Evaluation of International Curtailment Practices for High Wind and PV Penetration

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CIGRE Grid of the Future
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Project Background- Solar in Japan

- Significant solar penetrations are expected in Japan in coming years

- TEPCO and NEDO contracted with EPRI to help understand a range of issues:
  - Smart inverter behavior, testing and functionality
  - Communications and control (DERMS, standards, etc.)
  - Grid operations with high solar penetration and use of solar curtailment to manage potential impacts (focus of this paper)

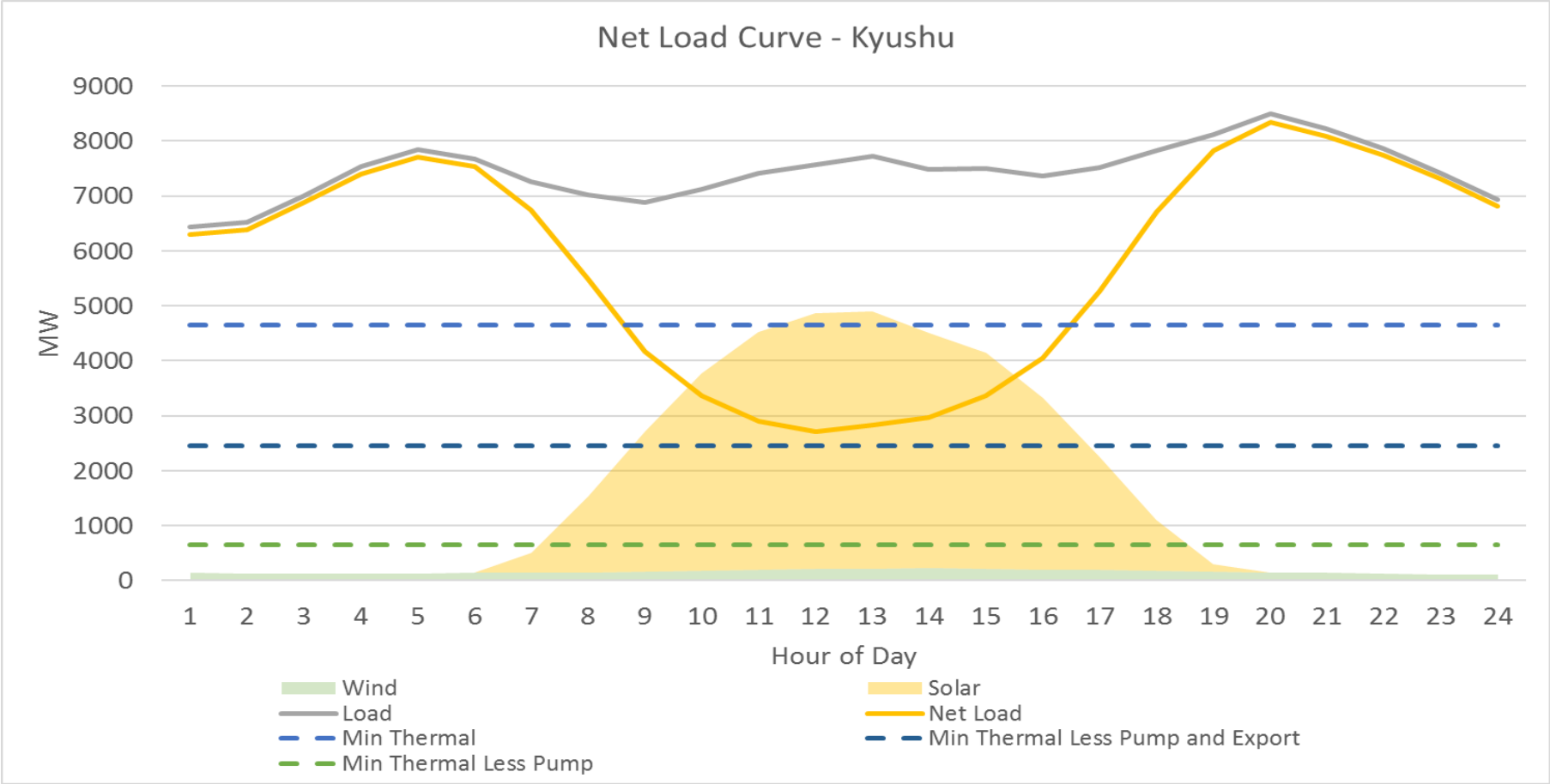
- Recommendations made around grid operations and control based on experience in other regions and short study of Japanese system
  - Phase 1: Surveyed multiple regions in US and Europe about curtailment practices and grid operations
  - Phase 2: High level analysis of Japanese system to develop recommendations on potential grid operations solutions, including curtailment
  - Phase 3: More detailed discussion of costs, benefits and application of solutions developed elsewhere to Japanese system (ongoing)

