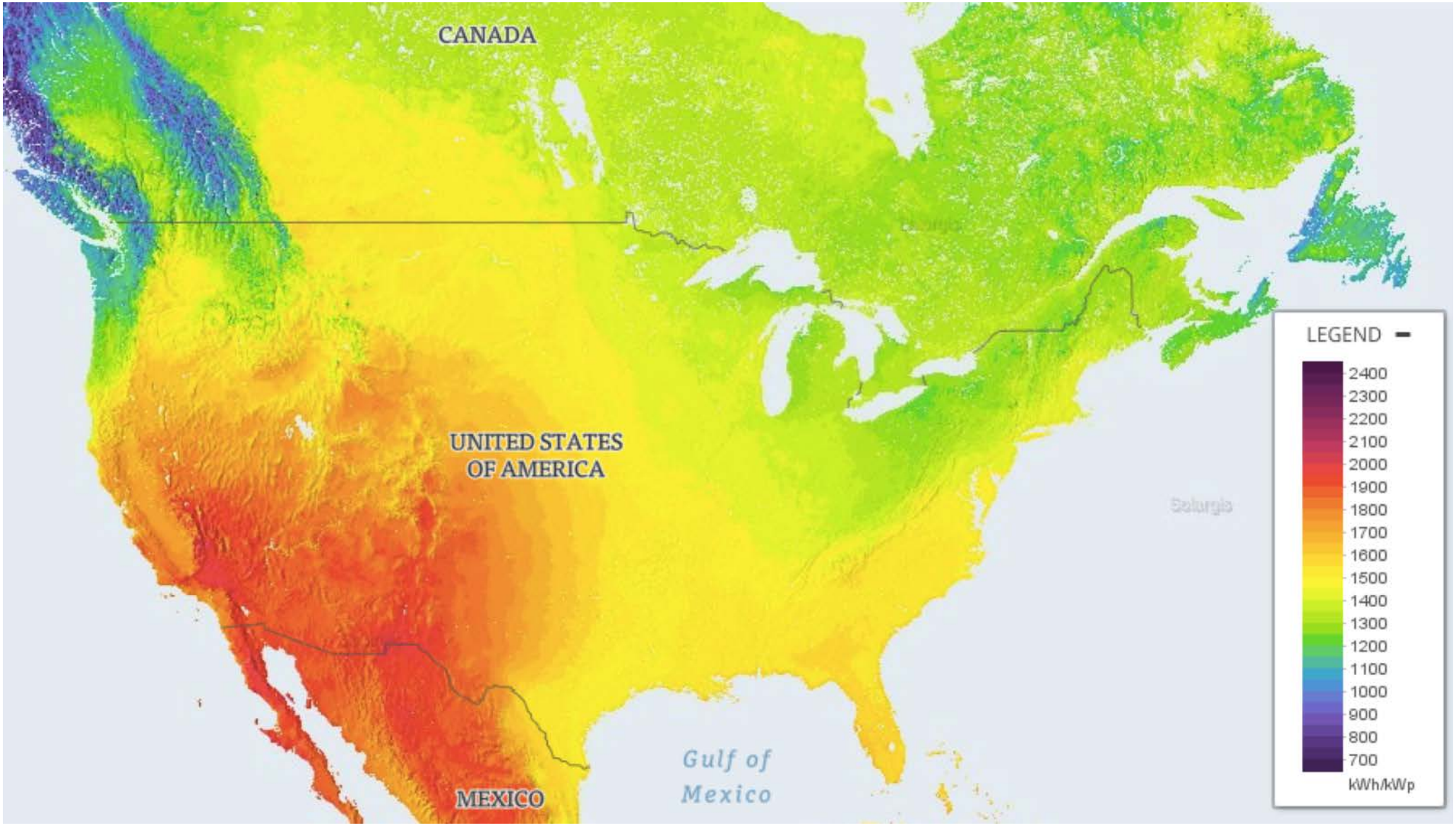
PHYSICAL CONSTRAINTS

Variations in *annual* wind resource



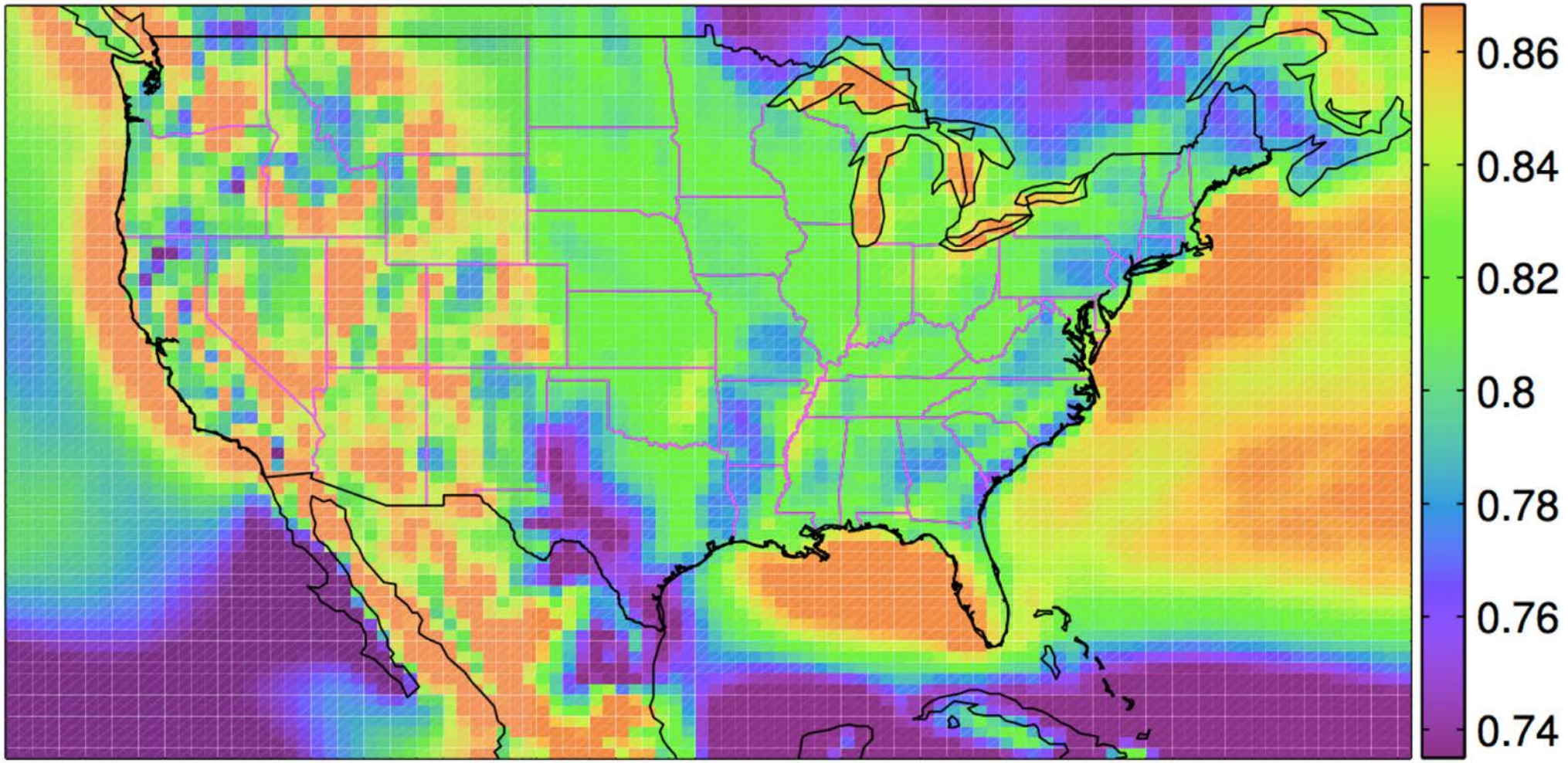
Global Wind Atlas

Variations in *annual* solar resource



Global Solar Atlas

Variations in wind *intermittency*

