Operating Reserves in Long-term Planning Models

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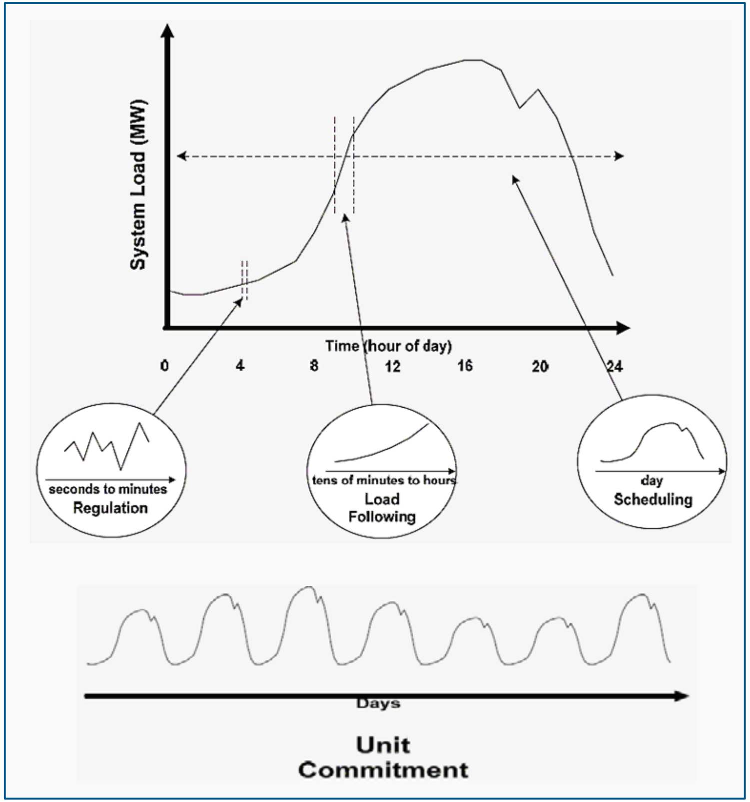
Reserves Overview

- Reserve Product Types
  - **Contingency Reserve:** ability to respond to a major unit or transmission outage
  - **Regulation Reserve:** ability to respond to regular small fluctuations in load-supply imbalances
  - **Flexibility Reserves:** ability to provide following and ramping needs
- Reserves are designed to maintain reliability despite inherent variability and uncertainty in demand and supply, including variable renewable generation



Challenges of Representing Operating Reserves in Long-term Models

- **Temporal resolution**
  - Capacity expansion models typically have ~10-100 timeslices to represent dispatch
    - Operating reserves will generally operate at the same resolution as the dispatch
  - Underlying data used to create these timeslices is often hourly data, limiting the ability to represent sub-hourly phenomena
  - Operating reserves are used to meet needs across many timescales from seconds to hours
- **Limited or no chronology**
  - Timeslices are often groups of representative or similar hours from across the year, and therefore often are nonchronological or only represent a small number of chronological hours (e.g., by using representative weeks as timeslices)
  - Without chronology it is challenging to capture plant availability (e.g., because of minimum up or down times) for providing operating reserves
- **Unit commitment**
  - Many capacity expansion models are linear, and thus cannot do true unit commitment (which would require a mixed-integer formulation)
  - A unit’s commitment state can impact its ability to provide different reserve products

Operating Reserves in the Regional Energy Deployment System (ReEDS) Model

- This deck describes a new representation of operating reserves in the ReEDS model
- ReEDS has three types of operating reserve requirements:

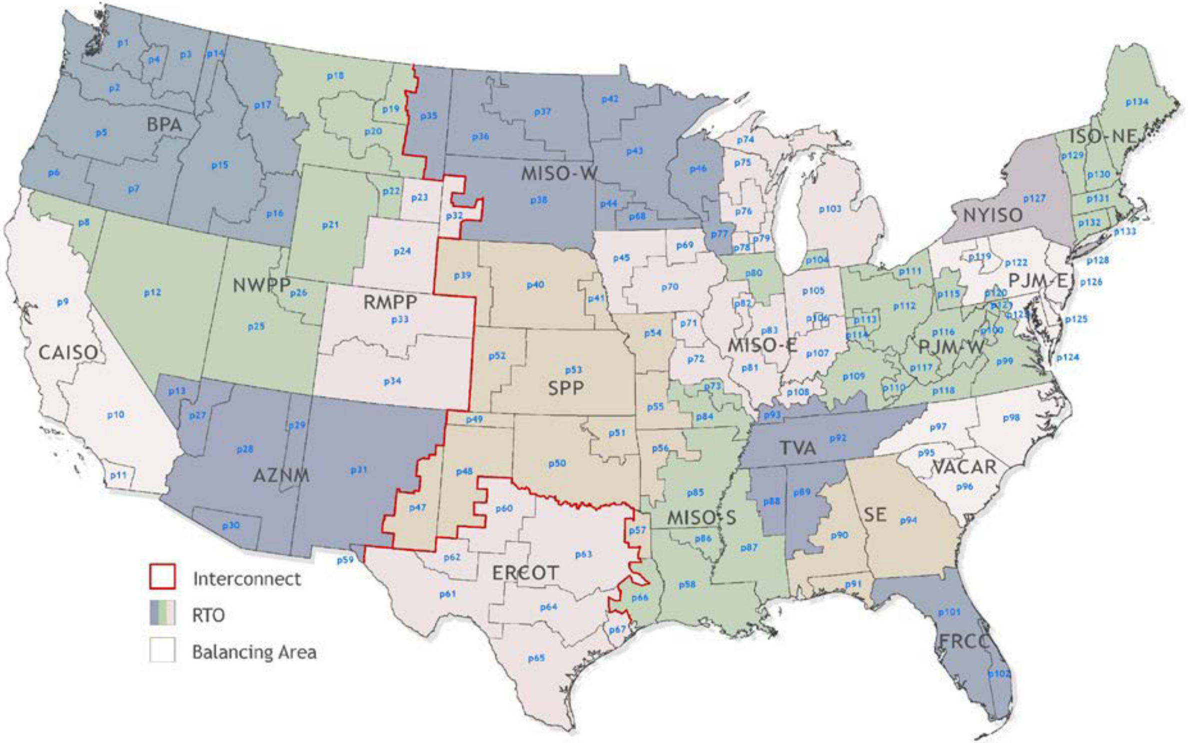
Product	Load Reqt	Wind Reqt	PV Reqt	Timescale	Extra cost
Spinning	3% of load	-	-	10 min	-
Regulation	1% of load	0.5% of wind generation	0.3% of PV capacity* during daytime hours	5 min	Table 3 from Hummon et al. (2013)
Flexibility	-	10% of wind generation	4% of PV capacity* during daytime hours	60 min	-