Penetration of Renewables across Japan

	Average Solar	Max Solar	Average Wind	Max Wind	Average VER	Max SNSP	Average SNSP
Hokkaido	5%	29%	2%	7%	8%	39%	9.7%
Tohuku	2%	29%	2%	8%	3%	26%	5%
Tokyo	4%	25%	0%	1%	4%	34%	11.3%
Chubu	5%	41%	0%	2%	6%	41%	5.8%
Hokuriku	2%	18%	0%	4%	3%	22%	2.9%
Kansai	3%	21%	0%	1%	3%	39%	17.1%
Chugoku	6%	41%	1%	5%	6%	48%	13.6%
Shikoku	8%	56%	1%	5%	9%	41%	6.8%
Kyushu	8%	61%	1%	3%	9%	58%	7.8%
Total (synchronized)	4.6%	30%	0.5%	2%	5%	31%	5%

- Solar provided 2%-8% of total energy in April-September, wind significantly lower in most regions
  - Average VER ranges from 3% to 14%, with 5% total
- Up to 30% of total load met by solar across system
  - Max solar was in Kyushu
- SNSP shows how some regions can rely on export ability to keep other resources online even when wind/solar is high
  - Kyushu has higher SNSP than others due to relatively low export capability
  - Many regions have higher SNSP than instantaneous as they are importing – less flexibility will be available during those periods

Net load curve for Kyushu in May 2016 – already seeing significant challenges!



Pumped hydro and exports were very helpful in managing ramp
Flexibility from conventional generation would be exhausted, relying on others

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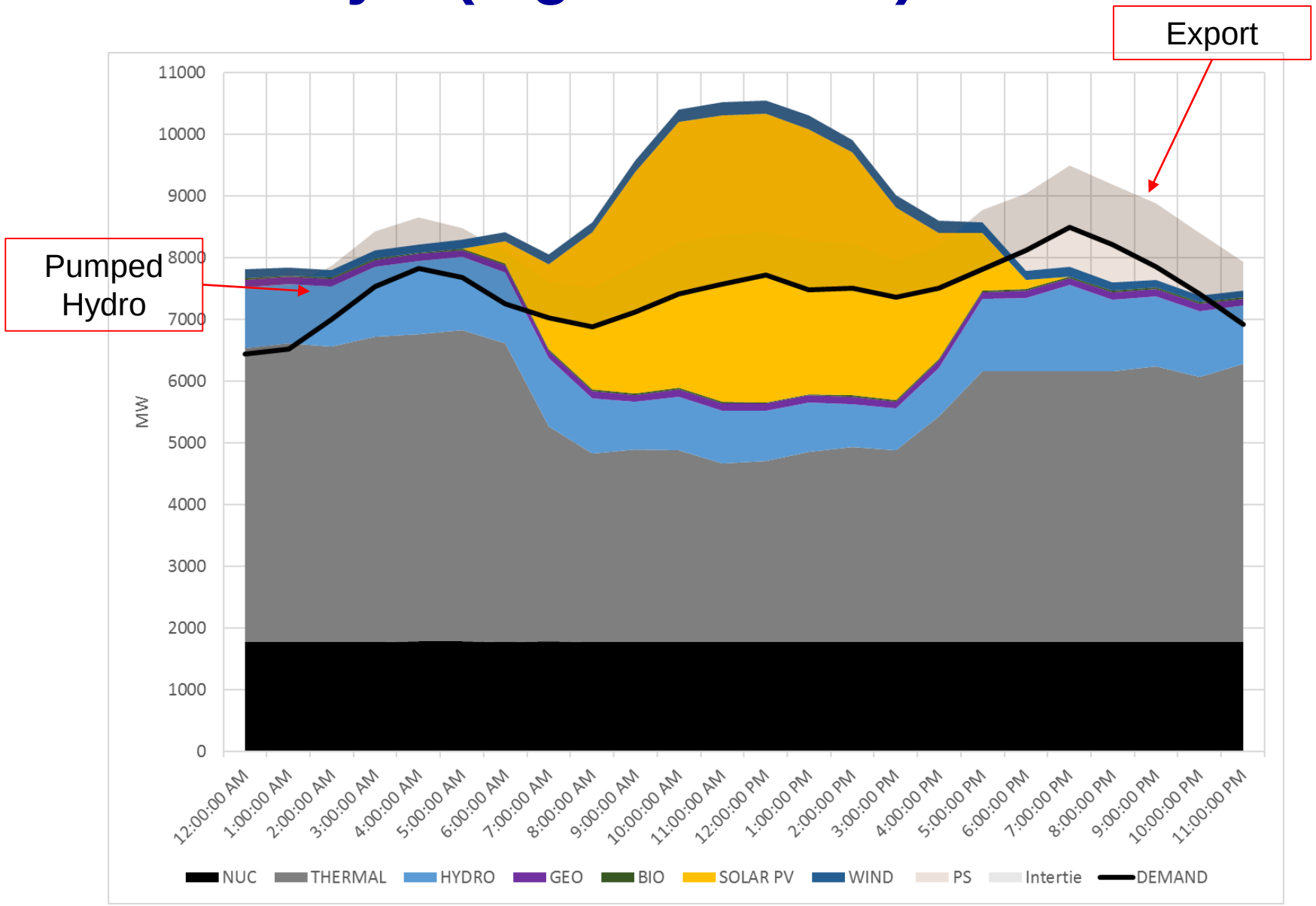
Generation on May 4 (highest SNSP)