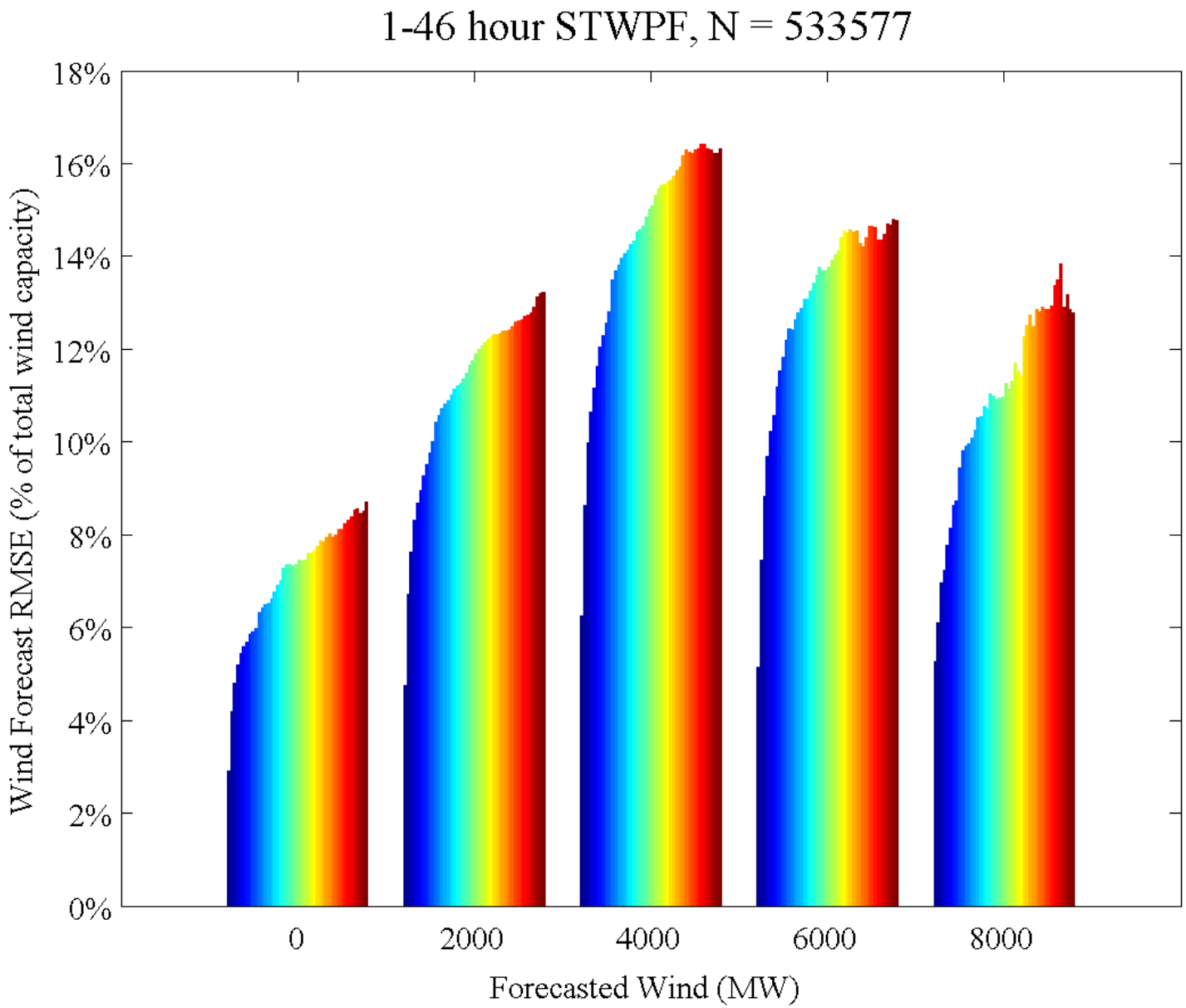


Less variable

$$\mathrm{RCoV} = \frac{\text{median(absolute deviation about the median)}}{\text{median}}$$

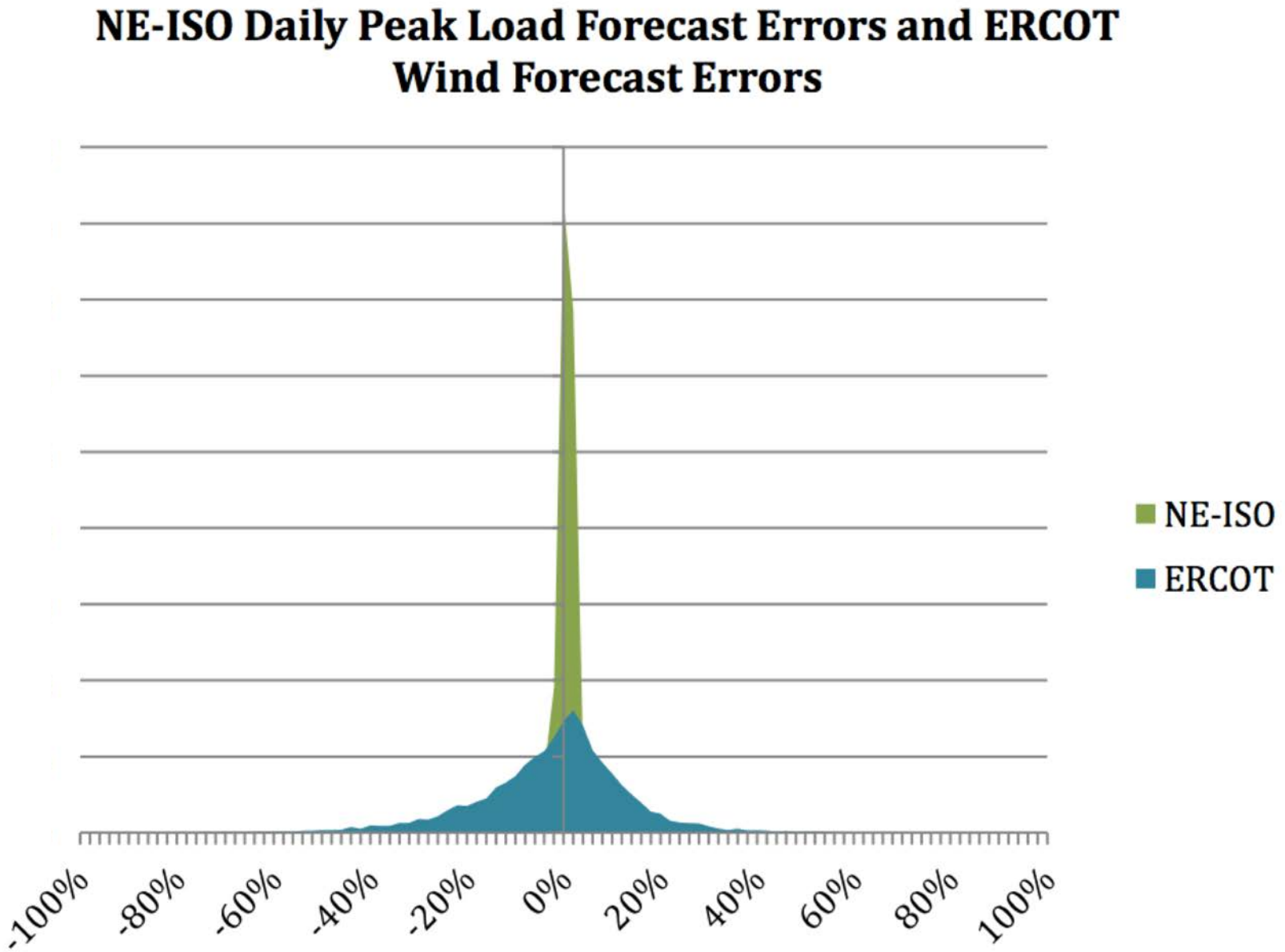
Gunturu & Schlosser (2012) *Atmospheric Chemistry & Physics*

