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NEPOOL Participants Committee
Summer Meeting

What Pathways Have Others Chosen Or Are Considering

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Summary

Review and analysis of different policy and design choices of the electric power sector (EPS) outside of New England to explore the range of possibilities, their interactions, and implications to inform New England's Transition to the Future Grid project.

Context for Presentation

1. Deep decarbonization of EPS by 2050 and use of electricity for transportation and heating
2. Large geographical region with multiple jurisdictions encompassing multiple generation and transmission companies
3. Focus is on the bulk power system design given the trends in the industry

Deep Decarbonization: Summary of Some U.S. & International Practices

Public Engagement re: Transmission Siting	Planning	Markets & System Flexibility	Diverse Resources	System Operations
TX: 18.5 GW of wind integration with new transmission Germany: Priority to extra-HV transmission projects & shorter planning process CA: Established renewable energy generation and transmission siting steering committee	TX: Centralized planning and Competitive Renewable Energy Zones with risk borne by ratepayers Australia: National rather than regional development based upon market-based cost differentials	TX: Demand response for frequency regulation Australia: 5 min. dispatch and negative prices Denmark: CHP required to participate in the spot power market Germany: substantial incentives for energy storage	Ireland: regional expansion and major interconnection expansion U.S. West: energy imbalance market and reserve sharing	Australia: Market forecast model integrates forecasts from variety of sources Denmark: uses multiple forecasts Spain: Wind farms > 10 MW and solar > 2 MW provide reactive power & most wind farms have fault-ride through capability

Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience, Summary for Policymakers, Cochran et al, April 2012, https://www.nrel.gov/docs/fy12osti/53730.pdf

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Deep Decarbonization: Some U.S. & International Practices

Public Engagement re: Transmission Siting	Planning	Markets & System Flexibility	Diverse Resources	System Operations
TX: 18.5 GW of wind integration with new transmission Germany: Priority to extra-HV transmission projects & shortens planning process CA: Established renewable energy generation and transmission siting steering committee	TX: Centralized pl… Cc… Re… Zo… bc… rat… Au… rat… re… de… based upon market-based cost differentials	TX: Demand … spot power market Germany: substantial incentives for energy storage	Ireland: regional … y … t … ng	Australia: Market forecast model integrates forecasts from variety of sources Denmark: uses multiple forecasts used Spain: Wind farms > 10 MW and solar > 2 MW provide reactive power & most wind farms have fault-ride through capability

- Practices span planning and operations
- Multiple practices are used
- No single set of practices are common among regions

Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience, Summary for Policymakers, Cochran et al, April 2012, https://www.nrel.gov/docs/fy12osti/53730.pdf

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Analysis Set-up: Problems and Timeline

Cycles/Sec 5 minutes Day-ahead Months Years

Political Economy Problem

Decarbonization, Economic development Coalition building, Political ideology, Equity, Multiple Jurisdictions (Years)

Economic/ Regulatory Problem

Economic efficiency, Incentive alignment, Strategic behavior/rent seeking: asymmetric information, market power, externalities, and public goods (Minutes to Years)

Engineering Problem

Optimization

System Control	*Economic Dispatch*	*Unit Commitment*	*Operational Planning*	*Expansion Planning*

Cycles/Sec 5 minutes Day-ahead Months Years Time

Major Overall Findings

1. Each of the three types of problems: political economy, economic/regulatory, and engineering must be addressed
2. These three problems may be solved inconsistently or incompletely and compounded by multiple and overlapping jurisdictions
3. Unless they are addressed in an integrated and consistent manner, political, economic, and reliability difficulties are likely to occur
4. Decisionmakers pursue their own strategic objectives
5. Important tradeoffs exist between different approaches

Analysis Set-up: Decisionmakers

Political Economy Problem

U.S. Context: Federal & State Regulators
International: Individual countries, perhaps as part of a larger cross-national union

Economic/ Regulatory Problem

Federal Energy Regulators
State Energy Regulators
International and National Environmental Regulators
Federal & State Environmental Regulators
State Economic Development Agencies

Engineering Problem

Integrated utilities OR
Merchant generators, transmission companies, system operator

Cycles/Sec → 5 minutes → Day-ahead → Months → Years → Time

Analysis Set-up: Design Variables

Political Economy Problem

- Types of resources and their products
- Air emission regulation
- Cost-of-service, performance-based, market oriented
- Regional scale definition

Economic/ Regulatory Problem

- Extent of joint planning: generation and transmission
- Extent of joint operations by generation and load
- Extent of trading

Engineering Problem

- Product and service definitions
- Optimization period
- Cost-based or bid/offer-based
- Settlement/pricing mechanism

Cycles/Sec → 5 minutes → Day-ahead → Months → Years → Time

Presentation Organization, Part 1: Deep Decarbonization

Political Economy Problem

Decarbonization, Economic development Coalition building, Political ideology, Equity, Multiple jurisdictions

Economic/ Regulatory Problem

Economic efficiency, Incentive alignment, Strategic behavior/rent seeking: asymmetric information, market power, externalities, and public goods

Engineering Problem

Optimization

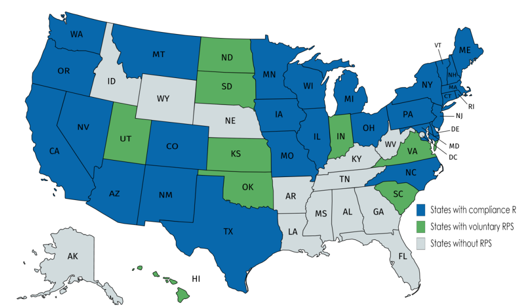
System Control	*Economic Dispatch*	*Unit Commitment*	*Operational Planning*	***Expansion Planning***	
Cycles/Sec	5 minutes	Day-ahead	Months	Years	Time

Deep Decarbonization: High-level Considerations

Political and Policy Objectives	Policy Development	Policy Options
Decarbonization & environmental co-benefits Economic development within a particular jurisdiction Political success	Political negotiation Legislative non-integrated resource planning Integrated resource planning	Ban/restrict fossil fuels Clean energy subsidies Feed-in tariffs Power Purchase Agreements Renewable portfolio standards Pricing greenhouse gases

Deep Decarbonization: Examples

Means	Some Examples
Ban/restrict fossil fuels	Countries in Europe and Asia banning fossil fueled cars; U.S. restrictions on air permits, pipeline developments
Clean energy subsidies	Many U.S. states both historically and currently; energy efficiency is a major example
Feed-in tariffs	Many European Countries, e.g., Germany
Power Purchase Agreements	Ubiquitous
Renewable portfolio standards	29 U.S. states and DC Multiple countries in Asia
Pricing greenhouse gases	Europe (economy wide), CA (economy wide), RGGI



Deep Decarbonization: Policy Supports, Asia

Asia and Pacific	Regulatory support				Economic support						
Country	Renewable energy law	Targets	Quotas/RPS	Auction schemes	Tradable green certificates	FIT/Feed-in premium	Capital grants and subsidies	Soft loans	Tax relief	Net metering	Carbon pricing
Australia	✔	●		■ ✓	✔	●	✔				✔
Bangladesh		✔		✔					✔		
India		✔✓	✔✓	✔✓	✔	✔	✓	✓	✔●	✔✓	✔
Indonesia		✔		●		●			✔		
Japan		●		■		●	✔		✔	✔	
Korea		✔	✔		✔	✓			✔		
Lao PDR*[1]		✔							✔		
Malaysia	✔	✔		●		●		✔	✔		
Mongolia	●	✔									
Myanmar		■							✔		
New Zealand		✔									✔
Pakistan		✔				●				⓪	
Philippines	✔	✔	⓪			●			✔	✔	
Singapore		✔					✔		✔		
Thailand		●		■		●	✔		✔		
Viet Nam		●				■		✔	✔		

Notes: ✔ = national-level policy; ✓ = state/provincial-level policy, ● = to be phased out/updated, or closed to new applicants, ⓪ = recently introduced; ■ – under review. For further information, refer to IEA/IRENA Policies and Measures Database for Renewable Energy: www.iea.org/policiesandmeasures/renewableenergy.

IEA Medium-Term Renewable Energy Market Report 2016, p. 267
https://webstore.iea.org/download/direct/424

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Deep Decarbonization: Policy Supports, Europe

Europe	Regulatory support				Economic support						
Country	Renewable energy law	Targets	Quotas/RPS	Auction schemes	Tradable green certificates	FIT/Feed-in premium	Capital grants and subsidies	Soft loans	Tax relief	Net metering	Carbon pricing
Austria	✔	✔				✔	✔		✔		
Belgium		✔	✔✓		✔✓		✔✓			✓	
Denmark	✔	✔	✔	•		✔	✔	✔	✔	✔	
Estonia		✔		⓪		•	✔		✔		
Finland	✔	✔				• ▶	✔				
France	✔	•		⓪		⓪	✔	✔	✔		
Germany	•	✔		⓪		•	•	•	✔		
Greece	■	✔		■		■	✔		✔	✔	
Hungary		✔		⓪		•	✔				
Ireland		✔				■			✔		
Italy	✔	✔		•		✔			✔	✔	
Netherlands		✔		⓪		•		✔	✔	✔	
Norway		•	▶		▶		✔				✔
Poland	⓪	✔	▶	⓪ •	▶		•			⓪	
Portugal		✔									
Slovak Republic	✔	✔				✔	✔		✔		
Slovenia		✔				✔	✔	✔		⓪	
Spain		✔		⓪							
Sweden		✔	✔		✔		✔		✔		✔
Switzerland		✔				✔	✔				
Turkey	✔	✔				•					
United Kingdom		✔	▶	•	▶	■		✔	✔		✔