*Note: PV is based on capacity because PV-induced reserves are most needed during dawn and dusk when generation is low

- Generator eligibility: all generators types except for nuclear, CSP without storage, PV, and wind are allowed to provide these three services
  - CSP without storage, PV and wind are capable of providing reserves, but doing so requires that they are partially curtailed. Currently, ReEDS does not allow these generators to provide reserves, but they could be allowed to provide reserves under the formulation described here.
- Reserves are implemented using the following model constraints:
  - **Reserve Requirement:** For each type of reserve product: local provision + import provision – exported provision >= reserve requirement
  - **Reserve Upper Bound**: Each generators contribution to each reserve <= the generator's ramp rate (% of online capacity/min) * the ramp requirement for the given reserve product (min) * the generator's online capacity (MW)
  - **Energy + Reserve Upper Bound**: Energy + Spin + Reg + Flex <= Capacity * (1-outage_rate)
  - **Transmission Upper Bound**: Energy trades + Spin trade + Reg trade + Flex trade <= carrying capacity of the transmission line between two BAs

Regional Considerations

- All operating reserves must be supplied within one of 18 model-defined "RTO" regions (see figure at right for region definitions). In other words, reserves are not allowed to be traded between these regions.
- This regional requirement ensures that low-cost reserves are not traded over long distances (e.g., prohibiting New York hydro from meeting the regulation reserve requirement in Florida)



Cost for Providing Regulation Reserves

- Opportunity costs are captured in the ReEDS formulation for all reserve products. However, additional costs are included for regulation reserves to account for the cost of following a rapidly changing signal.

- Generator costs are taken from Table 3 (shown at right) in Hummon et al. (2013)

- These costs are in 2013$

- Because ReEDS does not clearly distinguish between coal type, we use $12.5/MW-h for all coal technologies

- Gas-CT, geothermal, biopower, land-fill gas, and CAES are all assumed to provide regulation reserves at the same cost as gas/oil steam

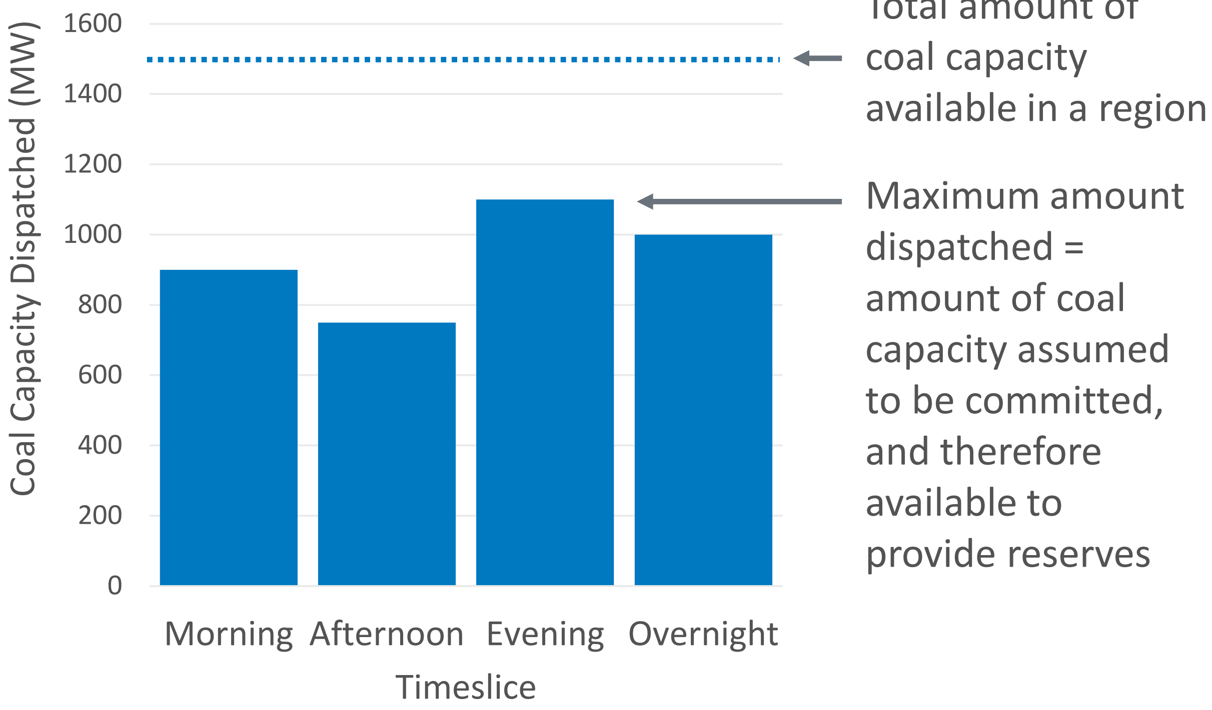
Generator Type	Cost ($/MW-h)
Supercritical Coal	15
Subcritical Coal	10
Combined Cycle	6
Gas/Oil Steam	4
Hydro	2
Pumped Storage Hydropower	2