Forecasting challenges



Data: ERCOT (2013-2014)

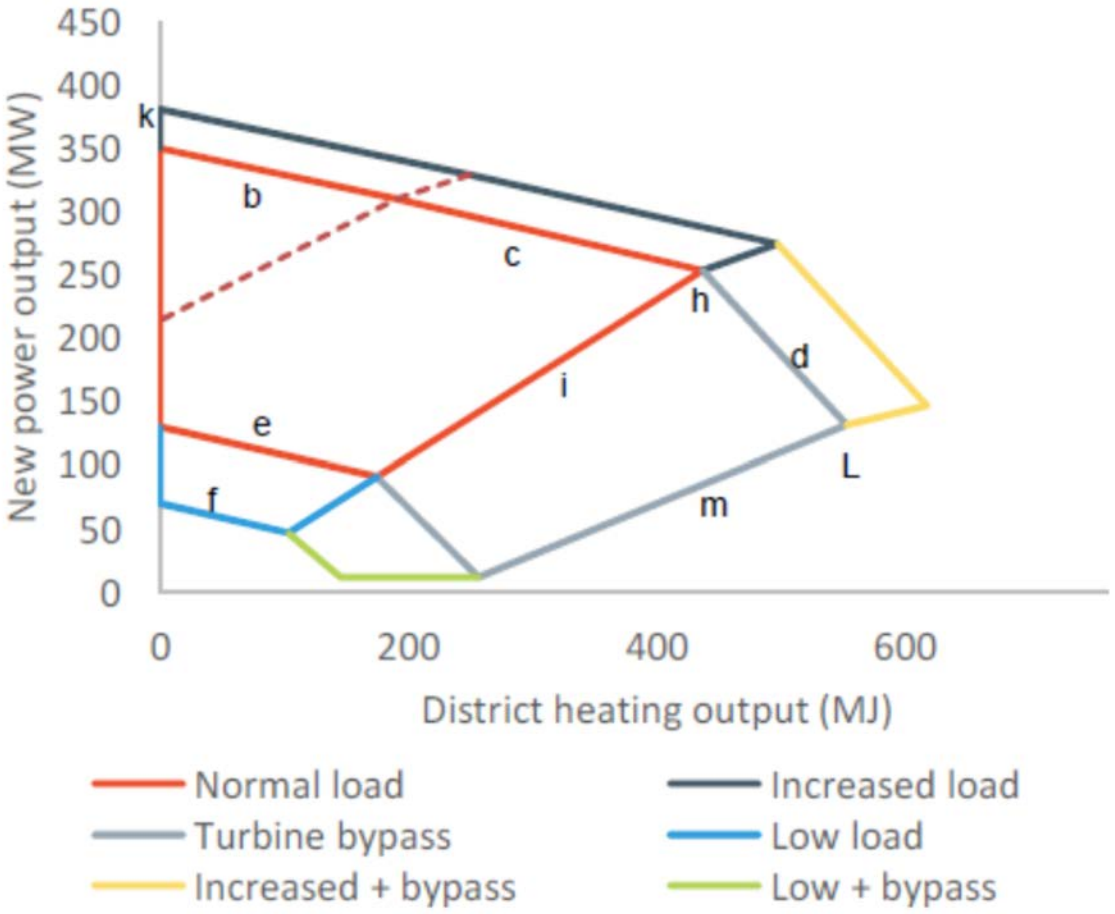
Forecasting challenges (2)