IEA Medium-Term Renewable Energy Market Report 2016, p. 268
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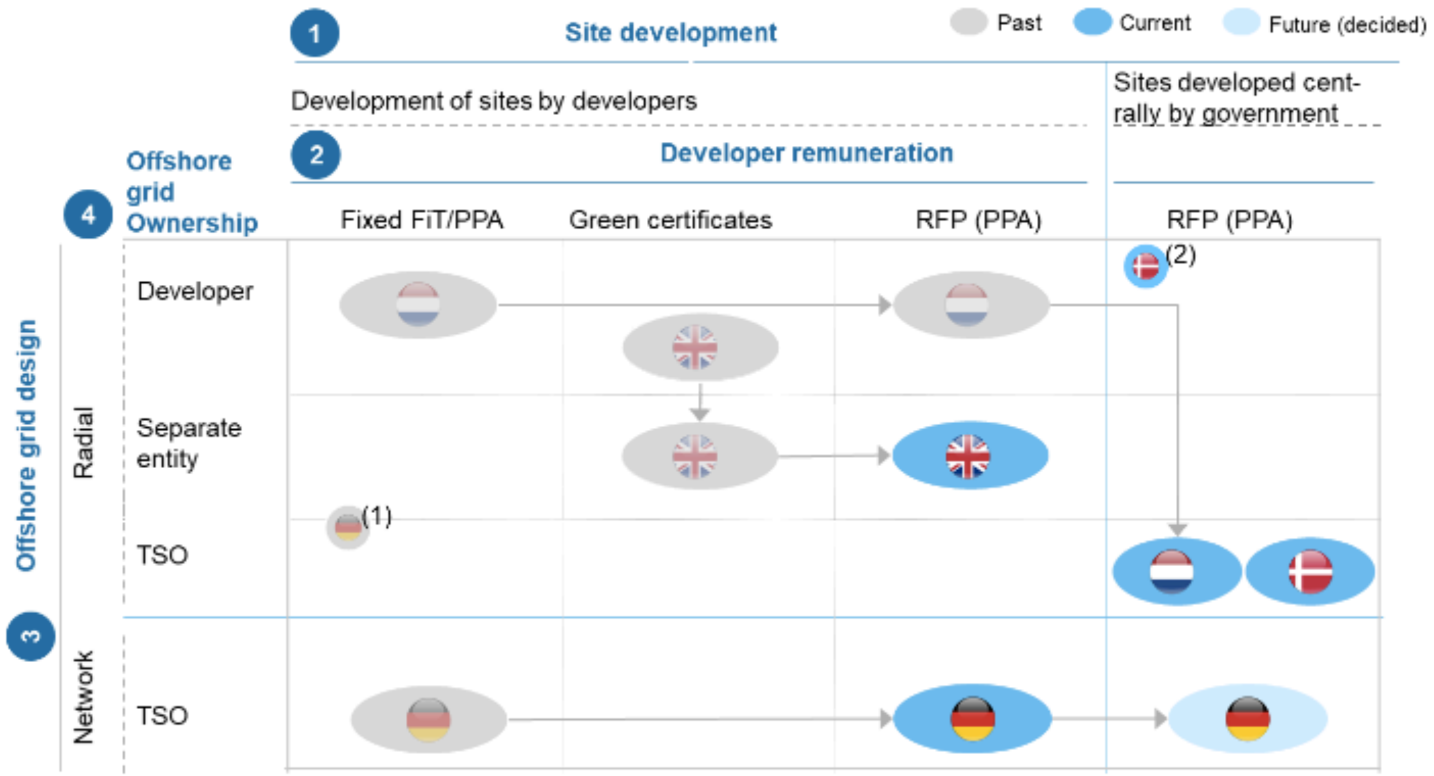
Offshore Wind: Investment Instruments



1 Some parks in the North and Baltic Sea connected point-to-point such as Alpha Ventus, Riffgat, EnBW Baltic 1/2, Nordergründe 2 Nearshore projects

Source: Energinet; TenneT; National Grid; International Energy Agency

Exhibit 6: *Evolution of OSW support models in Europe*

NYPA, Offshore Wind A European Perspective, Aug. 2019
https://www.nypa.gov/-/media/nypa/documents/document-library/news/offshore-wind.pdf

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Deep Decarbonization: Assessment of Policy Options

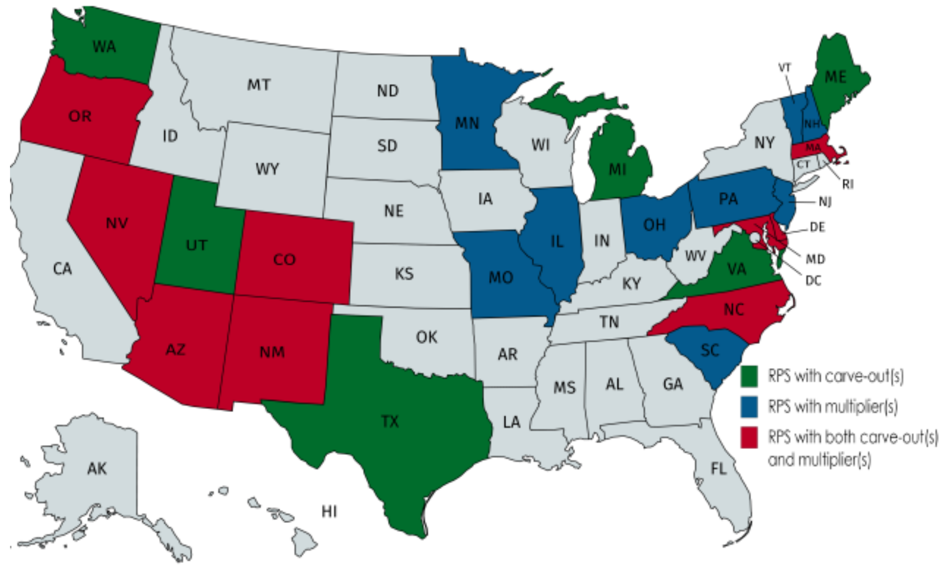
Means	Economic & Regulatory	Political Economy
Ban/restrict fossil fuels	Puts infinite price on fossil fuel externalities	Does not generate revenue or visibly contribute to economic development
Clean energy subsidies Feed-in tariffs	Due to information asymmetry, difficulty to set amount of subsidies Requires technology and project selection process Financial risk borne by ratepayers	Direct subsidies may quickly become too large to be politically supportable Can be tailored to further economic development goals
Renewable portfolio standards	If market-based, shifts risks to developers Selection of RPS may not be efficient Nascent & fractured markets: opaque & volatile pricing	
Pricing greenhouse gases	Efficient Financial risks borne by developers	Considered less politically viable Economic development disconnect Technically neutral; not know what investments will be made Raises revenue

Deep Decarbonization: RPS and Generation Investment

Many States have RPS carve-outs and multipliers

Many types of xRECs:
RECs, SRECs, ORECs, ZECs

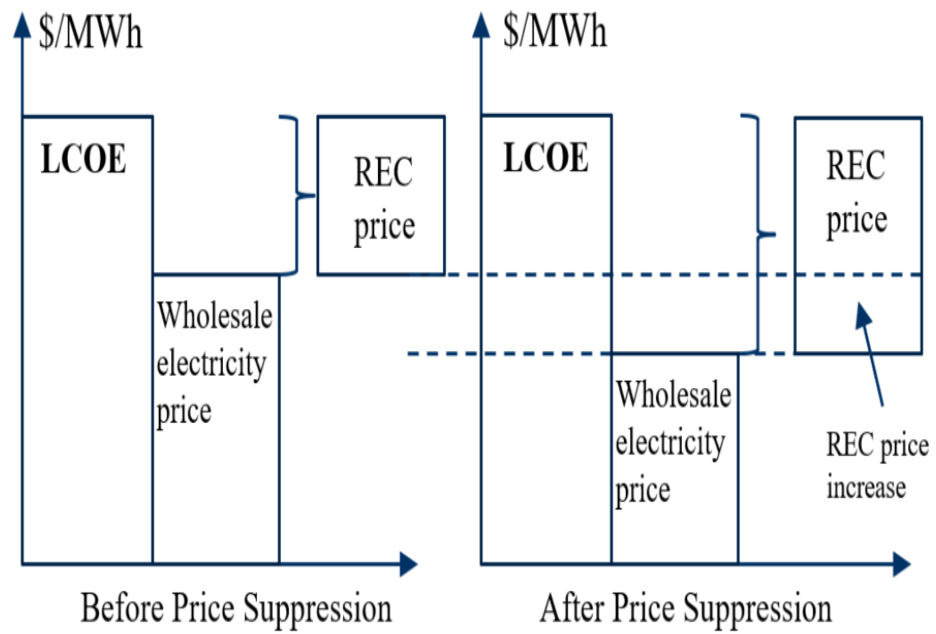
⇒ Partial explanation of these variations is states having different strategic goals



Note: RPS directly provide MWh, not inertia, regulation, ramping, or operating reserves

Deep Decarbonization: Out of Wholesale Electricity Market Payments

- Revenue stream of renewable energy generators comes from wholesale and REC markets
- Out of market payments not unique to RPS or nuclear resources
- Cost of RECs/ZECs amortized over all retail kWh
- Out of wholesale market payments suppress wholesale prices
- Multiple market failures

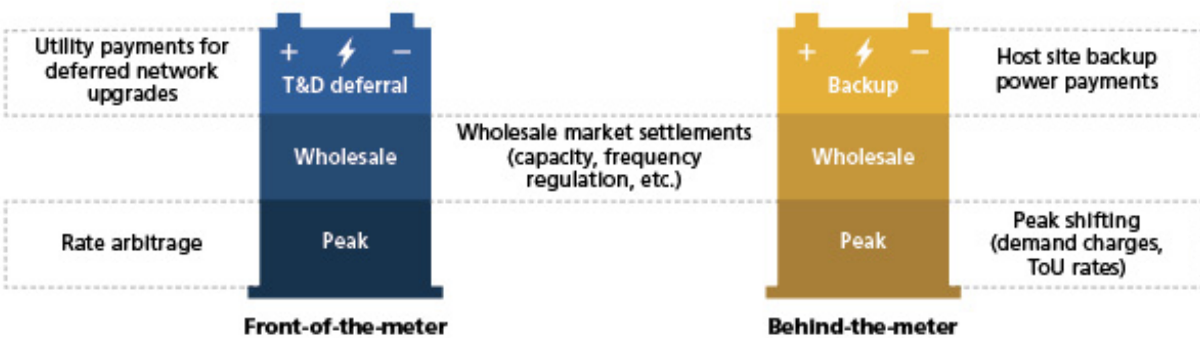


Deep Decarbonization: Generation and Transmission (and distribution)

Three important examples:

- Offshore wind: radial vs. backbone
- Energy storage
- Major regional and sub-national interconnections

Figure 4. Locations of U.S. Atlantic Coast offshore wind pipeline activity and Call Areas as of March 2019. *Map provided by NREL*



Smart Grid Solutions, https://www.renewableenergyworld.com/2018/02/13/unpacking-the-value-stack-the-challenge-facing-the-energy-storage-industry/#gref

Deep Decarbonization: Transmission Planning Options

Political and Policy Objectives	Policy Development	Policy Options
Federal/Regional Objectives: Reliability Economic efficiency State Objectives: Integrate renewables Lower electricity rates Shifting costs to another jurisdiction	Political negotiation Planning by transmission owners Planning by system operator	Integrated generation and transmission planning vs. sequential generation investment and transmission planning Types of transmission planning investments: • Public policy • Reliability • Economic Addressing uncertainty in transmission planning Cost allocation

Deep Decarbonization Investment: Examples of Three Major Tradeoffs

1. Long-term financing methods (e.g., cost-of-service regulation or long-term contracts) may reduce cost of capital but allocate risk to ratepayers

2. Wholesale markets shift risks to suppliers and may lower generation costs but may increase the costs of sequential generation and transmission planning

3. Commitments to long-term supply arrangements may address political economy objectives but restrict the ability to address operational requirements