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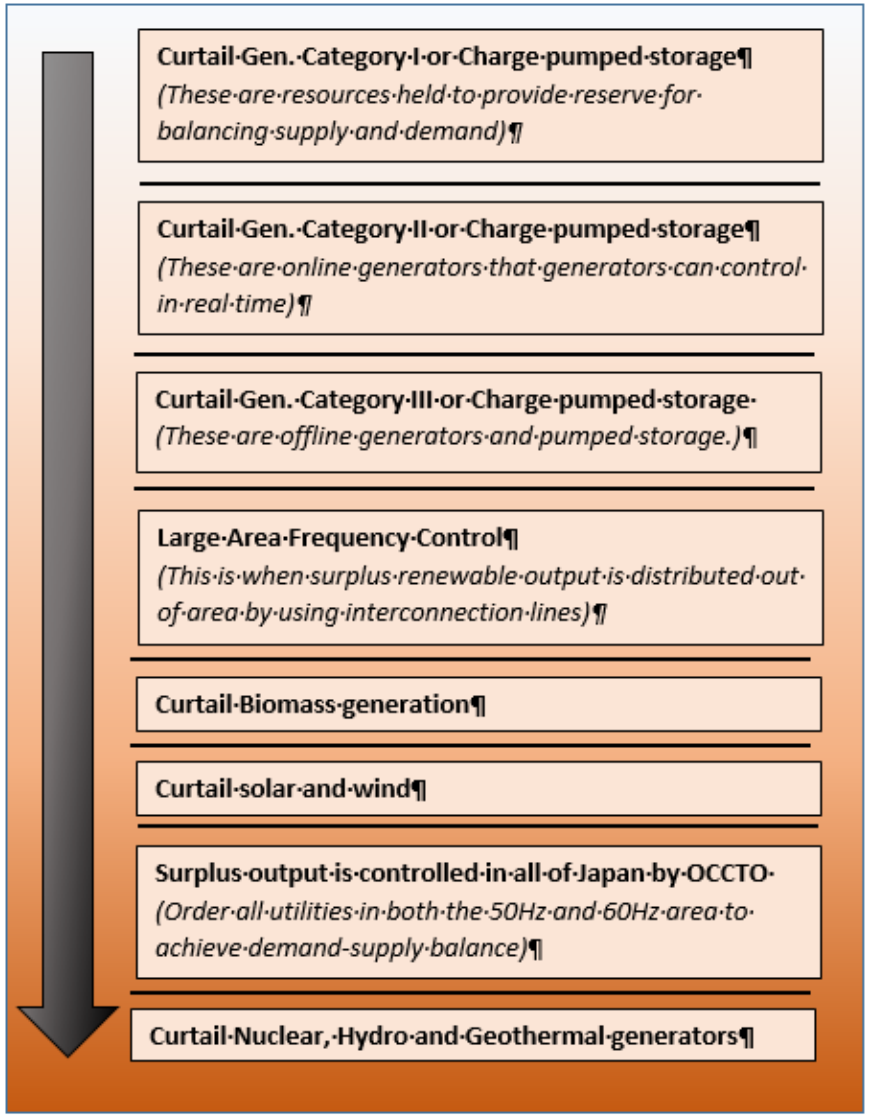
Visibility and Control of Solar PV

- Based on info from TEPCO and online, control and visibility is still very limited
- Forecasts for solar perform well, but locked down well in advance of real time
- Some curtailment happening in some regions, per EPRI understanding
- Curtailment process for Kyushu shown on right
  - Standard curtailment practice is based on a rule based system
  - Reflects periods when solar may be most challenging to system operations



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Experiences from US and Europe