ENGINEERING SOLUTIONS AND LIMITATIONS

Thermal generator flexibility

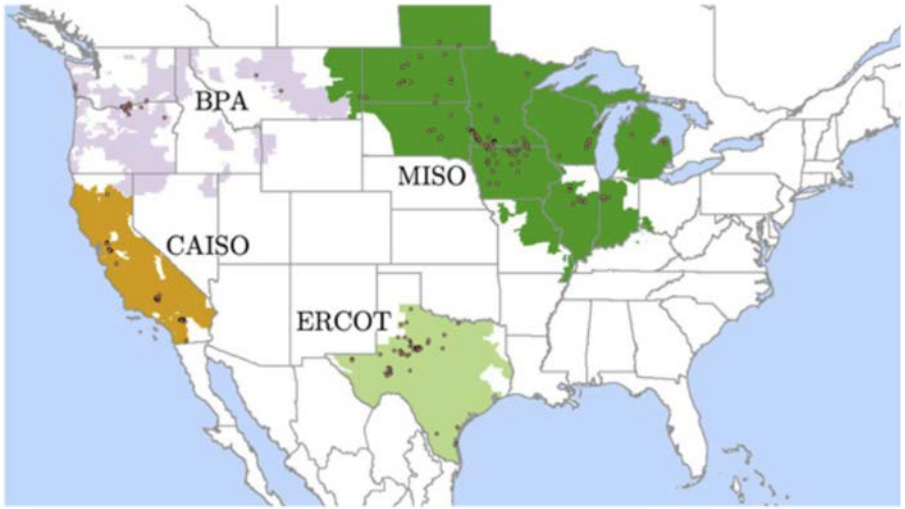
Cogeneration power-heat diagram

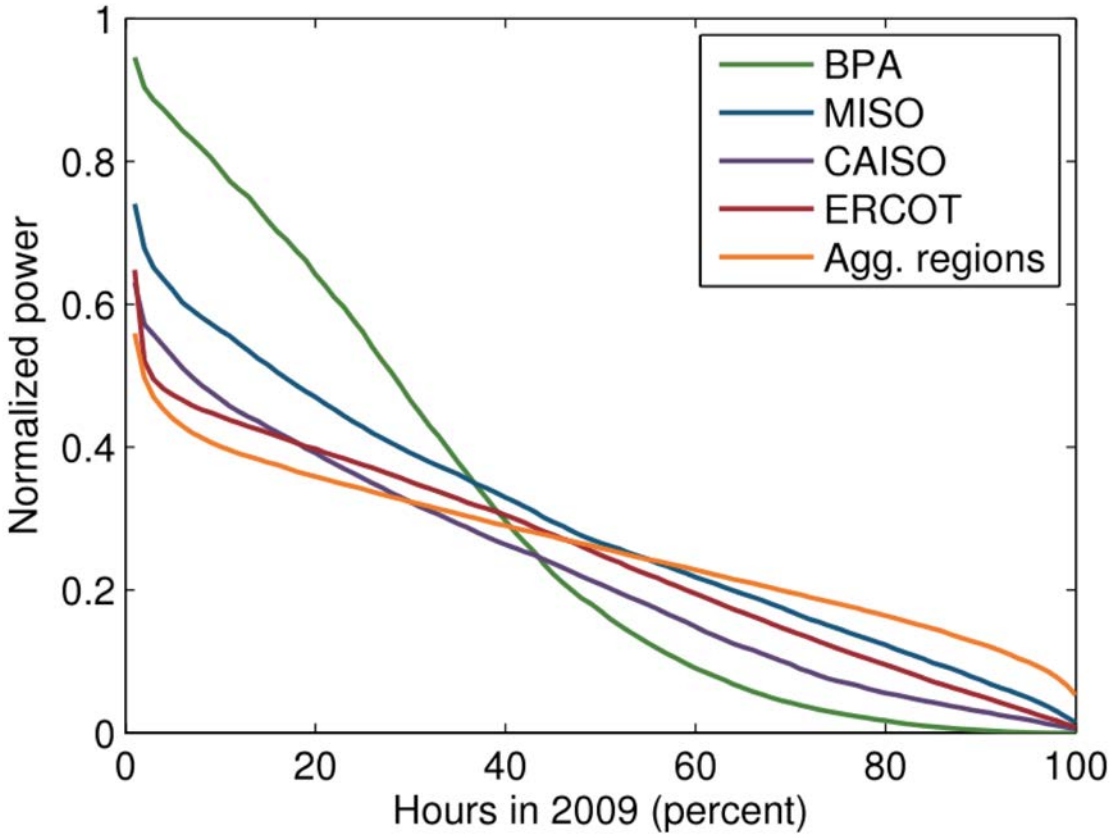


- Minimum load / overload firing and control systems
- Ramp-capable components
- Part load heat rate upgrades
- Heat storage
- Turbine bypass
- …

Wang & Riemann (2018) "Thermal Power Plant Flexibility"
ERPI (2010) "Efficiency Improvement for Cycling Service"