BREAK FOR QUESTIONS AND COMMENTS

Presentation Organization, Part 2: Balancing Supply and Demand

Political Economy Problem

Decarbonization, Economic development Coalition building, Political ideology, Equity, Multiple jurisdictions

Economic/ Regulatory Problem

Economic efficiency, Incentive alignment, Strategic behavior/rent seeking: asymmetric information, market power, externalities, and public goods

Engineering Problem

Optimization

System Control — ***Economic Dispatch*** — ***Unit Commitment*** — ***Operational Planning*** — *Expansion Planning*

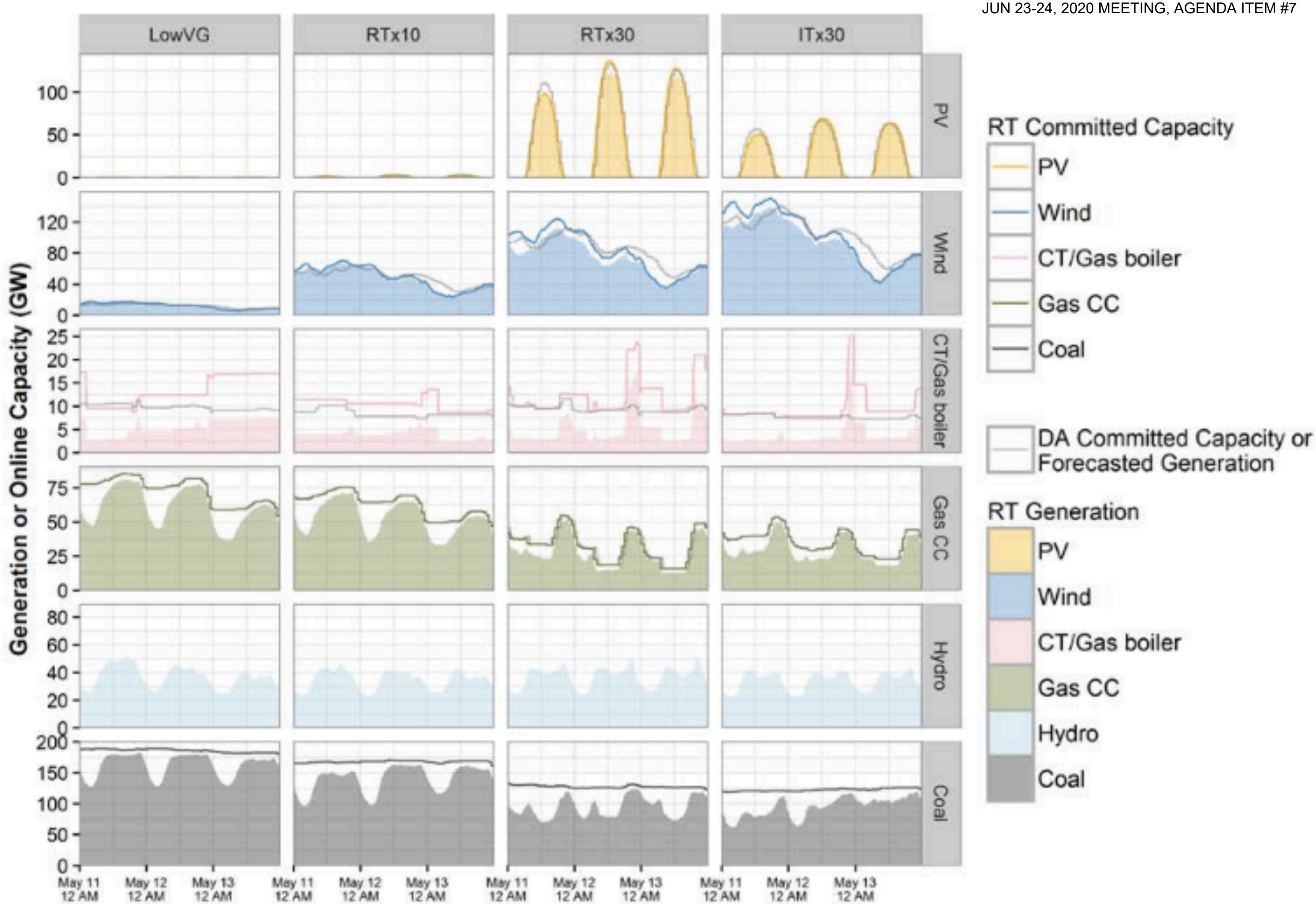
Cycles/Sec → 5 minutes → Day-ahead → Months → Years → Time

Generation Dispatch with Increasing Variable Energy Resources

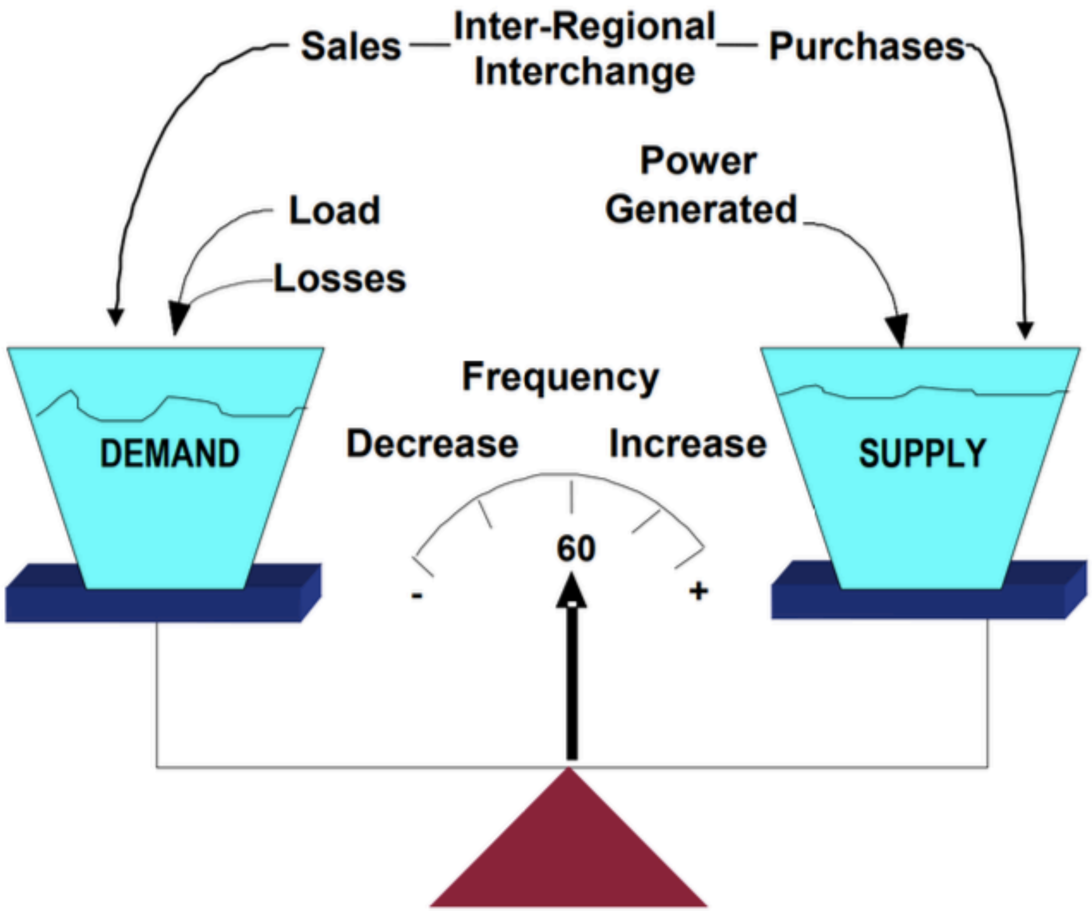
Table ES-1. ERGIS Includes Four Scenarios with Different Levels of Wind, PV, and Transmission Capacity Expansion

Scenario	Wind	PV	Total[a]	Attributes
LowVG	3%	0%	3%	• No new wind or PV generation installations after the year 2012. • Minimal transmission expansion.
RTx10 (Regional Transmission and ~10% VG)	12%	0.25 %	12%	• An approximately 10% VG penetration as reflected in state RPS and interconnection queues as of 2012.[b] • Intra-regional transmission expansion.
RTx30 (Regional Transmission and 30% VG)	20%	10%	30%	• Approximately 30% combined VG, with an emphasis on within-region wind and PV resources. • Identical transmission expansion to RTx10.
ITx30 (Inter-regional transmission and 30% VG)	25%	5%	30%	• Approximately 30% combined VG, with an emphasis on the best wind and PV resources in the U.S. EI. • Interregional transmission expansion with 6 large high-voltage direct current (HVDC) lines.

This slide and the next from NREL Eastern Renewable Generation Integration Study, 2016
https://www.nrel.gov/docs/fy16osti/64472-ES.pdf

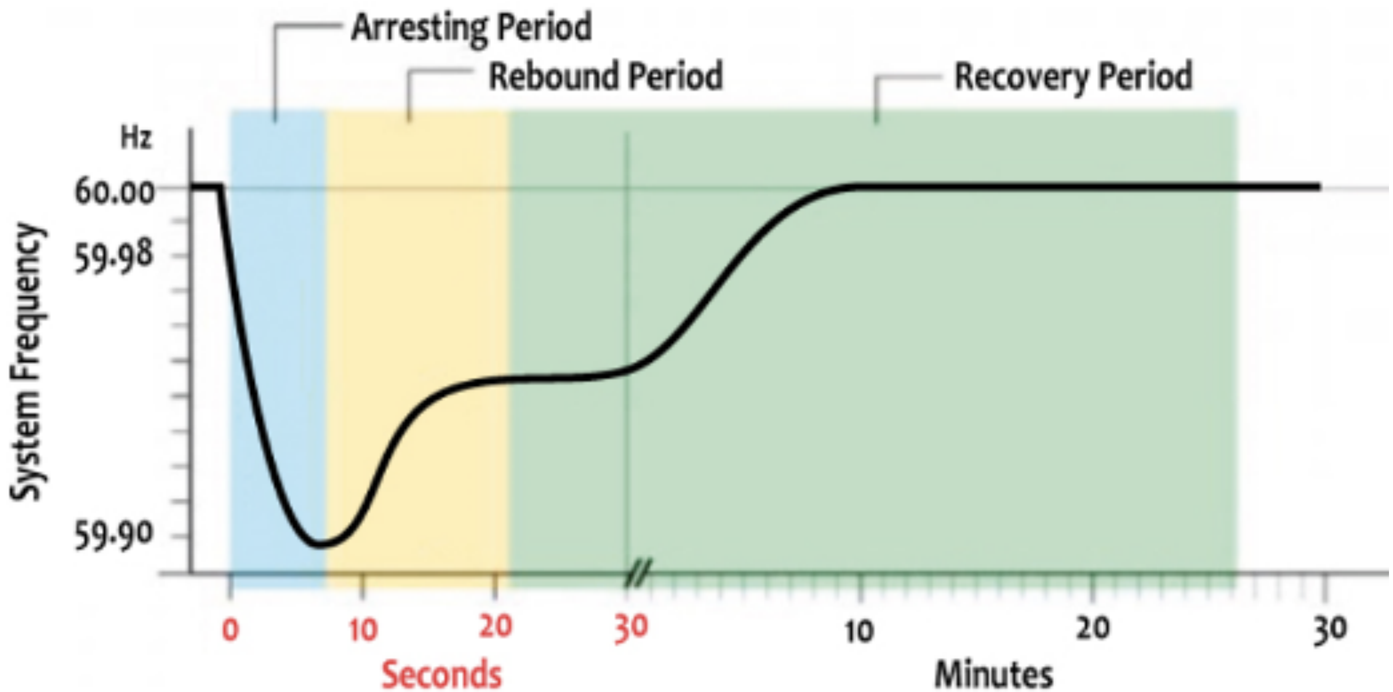

LowVG
RTx10
RTx30
ITx30
PV
Wind
CT/Gas boiler
Gas CC
Hydro
Coal
Generation or Online Capacity (GW)
May 11 12 AM
May 12 12 AM
May 13 12 AM
RT Committed Capacity
PV
Wind
CT/Gas boiler
Gas CC
Coal
DA Committed Capacity or Forecasted Generation
RT Generation
PV
Wind
CT/Gas boiler
Gas CC
Hydro
Coal