Curtailment Mechanisms

- Multiple reasons for curtailment, which drives how this can be done:

- Congestion or thermal limit based
  - Most common reason in most systems, and widely used over past decade
  - Location specific, and control sent to operator of wind or solar plant
  - Most common in areas with less transmission
  - Can be priced using Locational Marginal Pricing (e.g. in US ISOs) or can be based on redispatch of system to alleviate congestion (e.g. Europe)

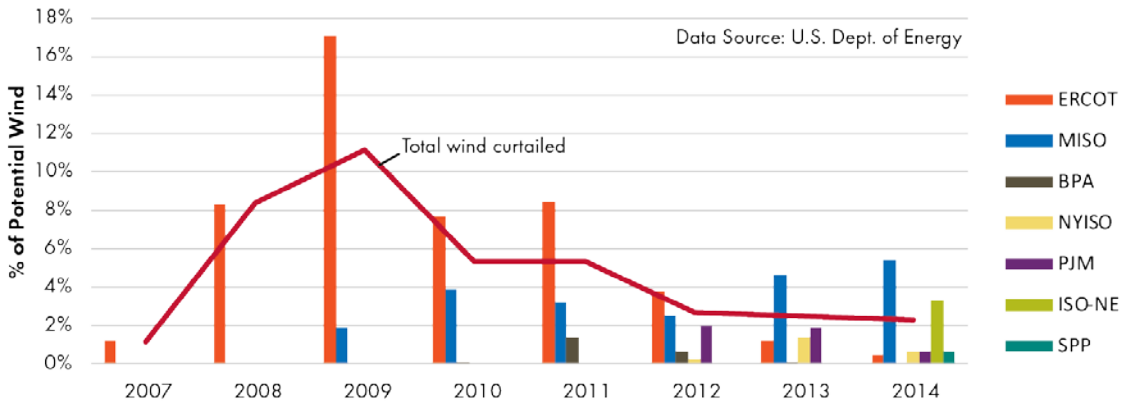
- Economic or balancing based
  - Becoming more common in some markets (MISO, ERCOT, Ireland, etc.)
  - Generally system wide, due to lack of balancing (reserves of dispatch flexibility)
  - Included in unit commitment and/or economic dispatch and may be result of negative pricing periods
  - Downward reserves often provided for balancing

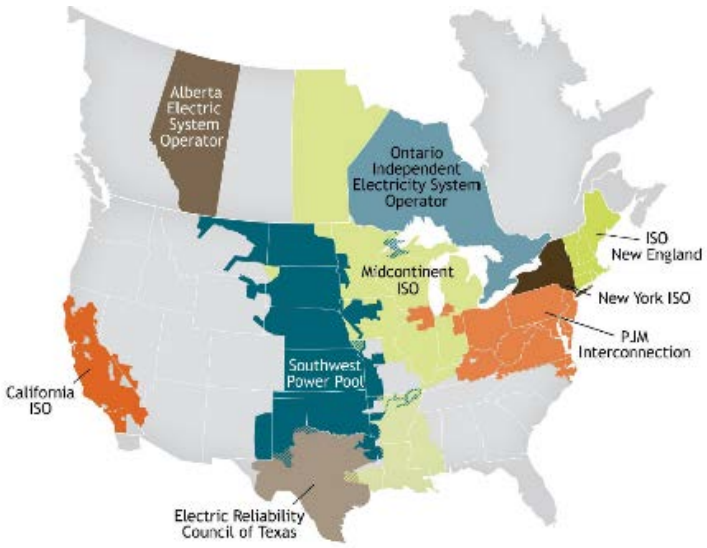
- Other reasons
  - Distribution network congestion relief (not covered here)
  - Provision of ancillary services from wind power (regulation, frequency response, etc.)
  - System non-synchronous penetration limits reached (mainly island systems such as Ireland)

Potential Challenges and Needs

- Forecasting and visibility
  - Need to know what is available for when curtailment is released
  - May require additional instrumentation in some cases
  - ISOs provide forecasts but may be augmented by plants
- Signals and verification
  - Most ISOs use Inter Control Center Protocol
  - SCADA used for signaling
  - Basepoint signal sent every 5 mins
  - Phone call sometimes still used
  - Order is dependent on the reason for curtailment
    - Congestion: based on relieving congestion most effectively
    - Balancing/other: varies – last in first out, contractual, or equal amount
- Compensation and incentives
  - Take or pay has been widely used in the past with lower levels of curtailment
  - Newer contracts may have more ability to curtail (Xcel, California, etc.)
  - When incorporated into market dispatch, no direct curtailment from ISOs but may be compensated based on contract with offtaker
  - Some areas don't compensate (e.g. Bonneville Power Authority), or only compensate if wind/solar can be automatically curtailed (PJM)