Unit Commitment in ReEDS

ReEDS has four representative days (one per season), and performs dispatch using four timeslices in each day: morning, afternoon, evening, and overnight

Approximating unit commitment

- Ideally ReEDS would only allow committed generators to provide reserves, but ReEDS does not model unit commitment
- Instead ReEDS uses the maximum generation across the timeslices in a day to represent the amount of committed capacity in each region
- This approximation only allows reserves from online and "spinning" resources and underestimates reserve provision from units that can start quickly



Availability of Technologies to Provide Operating Reserves

	Assumed Ramp Rate (%/min)	Ramp Rate * Ramp Time = Upper Bound (% of online capacity)		
		Spinning	Regulation	Flexibility
Gas-CT	8	8*10=80	8*5=40	8*60=480, so 100
Gas-CC	5	5*10=50	5*5=25	5*60=300, so 100
Coal	4	4*10=40	4*5=20	4*60=240, so 100
***Geothermal**	4	4*10=40	4*5=20	4*60=240, so 100
CSP w/ Storage	10	10*10=100	10*5=50	10*60=600, so 100
***Biopower**	4	4*10=40	4*5=20	4*60=240, so 100
Oil/Gas Steam	4	4*10=40	4*5=20	4*60=240, so 100
Hydro	100	No Upper Bound		
Storage	100			

*Geothermal and biopower values are assumed to be the same as oil/gas steam units. In practice, geothermal plants typically do not ramp given their zero or near-zero variable costs, and therefore only provide energy and not operating reserves.

Data sources: Bloom et al. (2016), Table 6 for NG-CT, NG-CC, Coal, Oil/Gas Steam
Jorgenson et al. (2013), Table 3 for CSP

Reserve Requirements

- The spinning reserve requirement as 3% of load and the regulation requirement as 1% of load were taken from Lew et al. (2013) section 5.3.4
- Reserve requirements for wind and PV were derived from the outcomes from Lew et al (2013) which relied on a more sophisticated statistical methodology
  - To estimate flexibility reserve requirements for wind, we divided the increased reserve requirement (Table 18) by the wind generation in the High Wind scenario
  - To estimate the flexibility reserve requirement for PV, we divided the increased reserve requirement by the PV generation in the High Solar scenario
  - For VRE-dependent regulation reserve requirements, we used the incremental increases in regulation reserves in all the scenarios in Table 18 and estimated factors (0.5% wind generation and 0.3% PV capacity) that would closely approximate those increases