System Control: Normal Operations



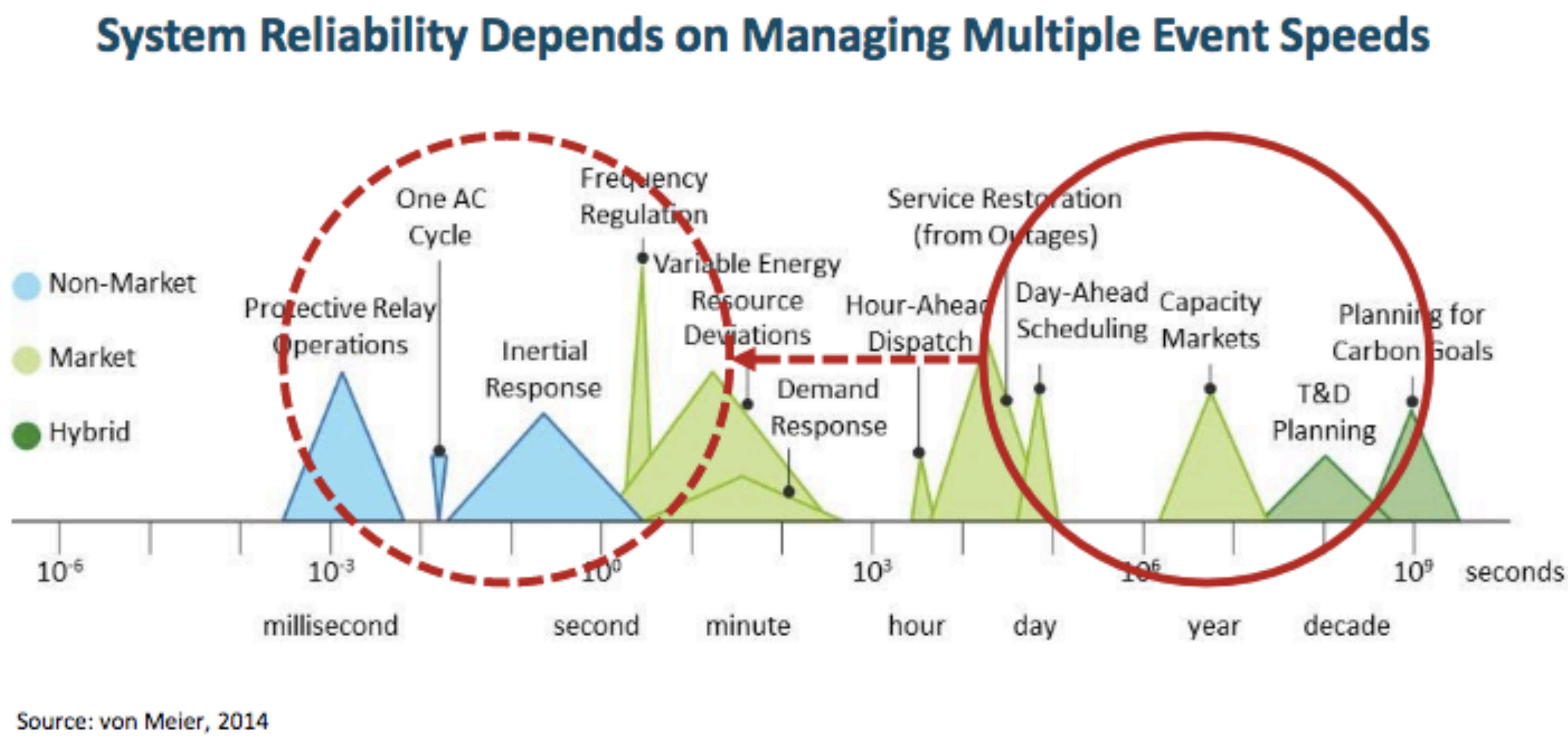
Source: NERC *Balancing & Frequency Control*, January 2011

System Control: Contingency



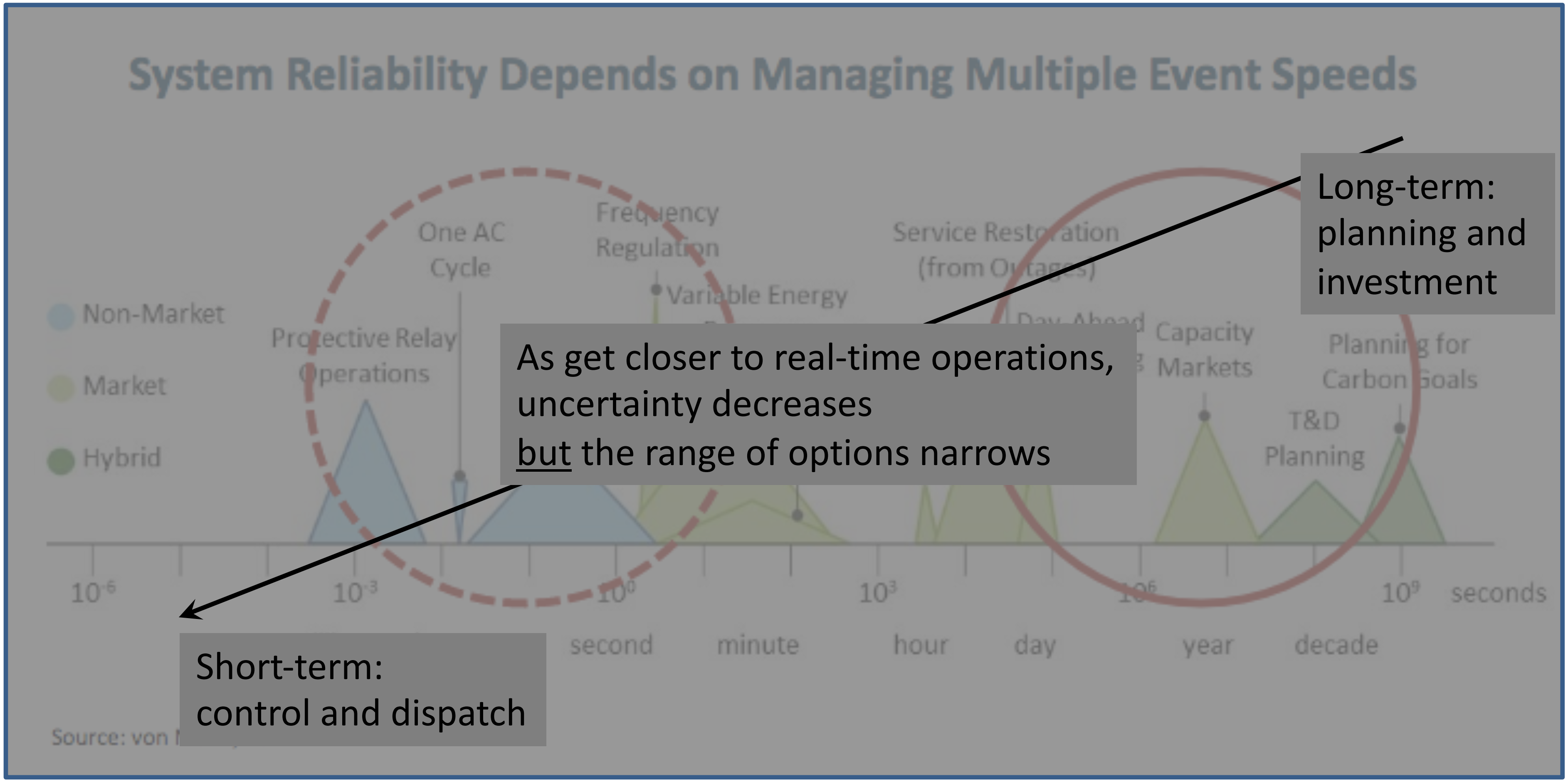
Source: http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERS%20Abstract%20Report%20Final.pdf

System Control: Occurs Over Entire Timeline



http://energyoutlook.naseo.org/Data/Sites/13/media/presentations/Battershell--QER-1.2-Briefin.PDF

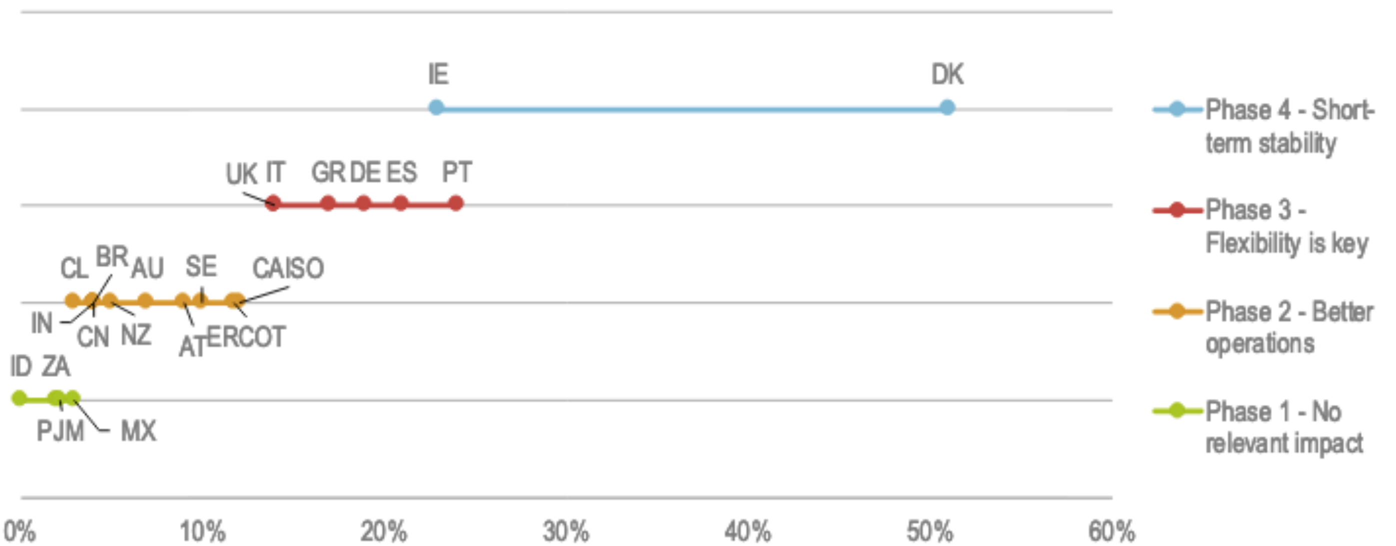
System Control: Relationship between Available Options and Uncertainty



http://energyoutlook.naseo.org/Data/Sites/13/media/presentations/Battershell--QER-1.2-Briefin.PDF

System Control: International Share of Variable Generation

Figure 3.2 • Annual VRE share of generation in selected countries and corresponding VRE phase, 2015



Notes: AT = Austria; AU = Australia; BR = Brazil; CL = Chile; CN = China; DE = Germany; DK = Denmark; ES = Spain; GR = Greece; ID = Indonesia; IE = Ireland; IN = India; IT = Italy; MX = Mexico; NZ = New Zealand; PT = Portugal; SE = Sweden; UK = the United Kingdom; ZA = South Africa. PJM, CAISO and ERCOT are US energy markets.