Summary of US ISO/RTO curtailment



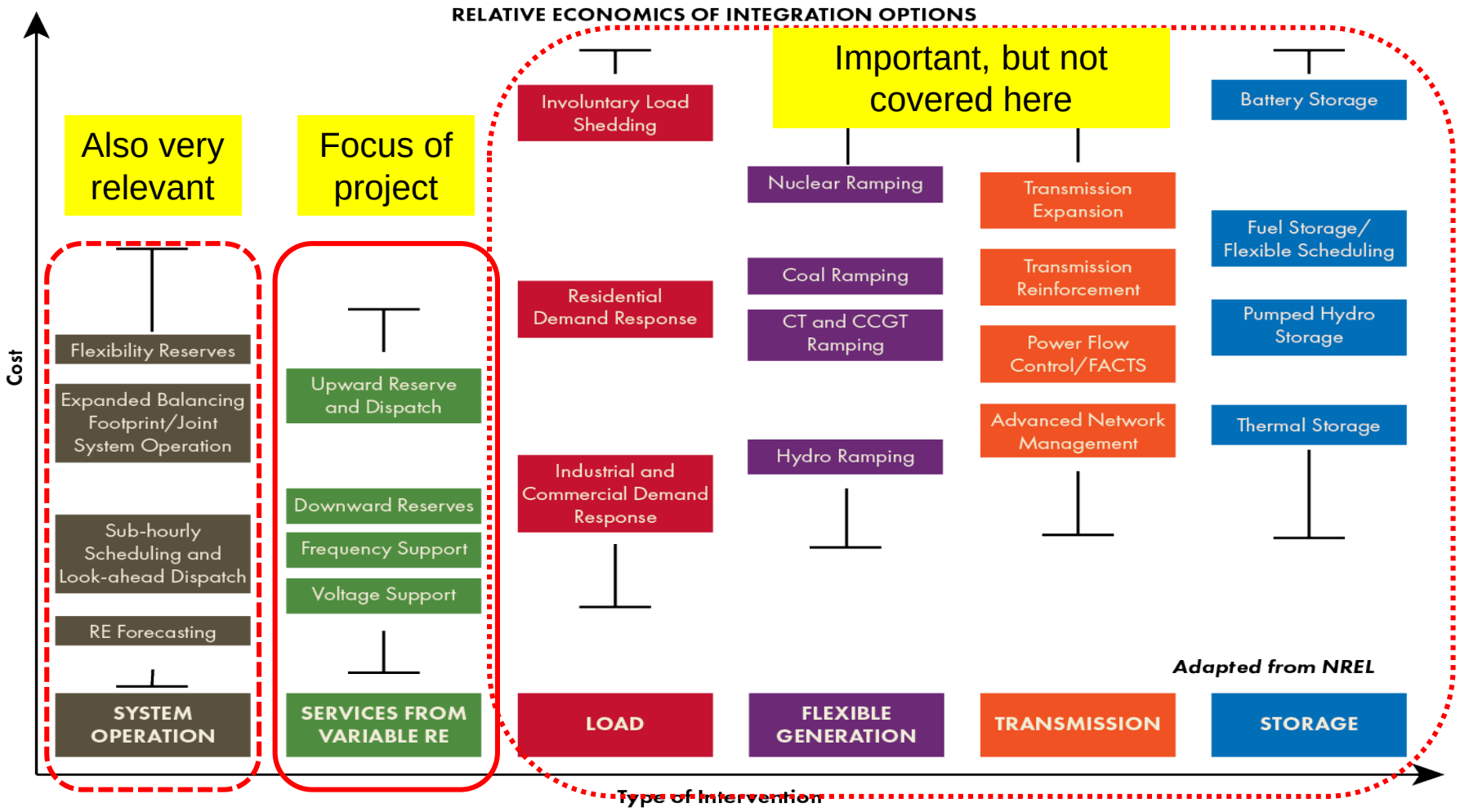


- Curtailment still being driven by lack of transmission capability and congestion
- ERCOT reduction due to addition of new transmission to Competitive Renewable Energy Zones (CREZ)
- Most ISOs have some form of wind on dispatch
  - ISO-NE introduced version called “Do Not Exceed” – further development of dispatch concept to account for changes in wind