Summary of Operating Reserves Implementation

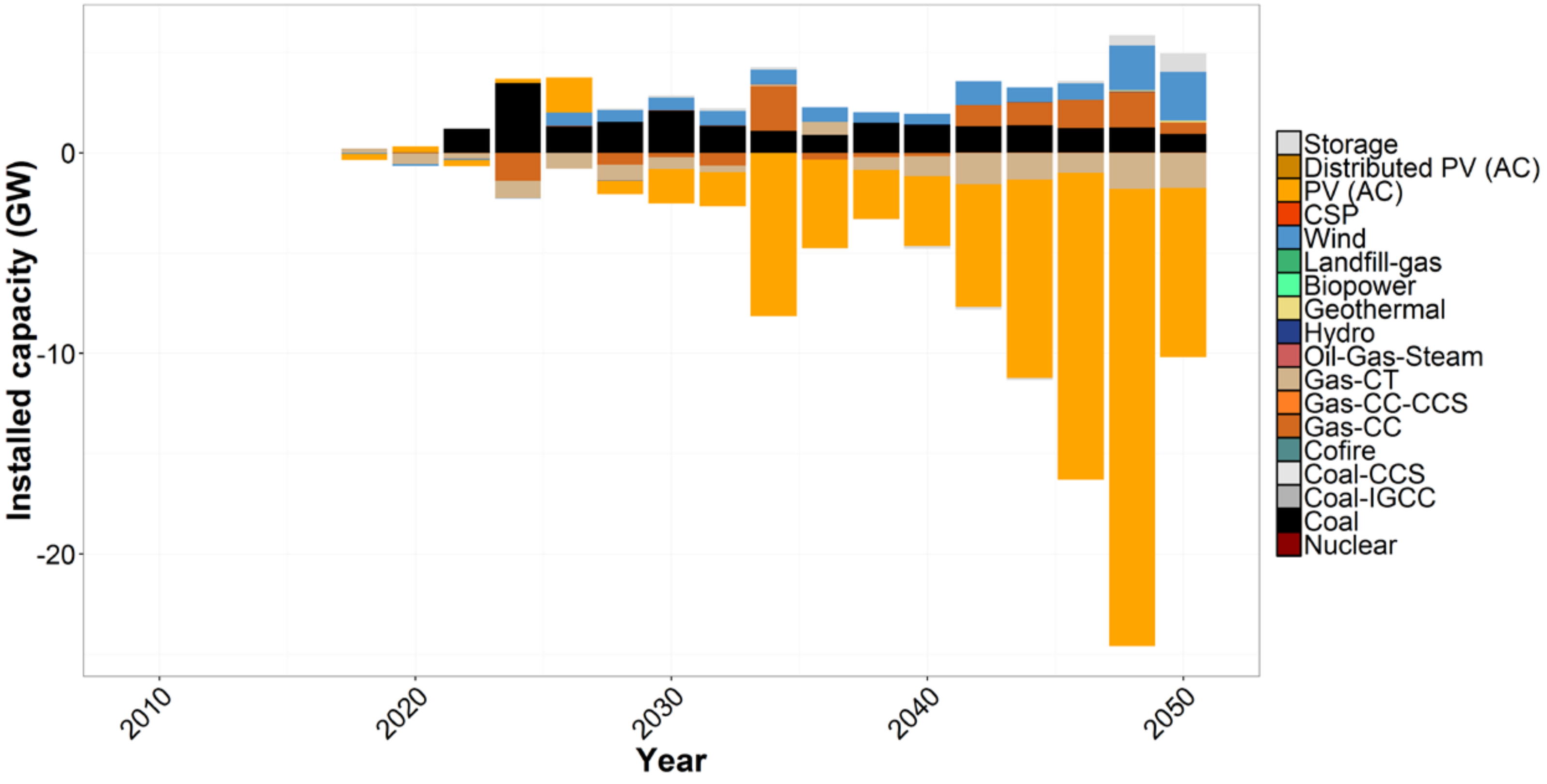
Data	**Qualifying Technologies**	Spin – all (including storage) except nuclear, PV, and wind Reg – all (including storage) except nuclear, PV, and wind Flex – all (including storage) except nuclear, PV, and wind
	Ramp Rates (per minute)	NG-CT–8%, NG-CC–5%, Coal–4%, Geothermal–4%, CSP–10%, Biopower–4%, Oil/Gas Steam–4%, Hydro–100%
Constraints	**Supply >= Demand**	Spin + Imports(Spin) – Exports(Spin) >= 3% * Load Reg + Imports (Reg) – Exports(Reg) >= 1% * Load + 0.5% * Wind Generation + 0.3% * PV Capacity during the day Flex + Imports (Flex) – Exports(Flex) >= 10% * Wind Generation + 4% * PV Capacity during the day
	Operating Reserve Upper Bound	Spin <= Committed Capacity * 10 min * ramp rate (%/min) Reg <= Committed Capacity * 5 min * ramp rate (%/min) Flex <= Committed Capacity * 60 min * ramp rate (%/min) *See slide 6 for "Committed Capacity" description*
	Storage Capacity Limit	Energy Discharged + Spin + Reg + Flex <= * (1 – outage_rate)
	Transmission Limits	Energy Trades + Spin Trades + Reg Trades + Flex Trades <= AC Line Capacity
	Generation Capacity Limit	Energy + Spin + Reg + Flex <= Capacity * (1 – outage_rate)

Impacts of Operating Reserves

- To demonstrate the impact of the operating reserve constraints, we ran two sets of scenarios:
  - Mid-case: Default assumptions, with and without operating reserves
  - High RE: Low RE costs + Accelerated Coal Retirements, with and without operating reserves
- Results on the next several slides show results of “With Operating Reserves” minus “No Operating Reserves”
  - Positive values indicate increase from the operating reserves, and negative values indicate decreases