Source: Adapted from IEA (2016a), *Medium-Term Renewable Energy Market Report 2016*.

Key point • Each phase can span a wide range of VRE share of generation; there is no single point at which a new phase is entered.

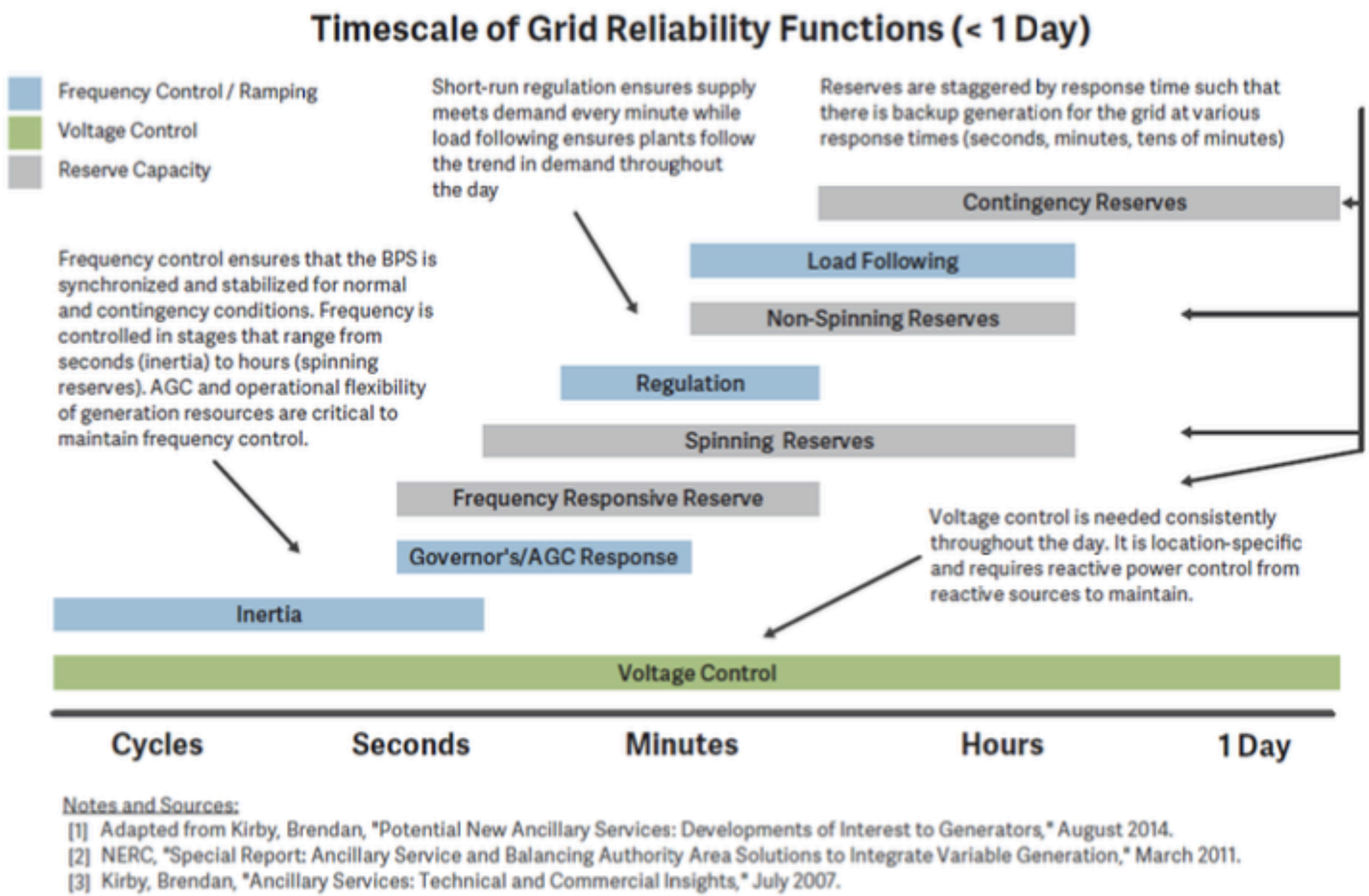
International Energy Agency, 2017, Status of Power System Transformation 2017: System Integration and Local Grids, p. 37, https://webstore.iea.org/download/direct/298

See Kroposki et al, Achieving a 100% Renewable Grid, IEEE Power & Energy Magazine, March/April 2017, http://ipu.msu.edu/wp-content/uploads/2018/01/IEEE-Achieving-a-100-Renewable-Grid-2017.pdf for non-technical discussion of technical issues related to operating a 100% variable energy power system.

Findings: Ancillary Services

1. Ancillary service prices are volatile
2. Ancillary service costs are currently small total of wholesale costs but their share of costs is increasing
3. No consensus exists for the types and definitions of ancillary services
4. Ancillary services become more important as the percentage of renewable energy increases
5. The types of ancillary services are likely to increase and change with increasing variable energy resources
6. Renewable resources can provide many ancillary services
7. Some ancillary services are substitutes with other ancillary services
8. Co-optimization and opportunity cost pricing become more important with increasing variable energy resources

Balancing Supply and Demand: Ancillary Services (U.S. & International)



Source: Analysis Group, *Advancing Past "Baseload" to a Flexible Grid*, June 2017

From Electricity Ancillary Services Primer, Reishus Consulting, August 2017
http://nescoe.com/wp-content/uploads/2017/11/AnxSvcPrimer_Sep2017.pdf

System Control: U.S. Regulation Prices

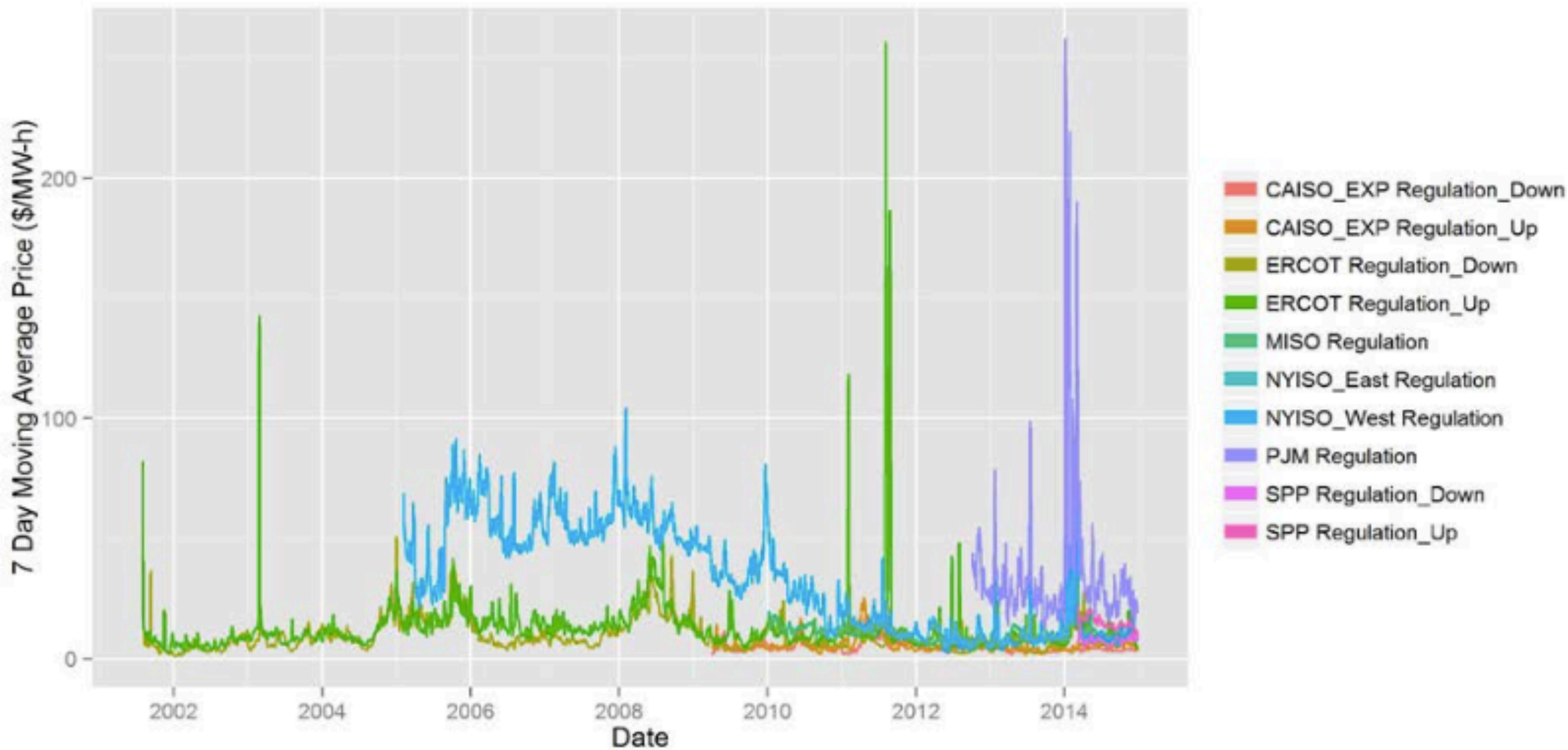


Figure 9-1 Seven-day moving average prices in each Regulation Reserves market

Argonne National Laboratory, Survey of U.S. Ancillary Services Markets, Jan. 2016
https://publications.anl.gov/anlpubs/2016/01/124217.pdf