Summary – selected US ISO practices for including wind (and solar) in dispatch

	NYISO	MISO	ISO-NE
Terminology	Wind Resource Management	Dispatchable Intermittent Resources (DIR)	Do Not Exceed dispatchable generator (DDG)
Forecast	Provided by ISO	Provided by market participant	ISO (wind), market participant (hydro)
How limits set	Security Constrained Economic Dispatch (SCED)	SCED	SCED (Do Not Exceed Dispatchable Generation), separate process (Do Not Exceed (DNE))
Non-performance	Penalty for over-generating during curtailment by over 3%	Penalty if over-generating for more than 4 consecutive intervals	Penalty for over-generation similar to other generators
Beyond forecast during unconstrained period	N/A	N/A	Resources must not exceed their DNE limit

Putting Flexibility Options in Context



Using solar to provide services is a 'low hanging' option, but should be considered in system context

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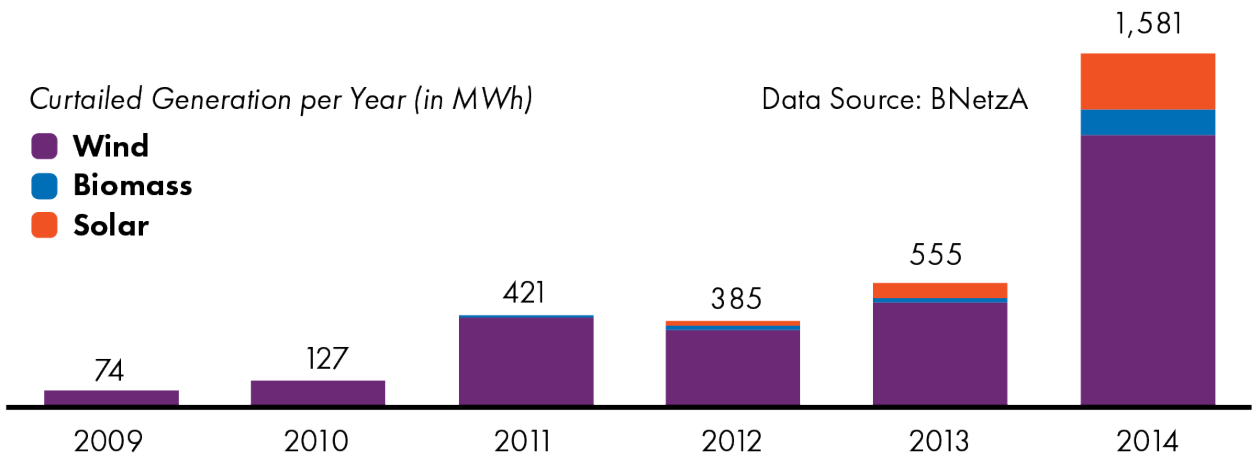
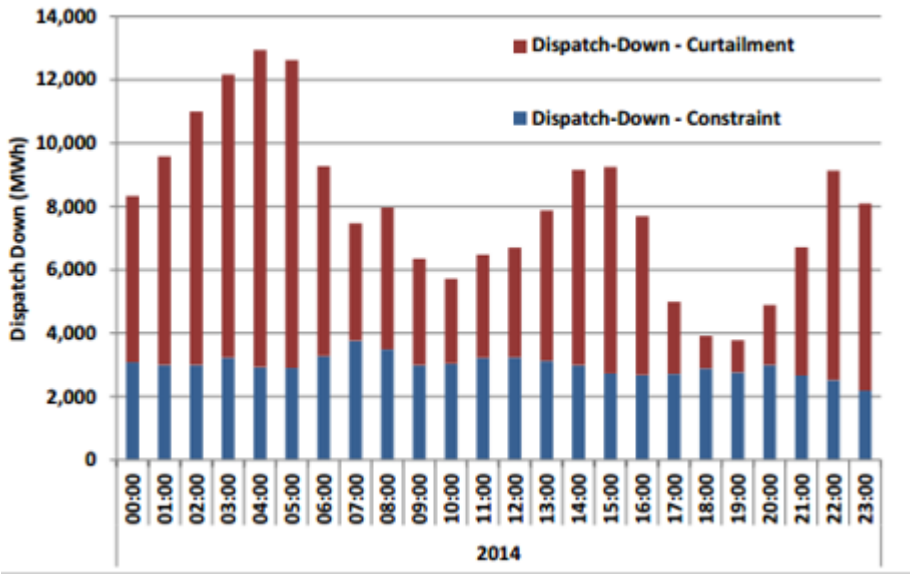
Germany



- Wind and solar now provide over 18% annual energy, >70% in some hours
  - Very strong links to neighbors helps integrate
  - No significant increase in balancing reserve needs
- Can curtail any distributed resources over 30kW, over 100kW requires 2-way communications
- Curtailment in 2014 was higher due to not having sufficient transmission from north to south
  - Still less than 1% of total energy, costs of $83m to compensate wind and solar, mostly in northern states
  - Redispatching system costs $180m
  - Building new High Voltage Direct Current (HVDC) and HV Alternating Current (HVAC), and improving integration with neighboring regions