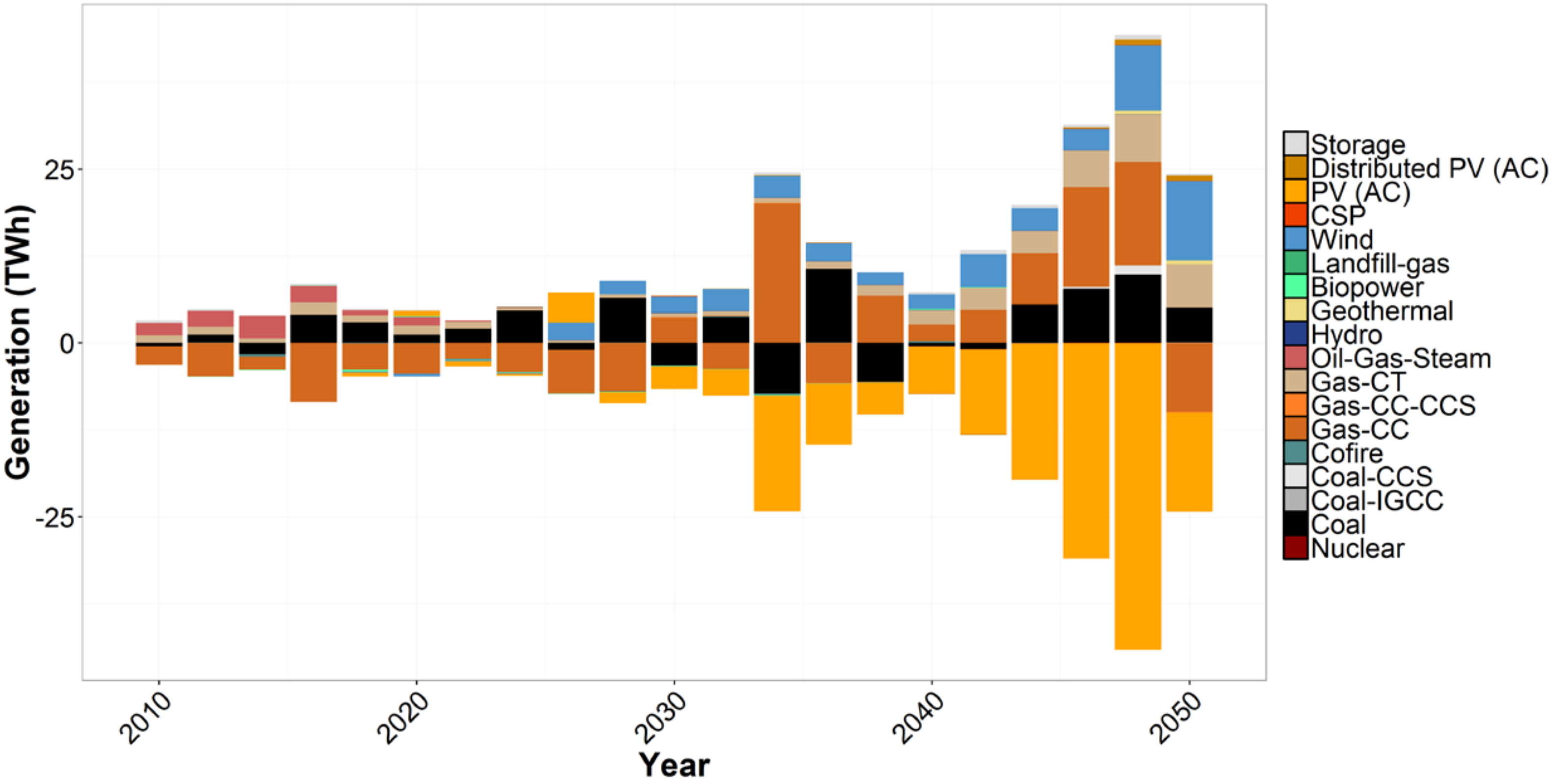
Capacity Difference – Mid-case

For context, the overall system has ~1000 GW of capacity



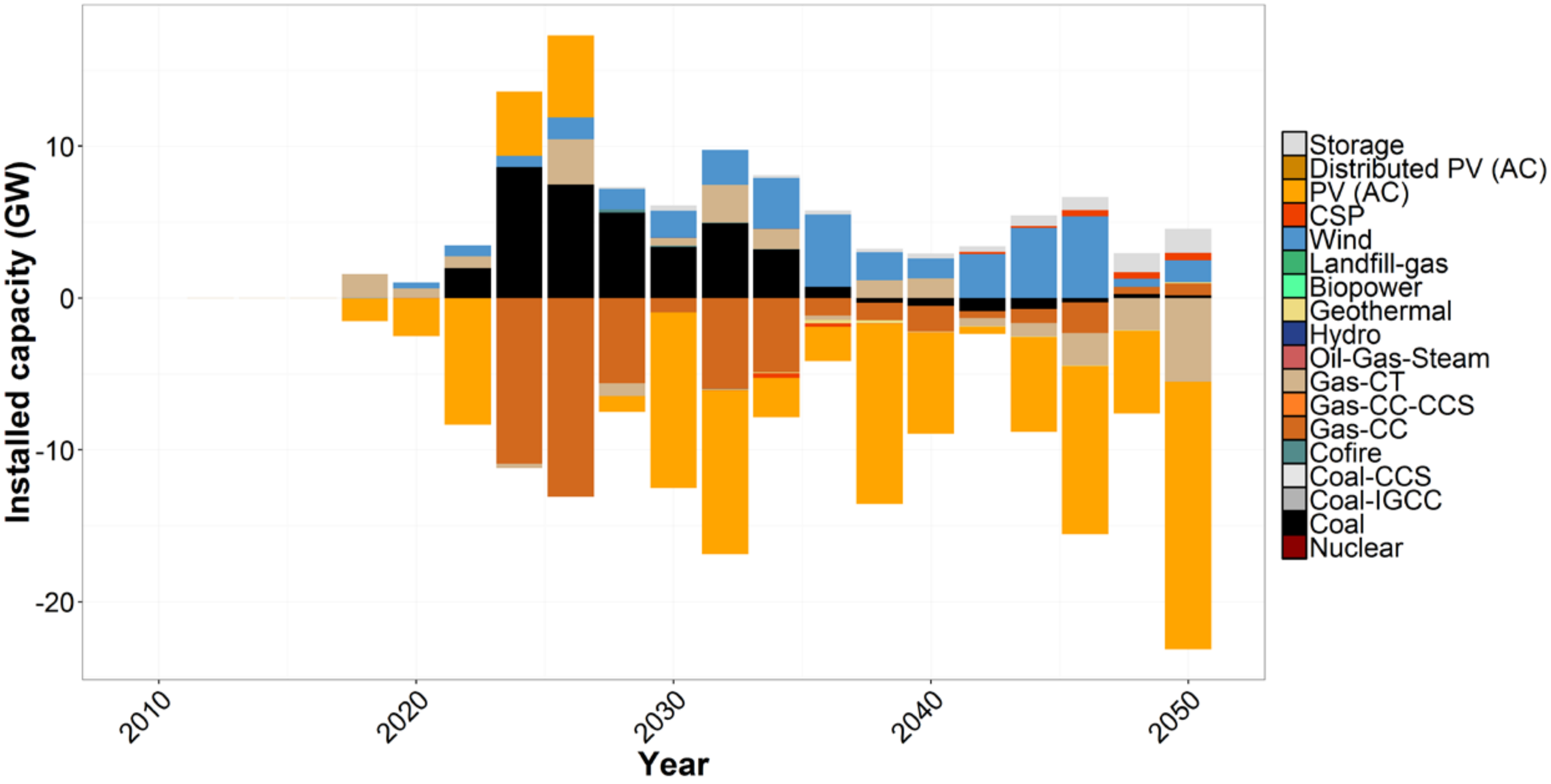
Generation Difference – Mid-case