System Control:
U.S. Reserve Prices

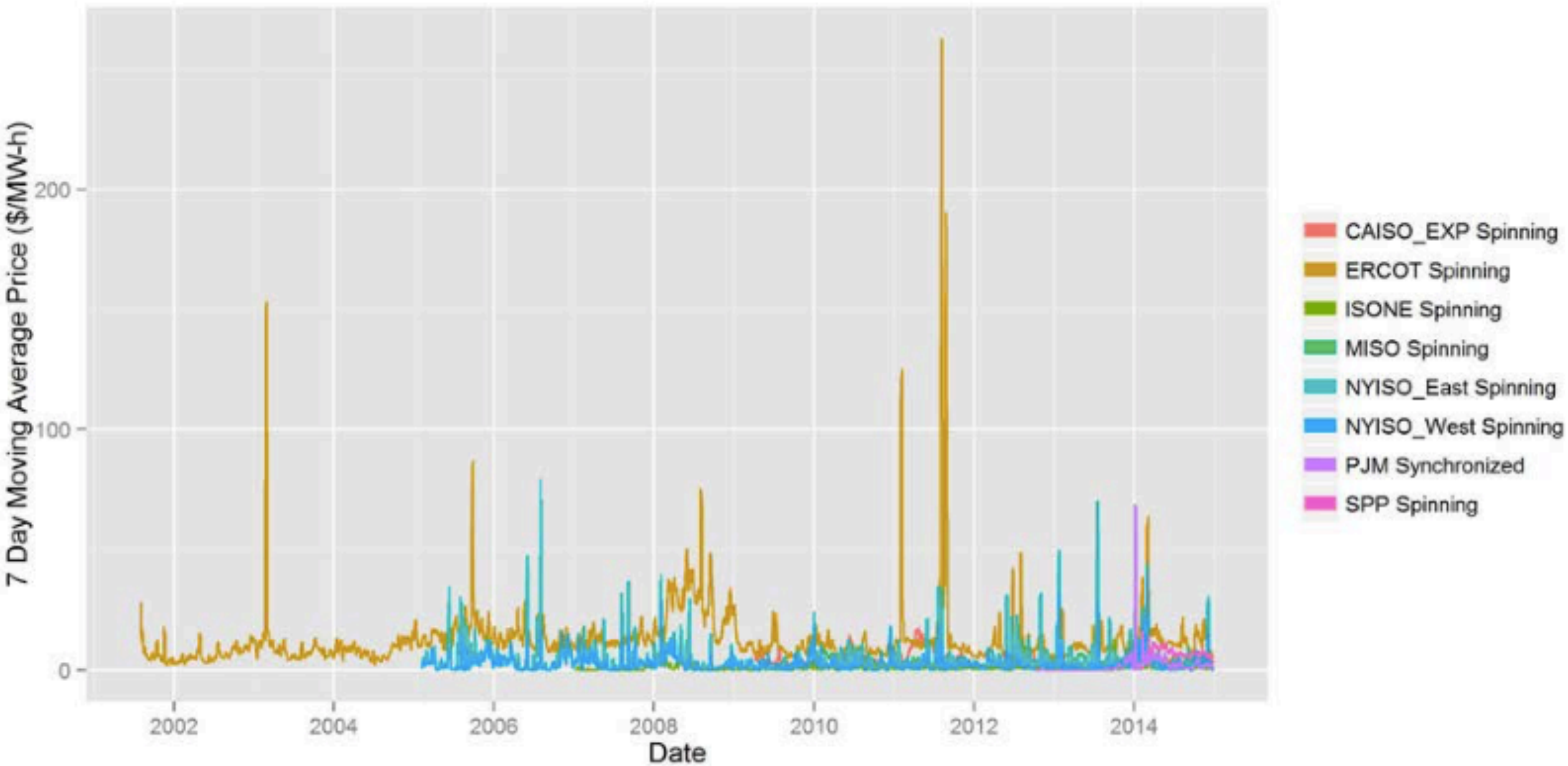


Figure 9-5 Seven-day moving average prices in each Spinning Reserves market

Argonne National Laboratory, Survey of U.S. Ancillary Services Markets, Jan. 2016
https://publications.anl.gov/anlpubs/2016/01/124217.pdf

Balancing Supply and Demand: Different Resources Provide Different Capabilities

● = Exhibits Attribute
◓ = Partially Exhibits Attribute
○ = Does Not Exhibit Attribute

Resource Type	Essential Reliability Services (Frequency, Voltage, Ramp Capability): Frequency Response (Inertia & Primary)	Voltage Control	Ramp: Regulation	Ramp: Contingency Reserve	Ramp: Load Following	Fuel Assurance: Not Fuel Limited (> 72 hours at Eco. Max Output)	On-site Fuel Inventory	Flexibility: Cycle	Short Min. Run Time (< 2 hrs.)/ Multiple Starts Per Day	Startup/ Notification Time < 30 Minutes	Other: Black Start Capable	No Environmental Restrictions (That Would Limit Run Hours)	Equivalent Availability Factor
Hydro	●	●	●	●	●	○	◓	●	●	●	●	◓	●
Natural Gas - Combustion Turbine	●	●	◓	●	◓	●	○	●	●	●	●	◓	◓
Oil -Steam	●	●	●	●	●	●	●	●	○	○	○	○	◓
Coal - Steam	●	●	●	●	●	●	●	◓	○	○	○	◓	◓
Natural Gas - Steam	●	●	●	●	●	●	○	●	○	○	●	◓	◓
Oil/ Diesel - Combustion Turbine	●	●	○	●	○	○	●	●	●	●	●	○	◓
Nuclear	◓	●	○	○	◓	●	●	○	○	○	○	◓	●
Battery/ Storage	◓	◓	●	●	○	○	○	●	●	●	◓	●	●
Demand Response	○	○	◓	◓	◓	◓	◓	●	●	◓	○	●	●
Solar	◓	◓	○	○	◓	○	○	●	●	●	○	●	●
Wind	◓	◓	○	○	◓	○	○	●	●	●	○	◓	●

From Electricity Ancillary Services Primer, Reishus Consulting, August 2017 citing PJM Evolving Resource Mix and System Reliability, 2017
http://nescoe.com/wp-content/uploads/2017/11/AnxSvcPrimer_Sep2017.pdf

Balancing Supply and Demand: High-level Considerations

Political and Policy Objectives	Policy Development	Policy Options	
Reliability Efficient grid operations Rapid deployment of renewable resources	Political negotiation with stakeholders (including system operator) Governance of system operator	Resource adequacy policy (prices or quantities) Operational planning Security constrained unit commitment Security constrained economic dispatch Ancillary services	Co-Optimization and Opportunity Cost Pricing (applies to: Security constrained unit commitment, Security constrained economic dispatch, Ancillary services)

Balancing Supply and Demand: International Examples

Means	Description
Flexible resources	Need sufficient incentives or regulatory approaches to ensure sufficient flexible are available when needed
Grid codes	Requirements for performance standards; needs to be enforced and resources tested for compliance
Demand response	Real-time demand response requires proper metering and information systems
Unit commitment/scheduling intervals	Include variable energy resources forecasting in unit commitment; submission of schedules closer to real-time; seamless integration of Supervisory Control and Data Acquisition (SCADA) and Energy Management System (EMS) systems

Operating and Planning Electricity Grids with Variable Renewable Generation, Madrigal and Porter, World Bank, 2013
https://openknowledge.worldbank.org/bitstream/handle/10986/13103/757310PUB0EPI0001300pubdate02023013.pdf?sequence=1&isAllowed=y

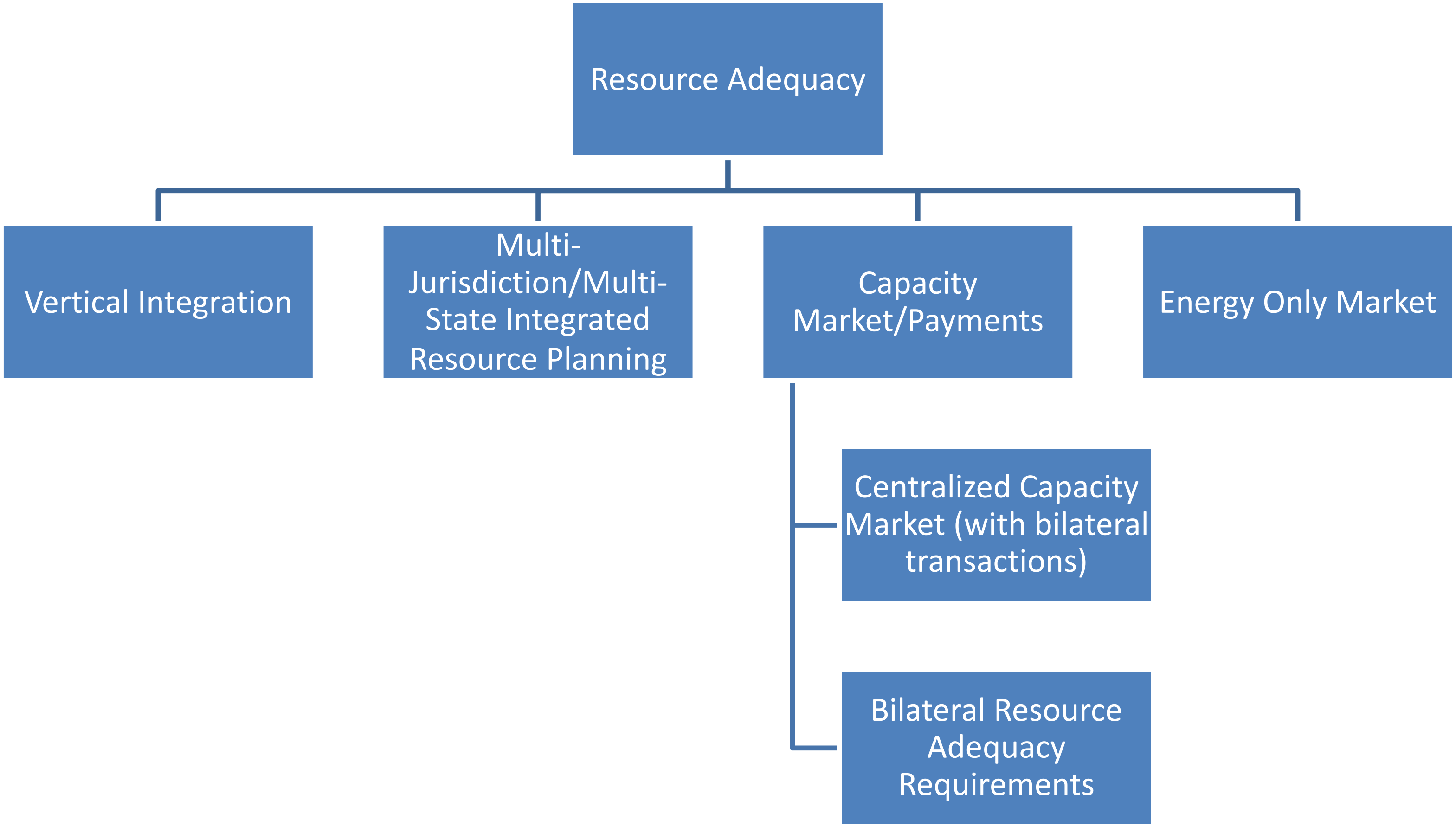
Based upon detailed case studies of China, Germany & Spain