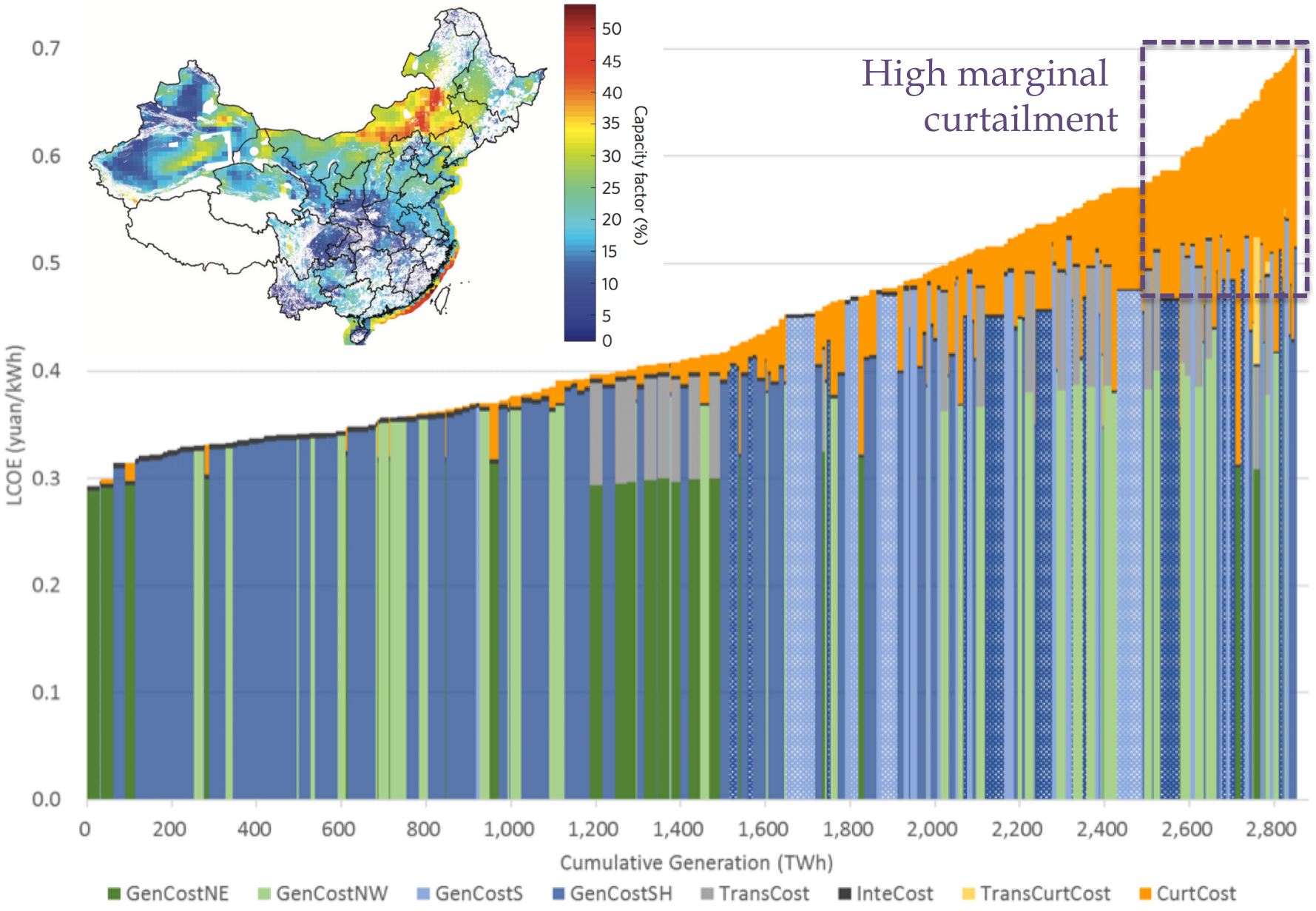
Transmission smoothing benefits





Fertig, Apt, Jaramillo, & Katzenstein (2012) *Environmental Research Letters*

Continent-wide integration limits

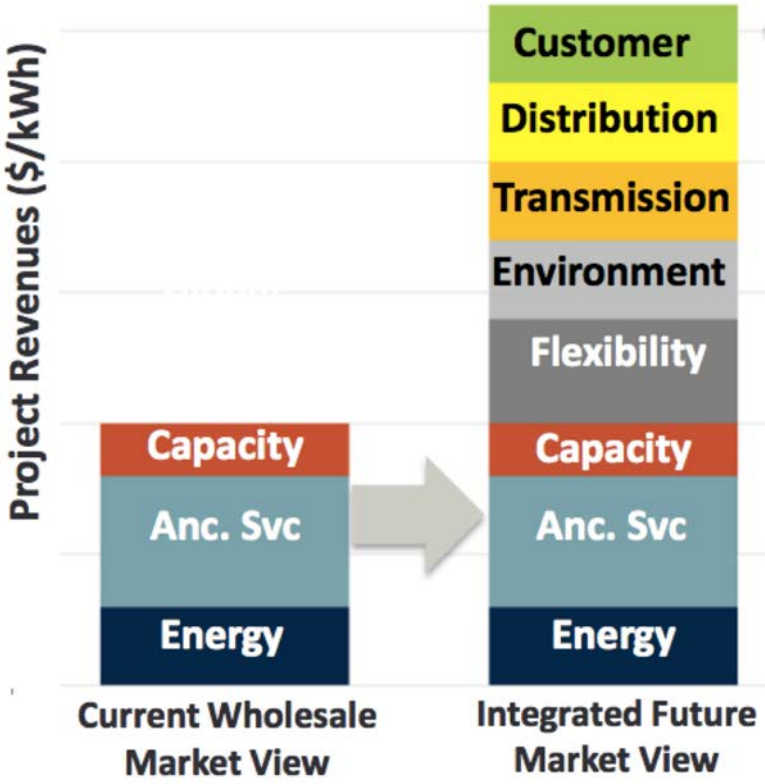


Davidson, Zhang, Xiong, Zhang, & Karplus (2016) *Nature Energy*

Storage economics

Dramatic reductions in storage costs, but:

- Still not enough revenue for most applications
- May increase emissions for current grid
- Short duration storage may have limited near-term benefits
- Long storage (weeks to seasons) important but difficult
- Don't forget thermal storage

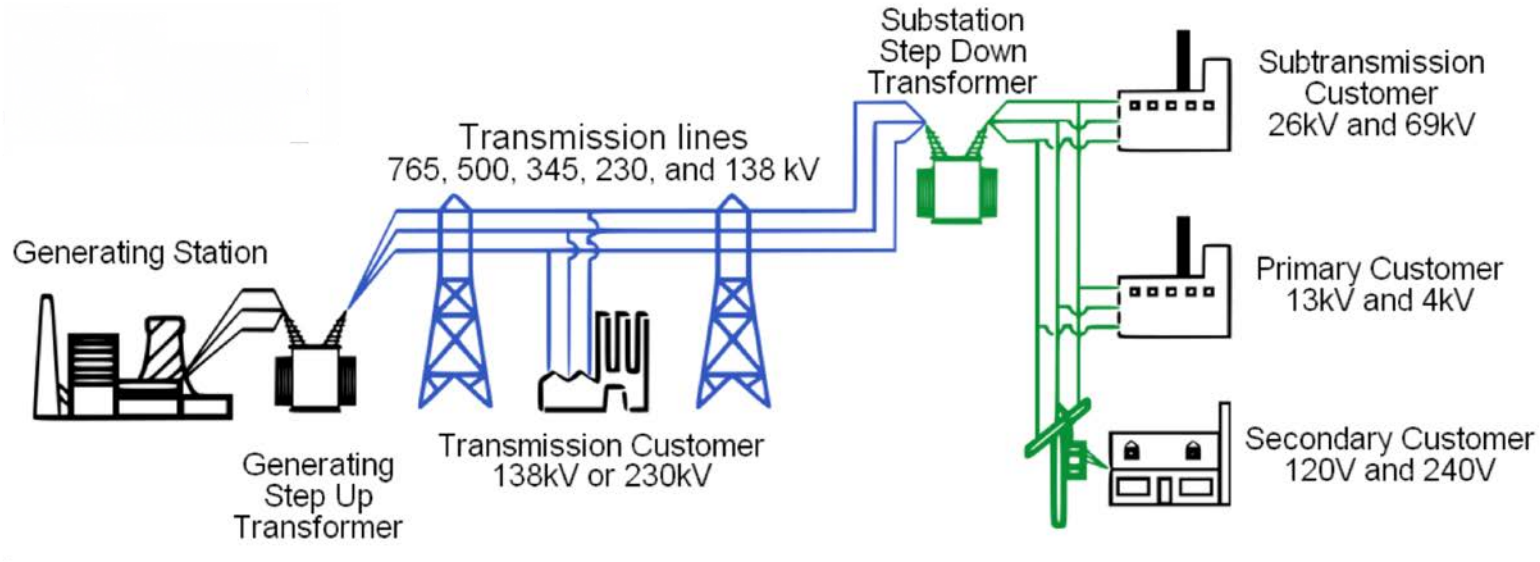


Brattle, 2018

Hittinger & Azevedo (2015) *Environmental Science & Technology*
de Sisternes, Jenkins, & Botterud (2016) *Applied Energy*