For context, the overall system has a ~4000 TWh of generation



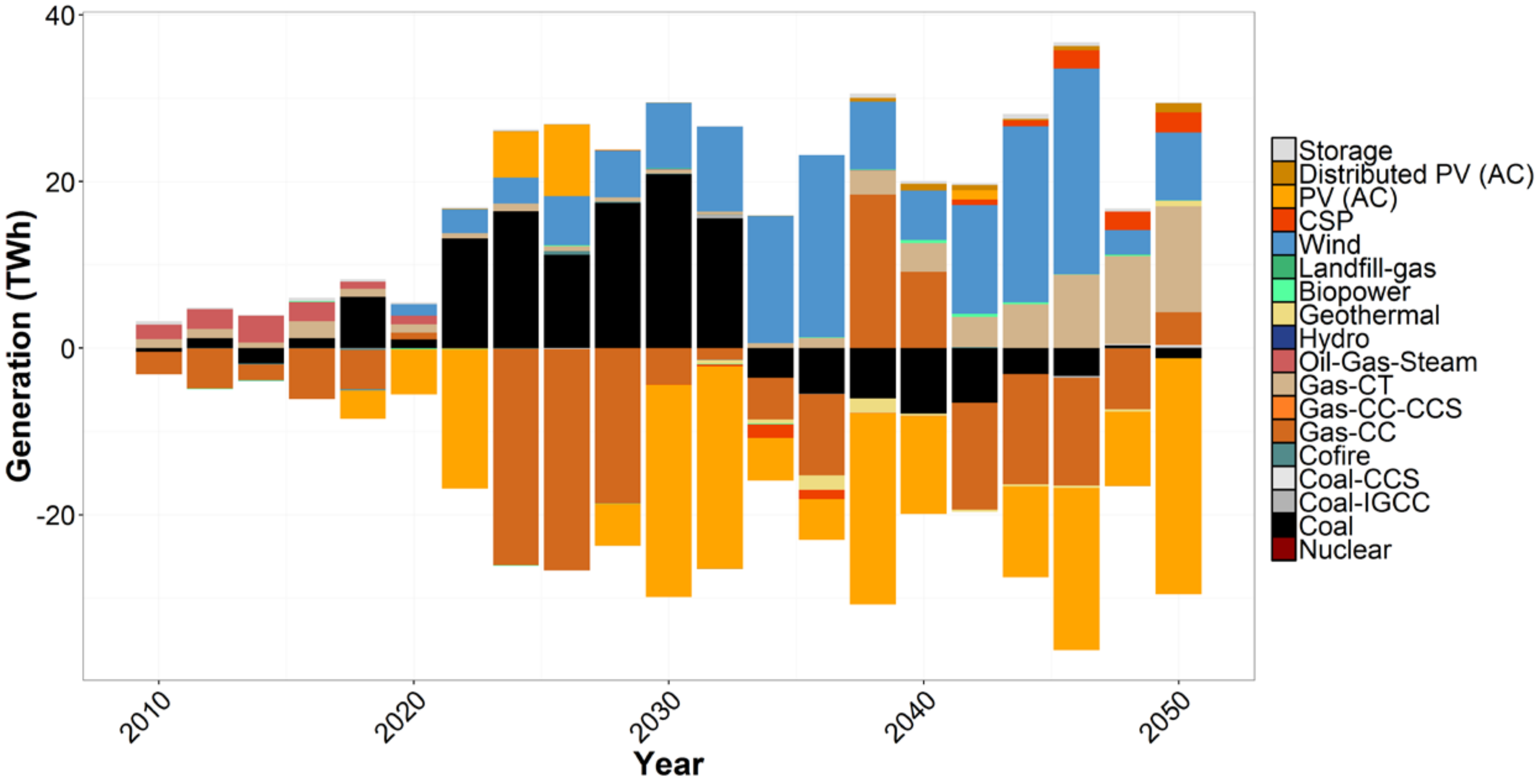
Capacity Difference – High RE

For context, the overall system has ~1000 GW of capacity