Balancing Supply and Demand: International Examples, con't

Means	Description
Transmission planning for renewables	Proper planning and cost allocation needed so that the best combination of transmission and renewables are developed first
Improved planning practices for transmission and supply adequacy	Development of cost-effective solutions and probabilistic planning analyses and criteria
Renewable energy curtailments	Proper definition of the rules and conditions under which variable energy resources will be curtailed as part of the grid code; renewable energy contracts need to be designed to account for curtailments and payment implications
Advances in variable energy resources	Track and incorporate technological advances that variable energy resources can provide ancillary services

Operating and Planning Electricity Grids with Variable Renewable Generation, Madrigal and Porter, World Bank, 2013
https://openknowledge.worldbank.org/bitstream/handle/10986/13103/757310PUB0EPI0001300pubdate02023013.pdf?sequence=1&isAllowed=y

Balancing Supply and Demand: Resource Adequacy



From Capacity Markets at a Crossroads, Bushnell, Flagg & Mansur, April 2017, with modifications
https://hepg.hks.harvard.edu/files/hepg/files/wp278updated.pdf

Balancing Supply and Demand: Resource Adequacy

ISO	Procurement Structure	RA Requirement	Timeline	Price Formation	Market Power Mitigation	Resource Obligations	Performance Incentives
ERCOT	**Energy-only market** that primarily relies on scarcity pricing mechanisms.	No requirement. 'Target' reserve margin is 13.75%	n/a	Operating Reserve Demand Curve adder and Reliability Deployment Adder. Use LOLE[16] and value of lost load.	System offer cap set to $9,000/MWh. Mechanism in place to reduce offer cap if costs become excessive.	n/a	n/a
CAISO	**Bilateral RA Requirement:** met through **bilateral contracts and self-supply**.	System requirements set by LRAs (most at 15% reserve margin). Local and flexible requirements determined by ISO.	Yearly and monthly requirements.	Largely unknown. Backstop capacity procured by ISO via auction, paid as bid.	n/a Backstop procurement auction subject to soft-offer cap.	Must-offer obligations vary by capacity type but involve scheduling and bidding in Day-Ahead and Real-Time markets.	**Average.** Incentive mechanism assesses adherence to must-offer obligation. No established performance criteria.
SPP	**Bilateral RA Requirement:** Procurement is through bilateral contracts and self-supplied.	Planning reserve margin set at 12%.	Peak summer season.	Unknown.	n/a	None.	None.
MISO	**Bilateral RA Requirement:** LSEs may use bilateral contracts, *or* procure through a voluntary centralized ***Planning Resource Auction (PRA)***	System-wide and zonal requirements set with LOLE study. The 2015 required reserve margin set to 14.7%	Auction held immediately prior to delivery year. Proposal for 3-yr forward auction for competitive retail states.	Currently demand curve is vertical at RA requirement. Proposal for sloped demand curve for competitive retail states.	Participants may self-schedule or submit $0 offers in PRA. Offer cap set at 2.7*zonal CONE.[17]	Must offer in Day-Ahead Energy and Reserve markets and first post Day-Ahead RAC process every hour.	**Weak.** MISO monitors must offer obligation but no formal incentive structure. Forced outages will reduce capacity counted.
ISO-NE	**Centralized capacity market:** called the *Forward Capacity Auctions (FCA)* Centralized capacity Market	System and local requirements set with LOLE study.	3-years in advance with additional auctions held annually and monthly.	Sloped demand curve, uses LOLE and CONE.	Minimum competitive offer prices. Requests to exit reviewed by market monitor.	Must offer into energy market and schedule maintenance with ISO	**Strong.** New pay-for-performance design integrates performance into capacity payment.
NYISO	**Centralized capacity market:** called the *Installed Capacity Auctions.*	System and local requirements set with LOLE study. Current reserve margin is roughly 17%.	Auctions held immediately prior to and during 6 month capability period.	Sloped demand curve, uses capacity requirement and CONE.	Market power tests determine when to impose offer floors and caps	Must schedule or bid in Day-Ahead market.	**Weak.** No performance mechanism but forced outages reduce capacity counted.
PJM	**Centralized capacity market:** called the *Reliability Pricing Model (PRM)*	System and local requirements set with LOLE study.	Base auction 3-years in advance. Incremental auctions held up to delivery year.	Slopped Demand Curve, based on requirement, net-CONE & demand reservation prices.	Minimum offer price set at net asset class CONE.	Must offer into Day-Ahead market.	**Strong.** New Capacity Performance product focuses on emergency events.

Capacity Markets at a Crossroads, Bushnell, Flagg & Mansur, April 2017, Table 3
https://hepg.hks.harvard.edu/files/hepg/files/wp278updated.pdf

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Balancing Supply and Demand: Resource Adequacy

ISO	Procurement Structure	RA Requirement	Timeline	Price Formation	Market Power Mitigation	Resource Obligations	Performance Incentives
ERCOT	**Energy-only market** that primarily relies on scarcity pricing mechanisms.	No requirement. 'Target' reserve margin is 13.75%	n/a	Operating Reserve Demand Curve adder and Reliability Deployment Adder. Use LOLE[16] and value of lost load.	System offer cap set to $9,000/MWh. Mechanism in place to reduce offer cap if costs become excessive.	n/a	n/a
CAISO	**Bilateral RA Requirement:** met through **bilateral contracts and self-supply**.	System requirements set by LRAs (most at 15% reserve margin). Local and flexible requirements determined by ISO.	Yearly and monthly requirements.	Largely unknown. Backstop capacity procured by ISO via auction, paid as bid.	n/a Backstop procurement auction subject to soft-offer cap.	Must-offer obligations vary by capacity type but involve scheduling and bidding in Day-Ahead and Real-Time markets.	**Average.** Incentive mechanism assesses adherence to must-offer obligation. No established performance criteria.
SPP	**Bilateral RA Requirement:** Procurement is through bilateral contracts and self-supplied.						None.
MISO	**Bilateral RA Requirement:** LSEs may use bilateral contracts, *or* procure through a voluntary centralized ***Planning Resource Auction (PRA)***					Day-Ahead eserve irst post Day- rocess every	**Weak.** MISO monitors must offer obligation but no formal incentive structure. Forced outages will reduce capacity counted.
ISO-NE	**Centralized capacity market:** called the *Forward Capacity Auctions (FCA)* Centralized capacity Market	System and local requirements set with LOLE study.	3-years in advance with additional auctions held annually and monthly.	Sloped demand curve, uses LOLE and CONE.	Minimum competitive offer prices. Requests to exit reviewed by market monitor.	Must offer into energy market and schedule maintenance with ISO	**Strong.** New pay-for-performance design integrates performance into capacity payment.
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Resource adequacy requirements and market structure affect the amount and flexibility of resources and load that are available to balance supply and demand

Capacity Markets at a Crossroads, Bushnell, Flagg & Mansur, April 2017, Table 3
https://hepg.hks.harvard.edu/files/hepg/files/wp278updated.pdf