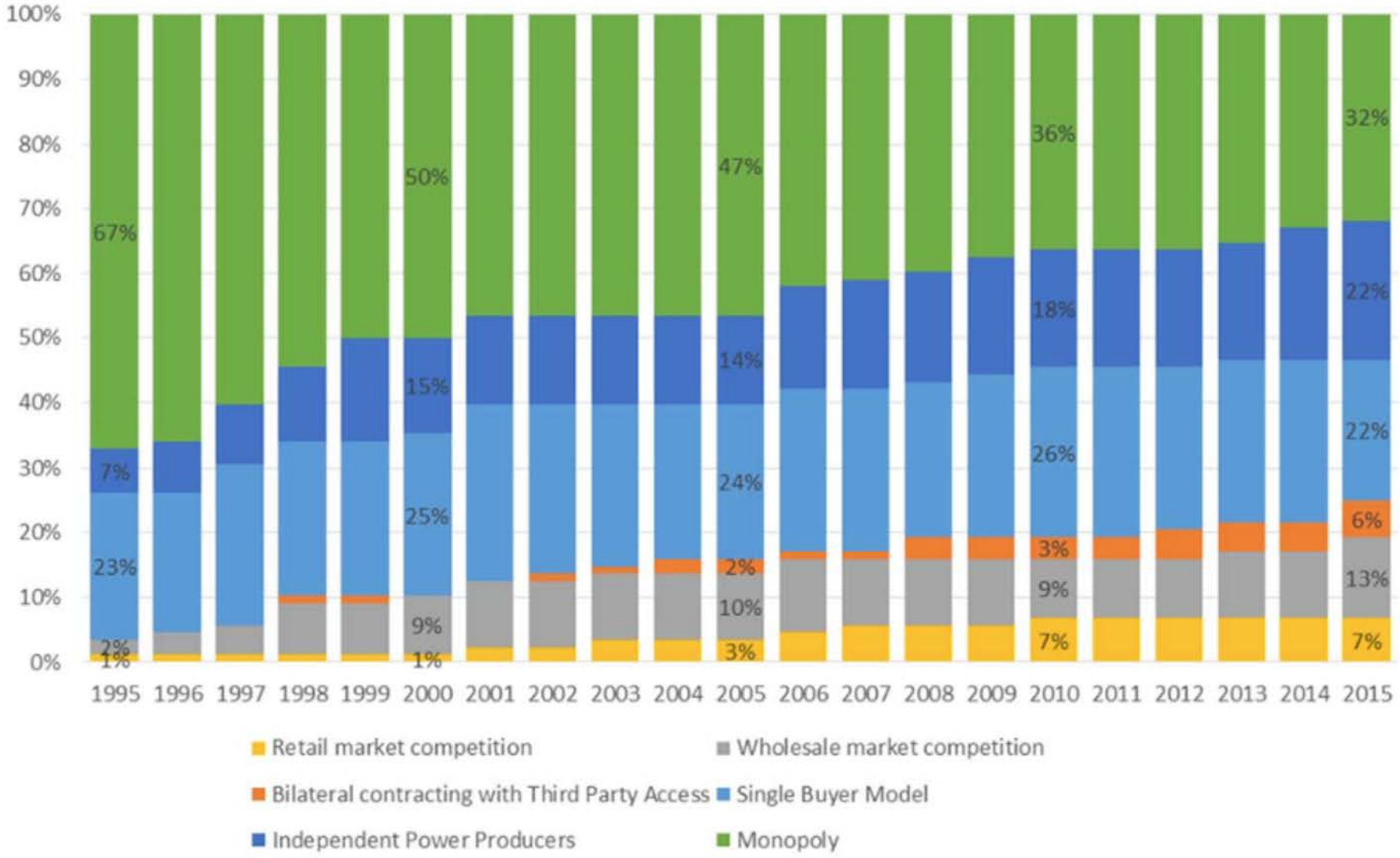
MARKET REQUIREMENTS

Best practice power system operation



- Vertically-integrated utility
  - Minimizes short-run costs
  - Regulatory challenge: incentivize efficient investments
- Restructured markets
  - Short-term spot markets with bid-based locational marginal pricing, naturally prioritizes renewables
  - Regulatory challenge: market power

Broad restructuring trend



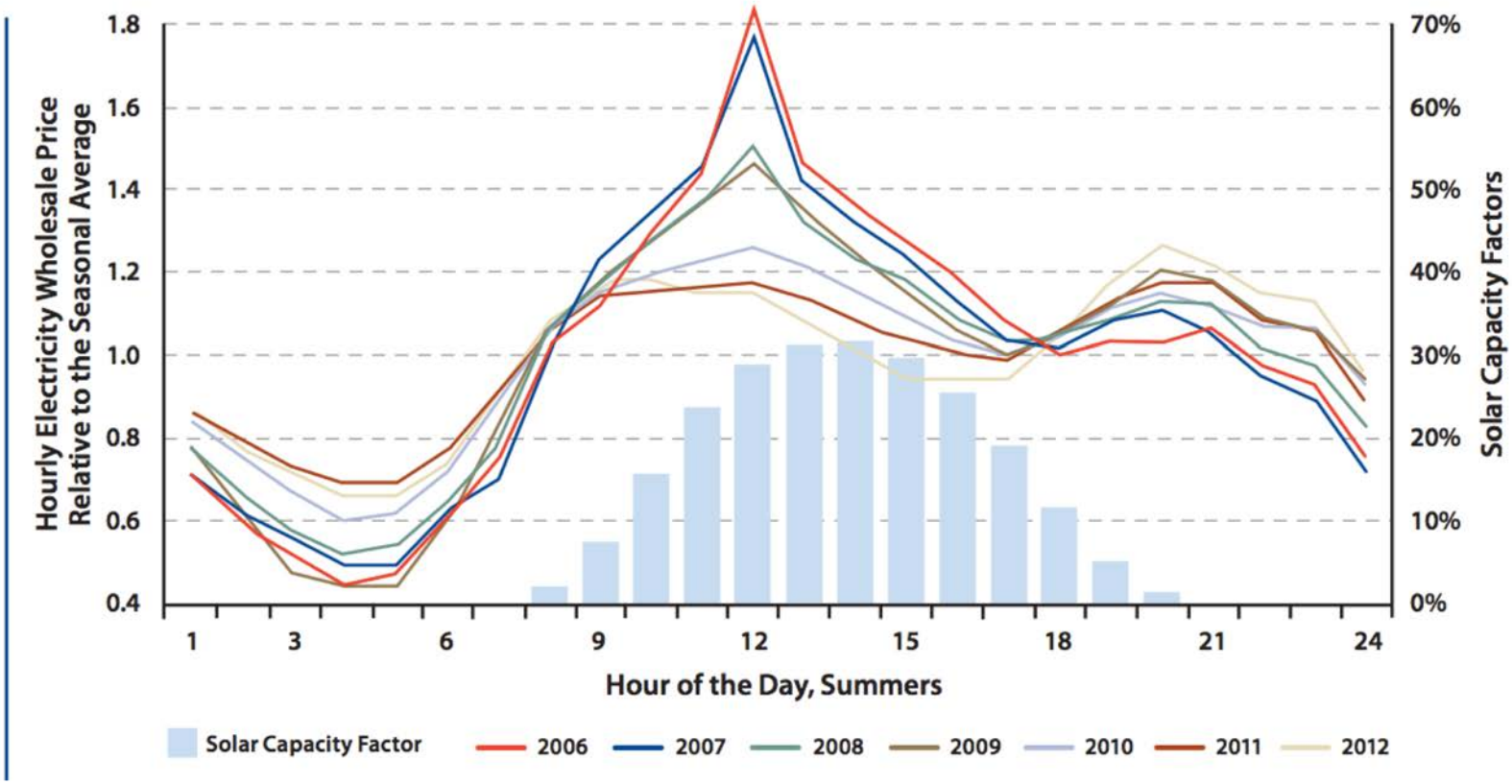
Percentage of developing countries adopting degrees of competition

Foster, Witte, Banerjee, & Vega Moreno (2017) *World Bank*

Next hurdle: value deflation

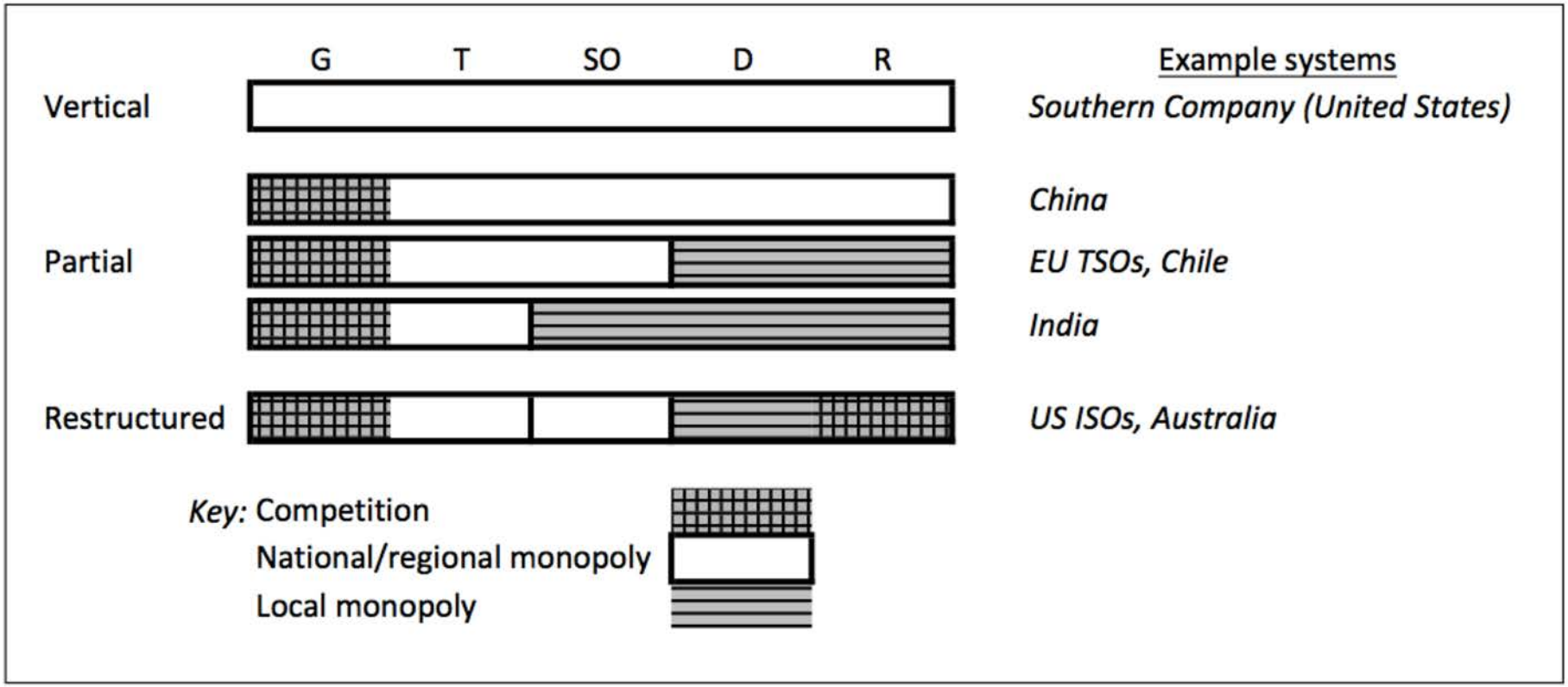
- With coincident renewable (esp. solar) additions, marginal value goes down
- As renewables face more wholesale prices (vs. fixed average costs), economics get worse