Ireland (Eirgrid)



- Single synchronous system with over 23% of energy from wind
  - Likely largest in world for single system to manage
- 3.1 GW win – peak demand is 6.8GW, min demand 2.3GW
  - 950MW from 2 HVDC interconnectors to Great Britain
- 4.4% energy from wind curtailed in 2014
  - 35% ‘constrained’ due to transmission limits from wind resource in west to load in east
  - Rest ‘curtailed’ due to balancing issues and resources choosing to reduce to avoid negative prices
- Half of wind is distributed generation – Transmission System Operator (TSO)/ Distribution System Operator (DSO) interaction important

Potential Solutions for Japanese situation

Solar PV curtailment AND system operations and planning based solutions

Curtailment tools for operators

- May have need for new tool capabilities in control room
- Needs accurate forecast of what is available now and in 5 mins-1 hour
- Provide awareness for operators as to what is possible and already curtailed
- Could be useful for OCCTO (coordinates Japanese system across interties)

CURTAILMENT TOOL INFORMATION

Total VER production
Controllable and non-controllable VER production forecasts across each utility

VER production by zone or node
Zones could be chosen so that within each zone there is normally no congestion.

VER production at each individual plant.
Ideally, this would be known at least at the level of each transmission substation.

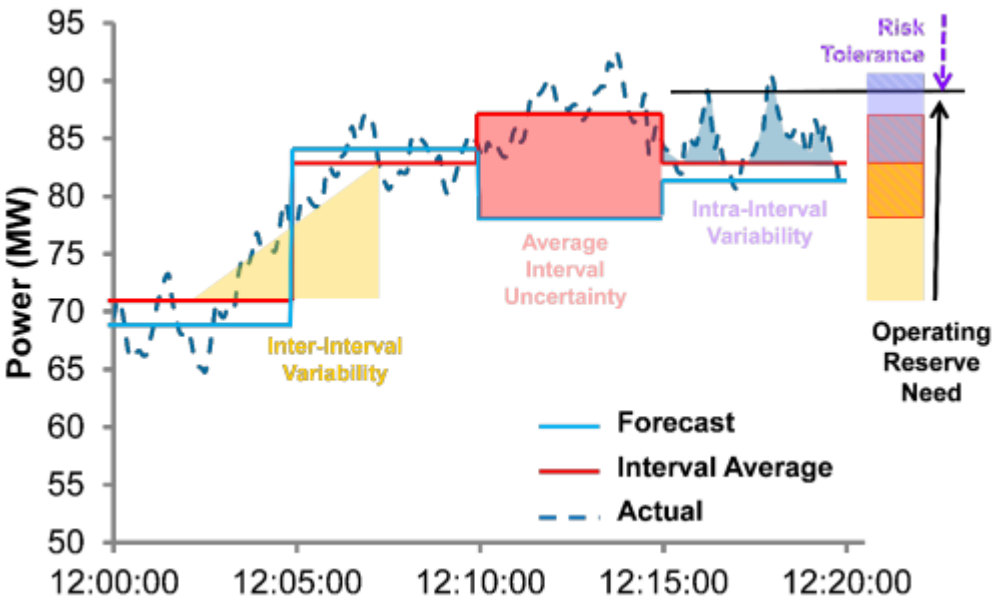
Forecasted production over next 0-72 hours
This should be done for at least the overall system VER, but ideally at each plant location, or transmission substation for distributed PV

Amount of curtailment
How that will be split amongst the various generator groups should be calculated and displayed

Tools that can be provided to operators to determine need for and awareness of curtailment

Advanced Scheduling Practices for VER

- Reserve requirements based on uncertainty and variability associated with VER
  - Dynamic reserves based on specific conditions
  - Load following over longer time frame as well as frequency regulation reserves
- Unit commitment and economic dispatch adjustments
  - Closer to real time when forecasts are better
  - Short scheduling intervals
  - Studies may be needed to quantify benefits
- Forecasting of VER
  - Improved sensor technology such as lidar, sonar
  - Probabilistic forecasts and decision tools to aid operators
  - Distributed PV methods to capture data that is not visible to operator