Balancing Supply and Demand: Scarcity Pricing, Today

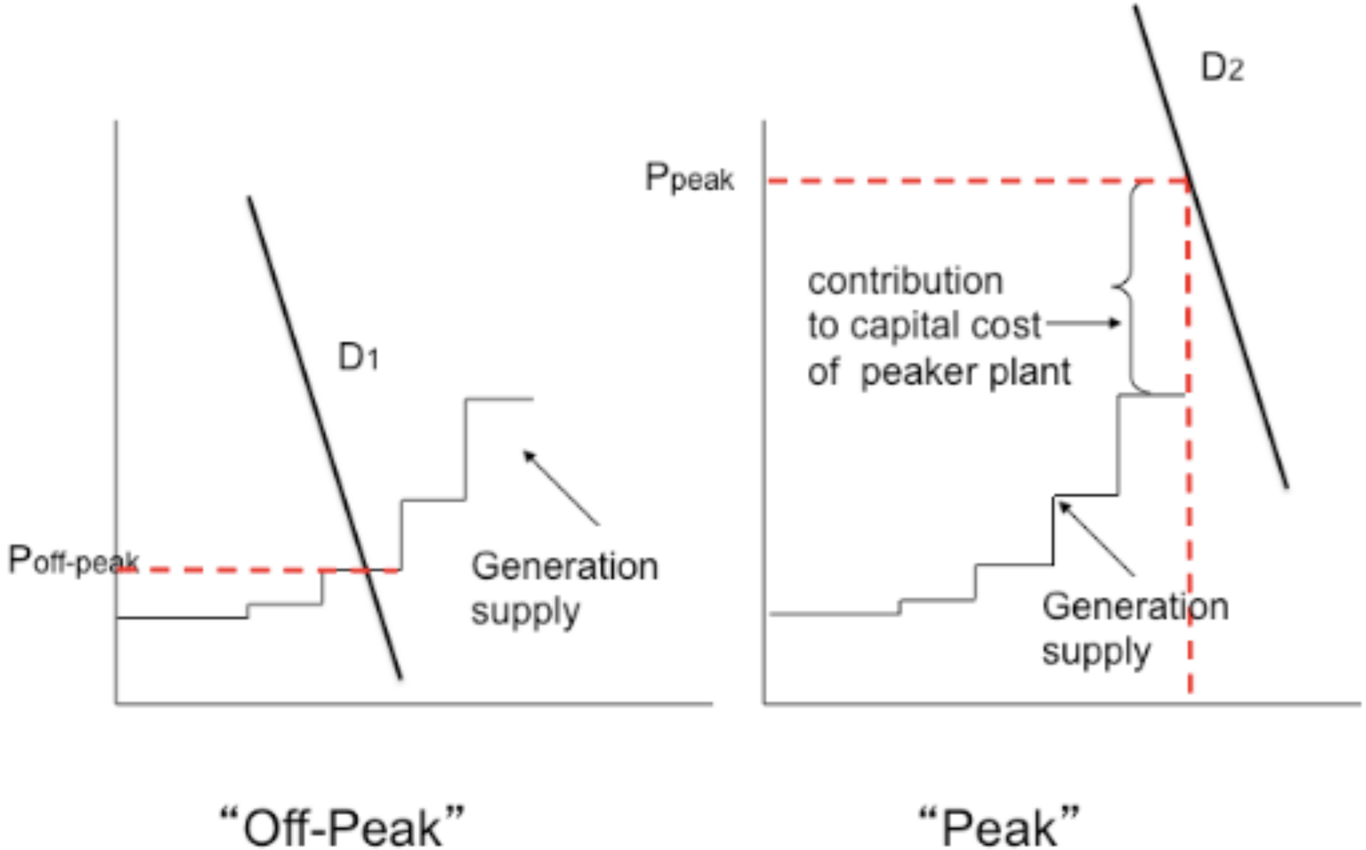
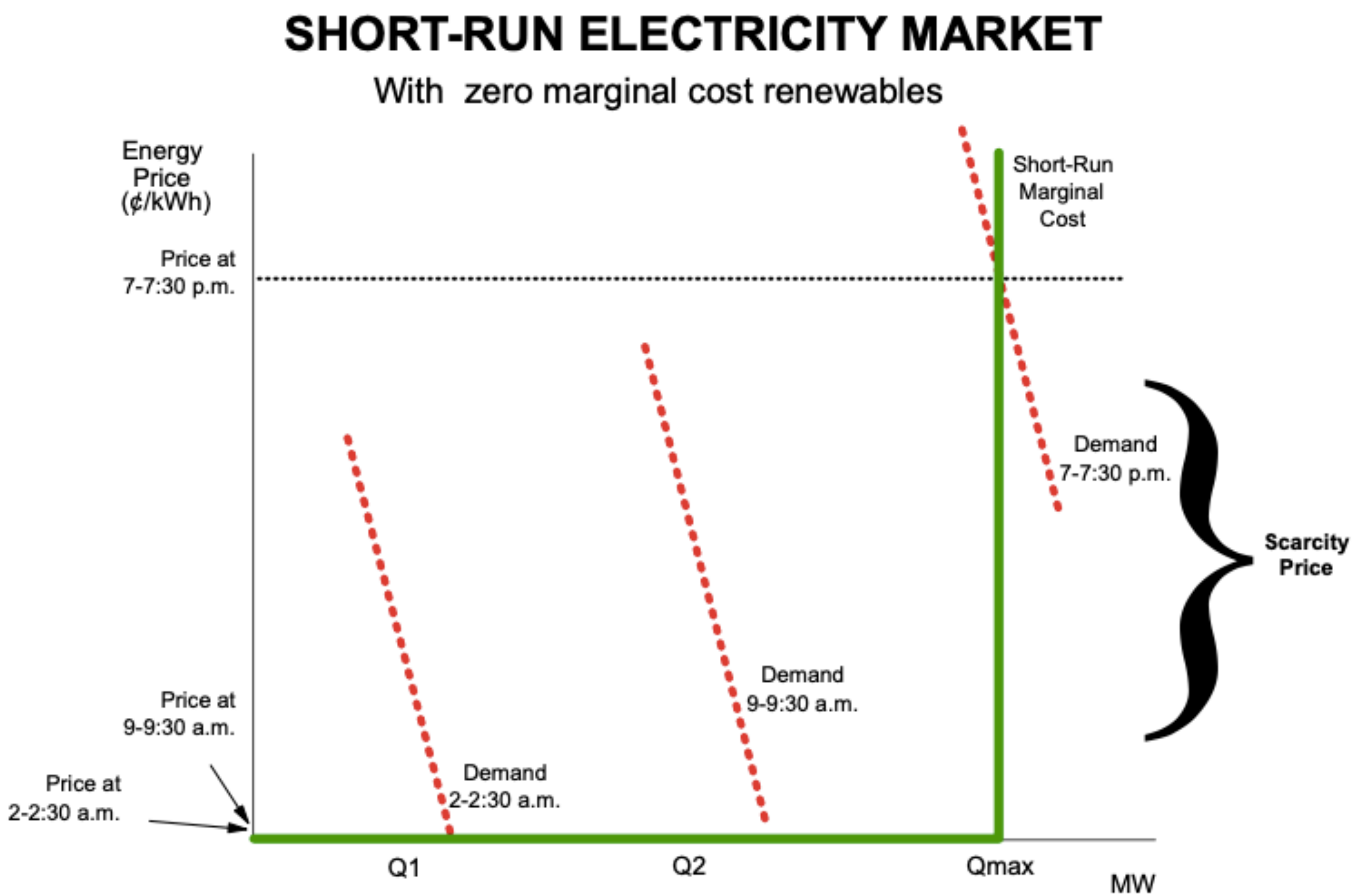


Figure 2: Scarcity Pricing Example

Capacity Markets at a Crossroads, Bushnell, Flagg & Mansur, April 2017
https://hepg.hks.harvard.edu/files/hepg/files/wp278updated.pdf

Balancing Supply and Demand: Pricing with Variable Energy Resources



Electricity Market Design and the Green Agenda, William Hogan, June 12, 2018
http://iaee2018.com/wp-content/uploads/2018/09/P2Hogan2018ppt.pdf

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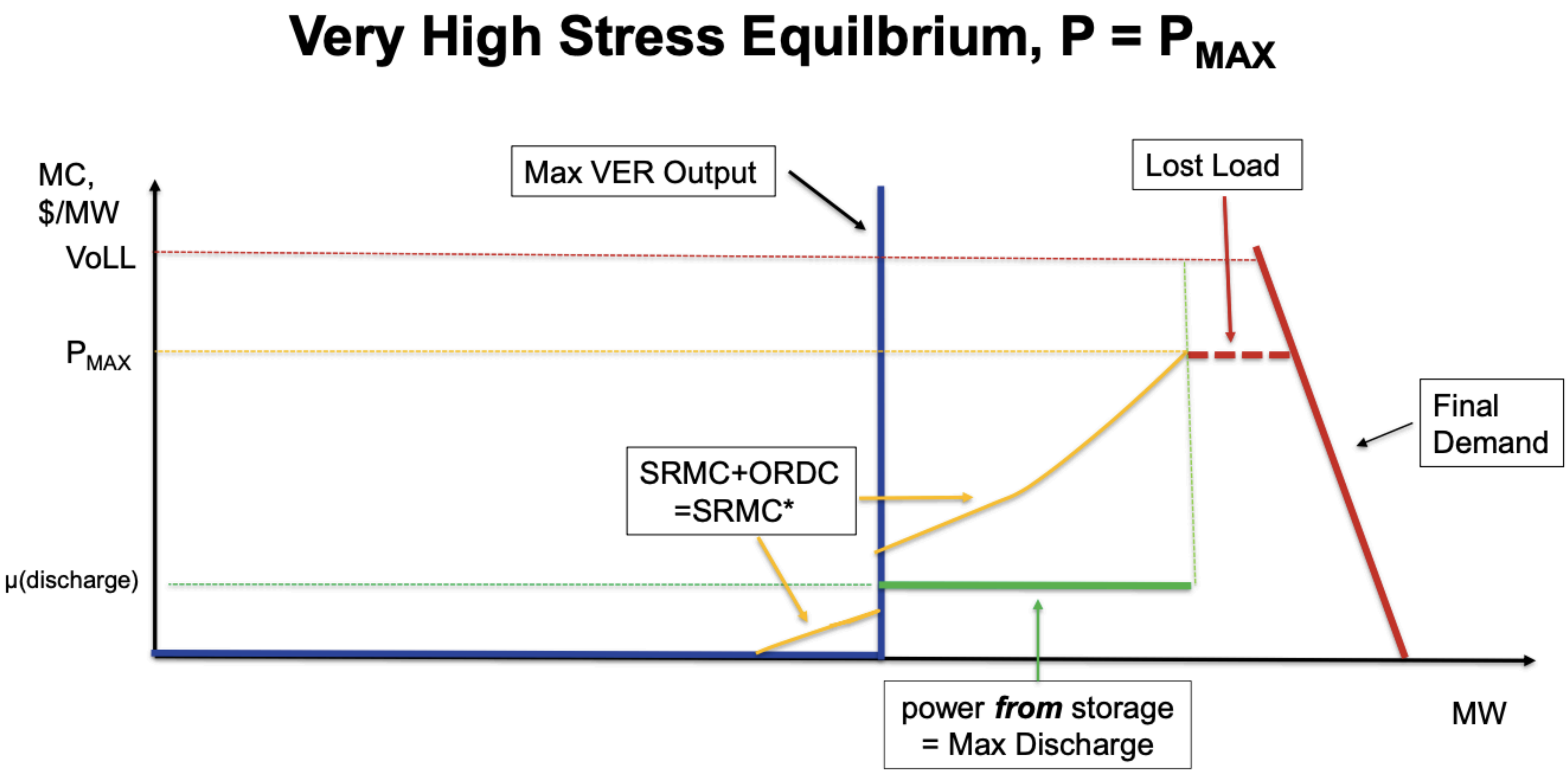
Balancing Supply and Demand: Pricing with Variable Energy Resources, Storage & Shortage



R. Schmalensee, Decarbonized Electric Power Systems: Some Preliminary Results, Feb. 10, 2020
https://www.belfercenter.org/sites/default/files/Decarbonized_Electric_Power_Systems.pdf

Balancing Supply & Demand: Examples of Tradeoffs

1. Prescribing ancillary capabilities of variable energy resources provides more grid flexibility but allocates costs to ratepayers and may require changes to renewable procurement mechanisms

2. Separate mechanisms for resources adequacy and variable energy resources allow for different decisionmakers to achieve their objectives but risks inconsistency and incompatibility in actual operations

3. High energy prices may balance supply and demand but cause both political concerns, operational challenges and pricing issues

In Summary

1. Each of the three types of problems: political economy, economic/regulatory, and engineering must be addressed
2. These three problems may be solved inconsistently or incompletely and compounded by multiple and overlapping jurisdictions
3. Unless they are addressed in an integrated and consistent manner, political, economic, and reliability difficulties are likely to occur
4. Decisionmakers pursue their own strategic objectives
5. Important tradeoffs exist between different approaches
6. Much other work needs to be done to improve the electric power sector in conjunction with decarbonization efforts

QUESTIONS AND COMMENTS

Annotated References

Below is an annotated list of some of the references used in this presentation.

International Energy Agency, 2017, Status of Power System Transformation 2017: System Integration and Local Grids, https://webstore.iea.org/download/direct/298 Covers many countries and includes case studies of Australia, Indonesia, Mexico and South Africa.

Kroposki et al, Achieving a 100% Renewable Grid, IEEE Power & Energy Magazine, March/April 2017, http://ipu.msu.edu/wp-content/uploads/2018/01/IEEE-Achieving-a-100-Renewable-Grid-2017.pdf This article provides a non-technical description of the technical issues of operating a grid with 100% renewables.

NREL, Eastern Renewable Generation Integration Study, August 2016, https://www.nrel.gov/docs/fy16osti/64472.pdf Detailed study of up to 30% renewable generation in the eastern interconnection.

Reishus Consulitng LLC, Electricity Ancillary Services Primer, August 2017, http://nescoe.com/wp-content/uploads/2017/11/AnxSvcPrimer_Sep2017.pdf Prepared for the New England States Committee on Electricity (NESCOE).