Figure 5.1 Summertime Hourly Electricity Wholesale Prices Relative to Seasonal Average Price in Germany 2006–2012



MITEI (2015) *The Future of Solar Energy*

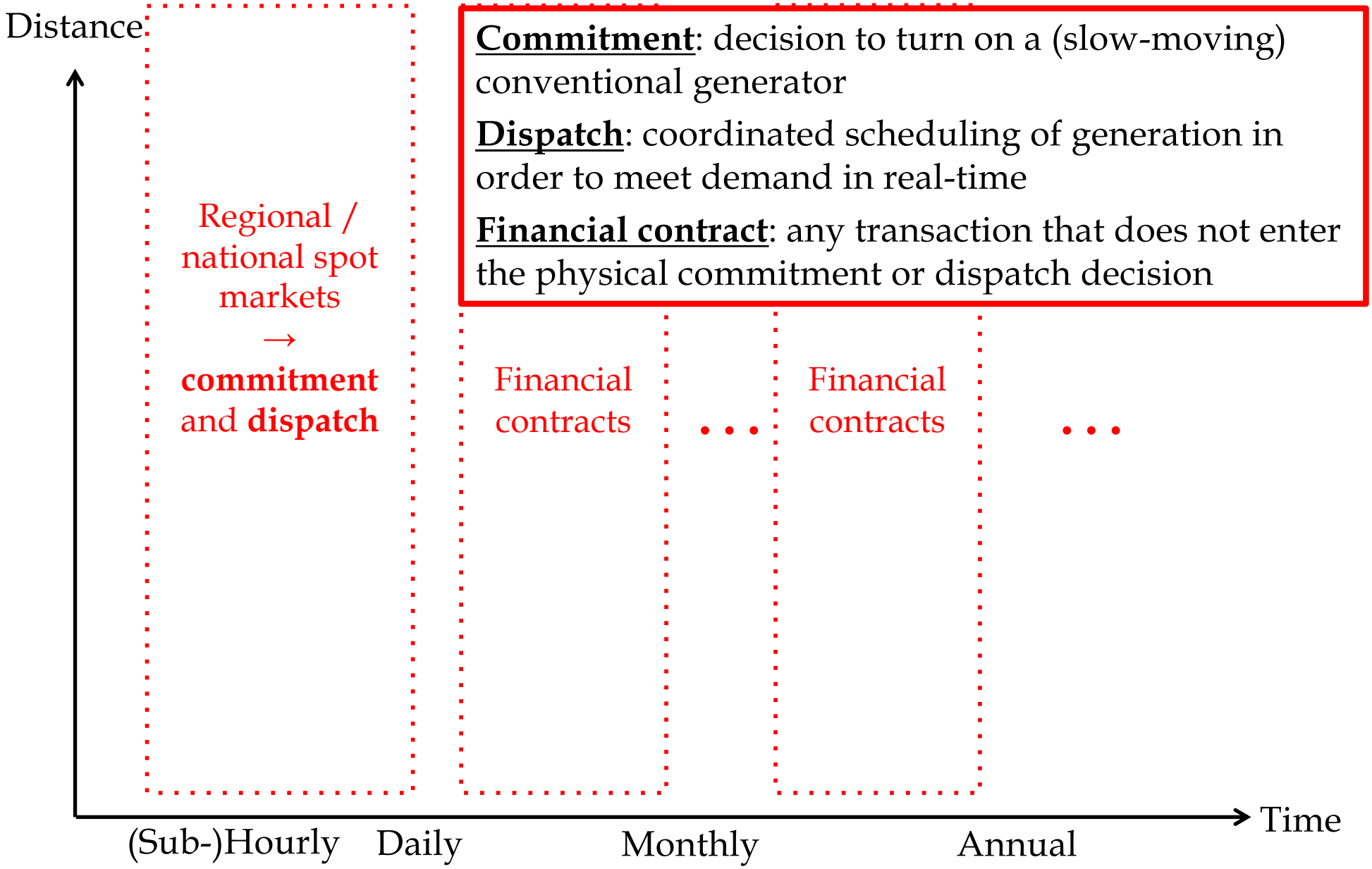
Diversity of actual systems



Note: G, generation; T, transmission; SO, system operation; D, distribution; R, retail; ISO independent system operator; TSO transmission system operator. This figure is intended to be illustrative. In the United States, for instance, there are a number of vertically integrated utilities that are part of regional transmission organizations and participate in wholesale markets.

Davidson, Kahrl, & Karplus (2017) in *The Political Economy of Clean Energy Transitions*