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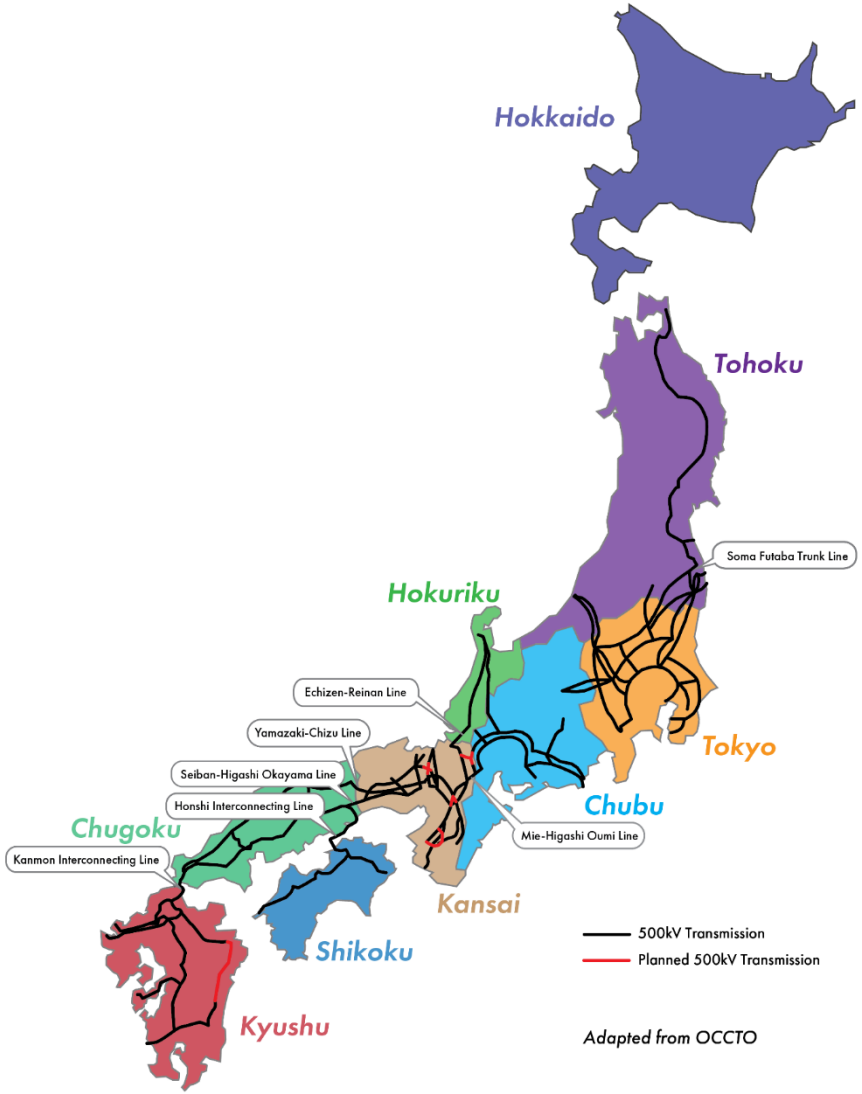
Increased coordination between regions

- Large drive in Europe and US to increase coordination between regions, mirrored in Japan
- California energy imbalance concept could help manage short term variability
- European market coupling to provide information in day ahead and real time balancing markets
- Significant reduction in overall flexibility needs over larger areas



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Flexibility from existing and new resources

Existing resources

- Understand flexibility of conventional generation fleet
  - Can more flexibility be obtained?
  - What are the costs?
- Retrofits to improve flexibility have been shown to help in many regions
  - Lower minimum generation levels can have significant advantage
  - Studies can show costs/benefits

New resources – batteries and demand

- Much R&D on storage technologies and reduction in costs
  - Need to understand value proposition and how these fit with other resources
  - Ambitious battery targets for Japan as well as other regions
- Demand response could also be an option to provide flexibility
  - Increase as well as decrease demand
  - Move demand around in time

Summary and Conclusions

- Flexibility is key - the ability to ramp the system up and down over multiple hours
  - Institutional sources of flexibility should be considered
  - Power Purchase Agreements (PPAs) and other contractual and regulatory schemes may need to evolve
- Significant experience for large transmission-connected variable generation, in particular wind
  - Distributed resources, including distributed PV, have not been curtailed to the same extent
  - Automatic curtailment in system operations improves system operations substantially
  - Forecasting and communications are both crucial
- Metrics such as instantaneous hourly penetration and System Non Synchronous Penetration (SNSP) show Japan has a range of experiences but does have some high penetration areas
  - Different solutions will be best for different regions
  - Kyushu already seeing high penetrations → uses flexible generation, pumped storage and exports to help integrate smoothly
  - Tokyo is not as far along, though does have high penetration days and not easy to lean on neighbors due to large system size
- Solutions include both solar PV plant level and system level changes
  - Visibility and control
  - Scheduling and reserves
  - Curtailment of wind/solar
  - Flexibility resources

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