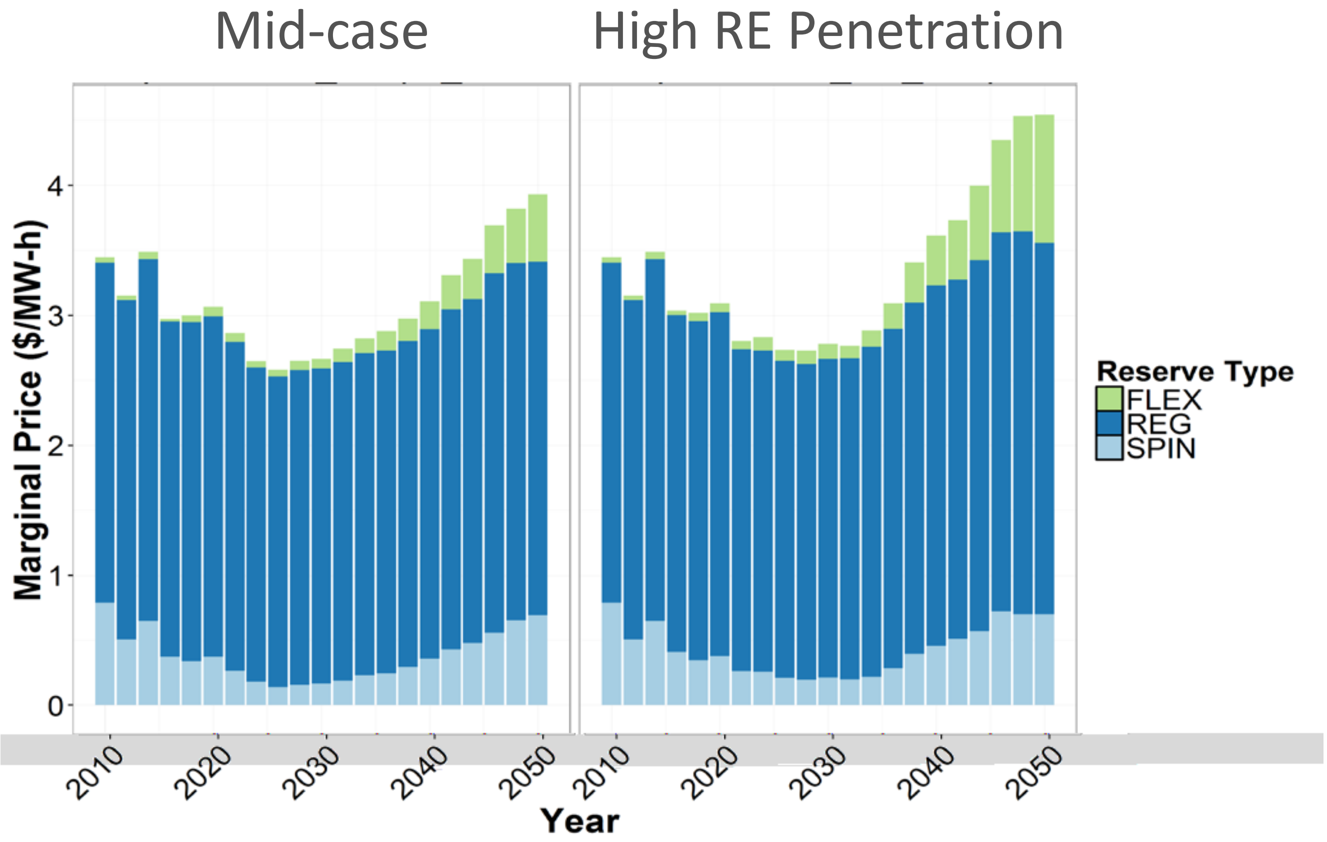


Generation Difference – High RE

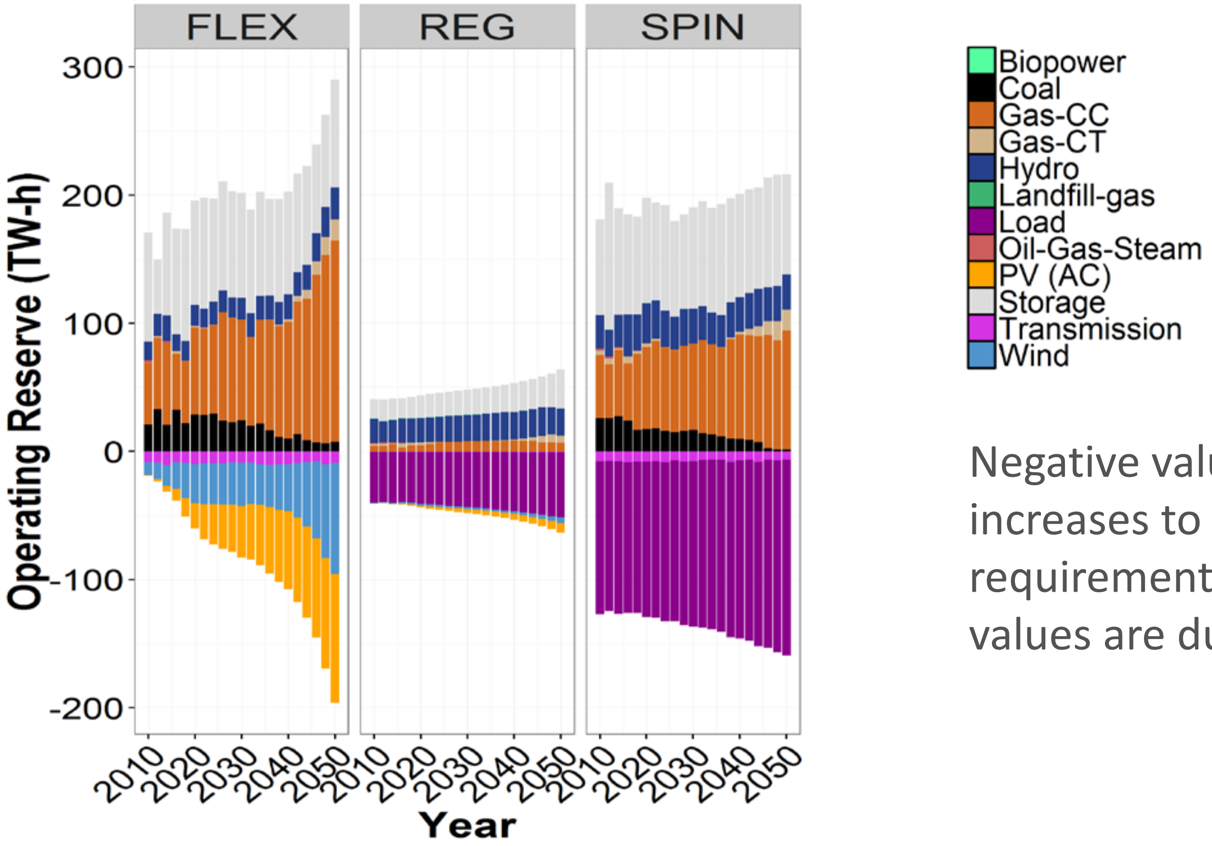
For context, the overall system has a ~4000 TWh of generation