Ideal electricity dispatch and scheduling

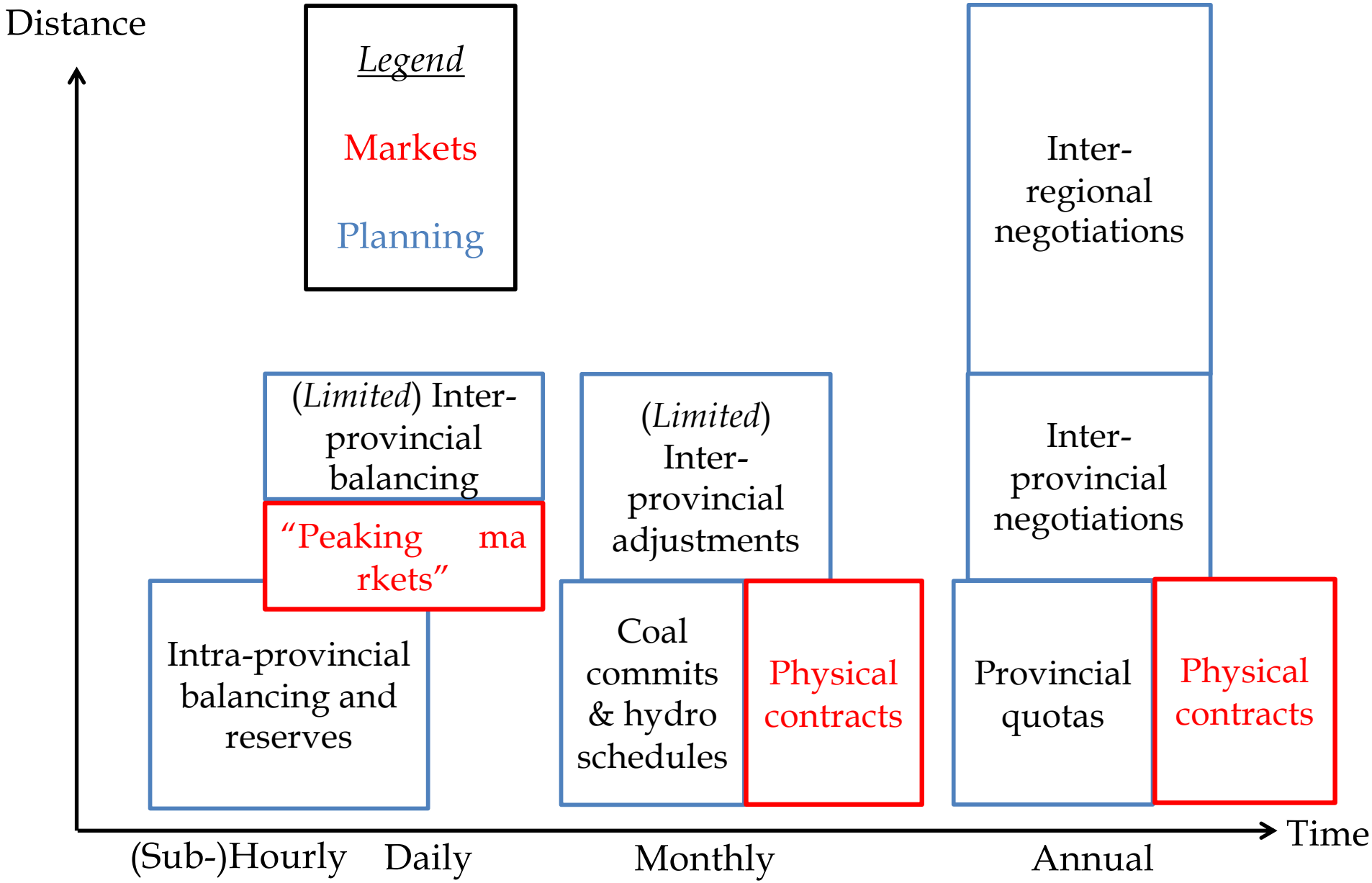


Commitment: decision to turn on a (slow-moving) conventional generator

Dispatch: coordinated scheduling of generation in order to meet demand in real-time

Financial contract: any transaction that does not enter the physical commitment or dispatch decision

China's electricity dispatch and scheduling *with market experiments*

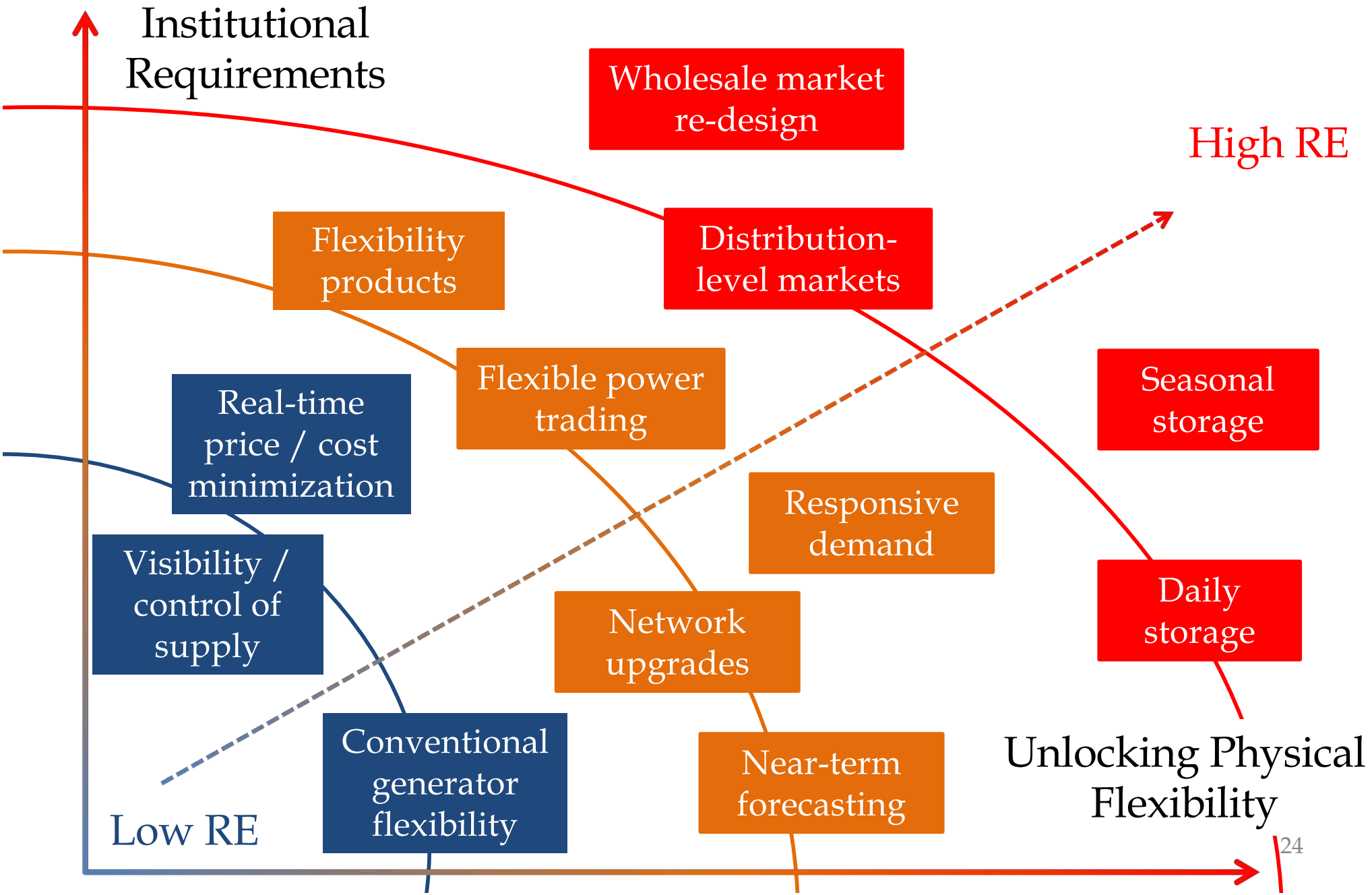


Many market changes for high-RE future

- Establish real-time price / cost signals
- Flexibility products
  - For systems that cannot cope with high RE… "at politically acceptable prices"
- Distribution-level pricing
  - Net metering
  - …eventually D-LMPs
- Fundamental market redesign?
  - Address majority zero-marginal cost resources
  - E.g., greater reliance on capacity mechanisms

Pollitt & Anaya (2016) *The Energy Journal*

On the path to high renewables



Thank you for your attention.

Questions?

Michael Davidson

michael_davidson@hks.harvard.edu

www.mdavidson.org @east_winds