Annual Average Marginal Prices for Operating Reserves

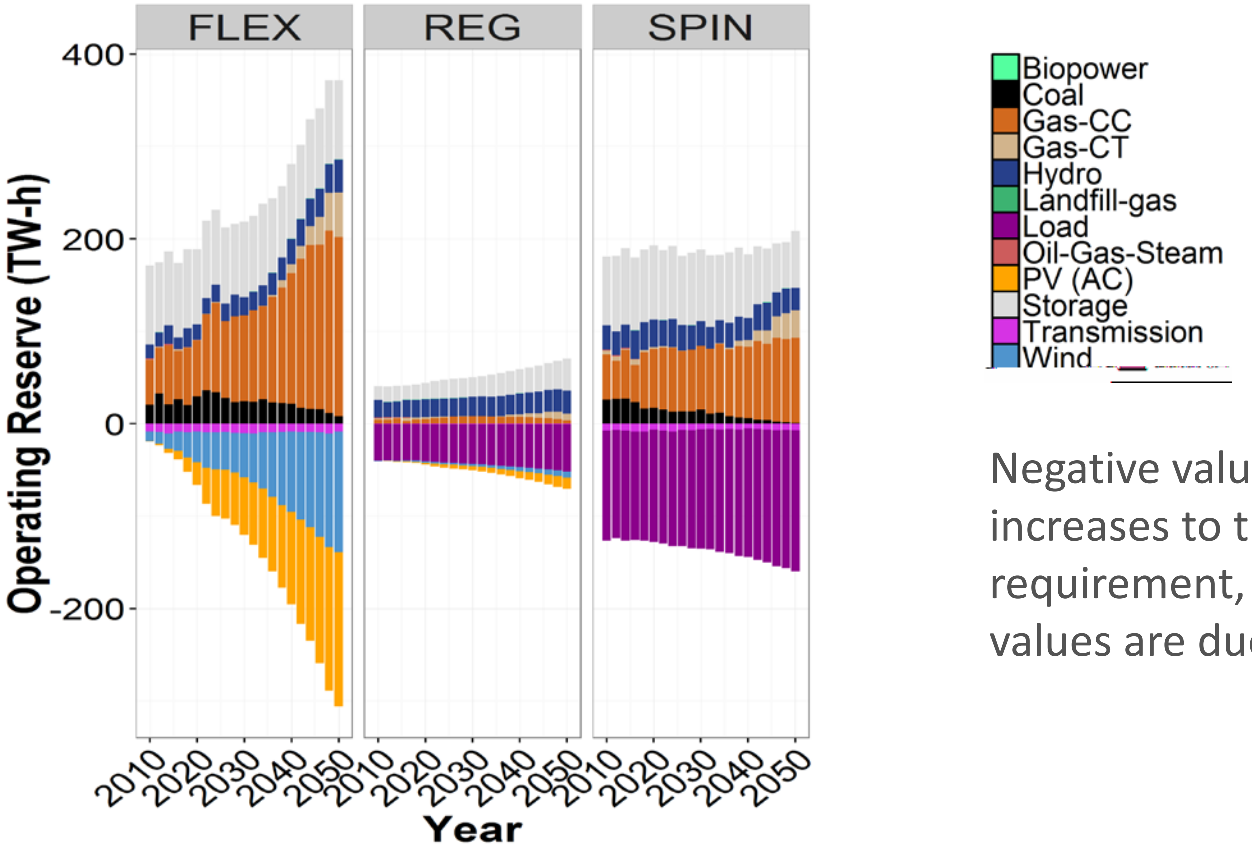


Operating Reserve Contributions: Mid-case



Negative values represent increases to the requirement, transmission values are due to losses

Operating Reserve Contributions: High RE Penetration



Negative values represent increases to the requirement, transmission values are due to losses

References

- Bloom, Aaron, Aaron Townsend, David Palchak, Joshua Novacheck, Jack King, Clayton Barrows, Eduardo Ibanez, et al. 2016. "Eastern Renewable Generation Integration Study." NREL/TP-6A20-64472. Golden, CO: National Renewable Energy Laboratory. https://doi.org/10.2172/1318192.
- Ela, E., M. Milligan, and B. Kirby. (2011). *Operating Reserves and Variable Generation: A Comprehensive Review of Current Strategies, Studies, and Fundamental Research on the Impact That Increased Penetration of Variable Renewable Generation Has on Power System Operating Reserves*. NREL/ TP-5500-51978. Golden, CO: National Renewable Energy Laboratory. www.nrel.gov/docs/fy11osti/51978.pdf.
- Hummon, M. R., P. Denholm, J. Jorgenson, D. Palchak, B. Kirby, O. Ma, and Washington U. S. Department of Energy. (2013). Fundamental Drivers of the Cost and Price of Operating Reserves. NREL/TP-6A20-58491. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy13osti/58491.pdf.
- Jorgenson, Jennie, Paul Denholm, Mark Mehos, and Craig Turchi. 2013. "Estimating the Performance and Economic Value of Multiple Concentrating Solar Power Technologies in a Production Cost Model." NREL/TP-6A20-58645. Golden, CO: National Renewable Energy Laboratory. https://doi.org/10.2172/1260920.
- Lew, Debbie, Greg Brinkman, Eduardo Ibanez, Anthony Florita, M. Heaney, Bri-Matthias Hodge, Marissa Hummon, et al. 2013. "The Western Wind and Solar Integration Study Phase 2." NREL/TP-5500-55588. Golden, CO: National Renewable Energy Laboratory. https://doi.org/10.2172/1095399.

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