21st Century POWER PARTNERSHIP

Accelerating the transformation of power systems

THE 21ST CENTURY POWER PARTNERSHIP

Capacity value of variable renewable energy (VRE) resources

7 May 2018

Bethany Frew

CLEAN ENERGY MINISTERIAL

Accelerating the Transition to Clean Energy Technologies

OUTLINE

- Why we use capacity expansion models (CEMs)
- A little bit about one CEM
- How CEMs (and real systems) ensure “enough” capacity is built
- What is capacity value (CV)?
- How to estimate CV for variable renewable energy (VRE) resources
- Other considerations for calculating CV

DECISIONS, DECISIONS, DECISIONS

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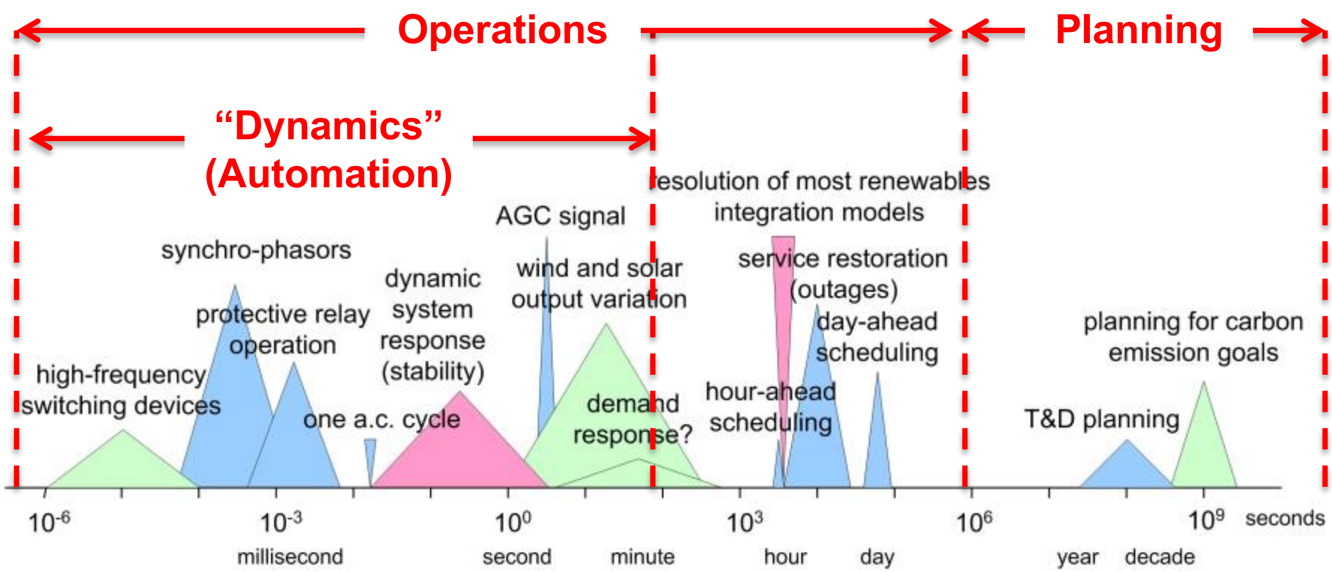
Relevant decision time scales in running a power grid span 15 orders of magnitude....dynamics all the way to investment



Source: Alexandra von Meier

Capacity Expansion Models (CEMs)

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Brazil | China | India (co-lead) | Denmark | Finland | Mexico (co-lead) | South Africa | Spain | United States (co-lead, under review)

WHAT QUESTIONS CAN CEMS ANSWER?

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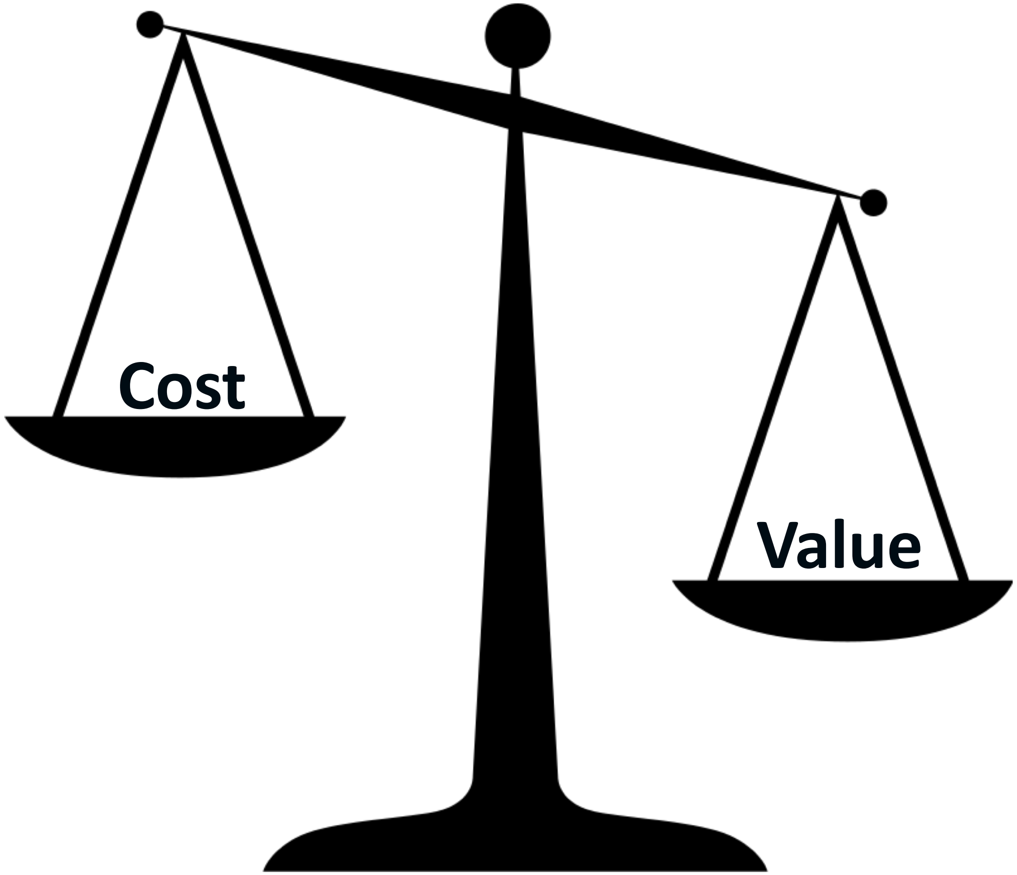
- **What** resources (and **where**) should I **build** in order to meet projected load growth with minimal cost in 2030?
- What is the impact of implementing a new **policy** on total system cost and generator deployment?
- What range of generator **deployment** could be experienced in the near-, mid-, and long-term under various projected **costs**?
- What is the impact of reduced **water** availability on **hydro** deployment and the **operations** of the rest of the system?

CEMs capture costs incurred and value added



Brazil

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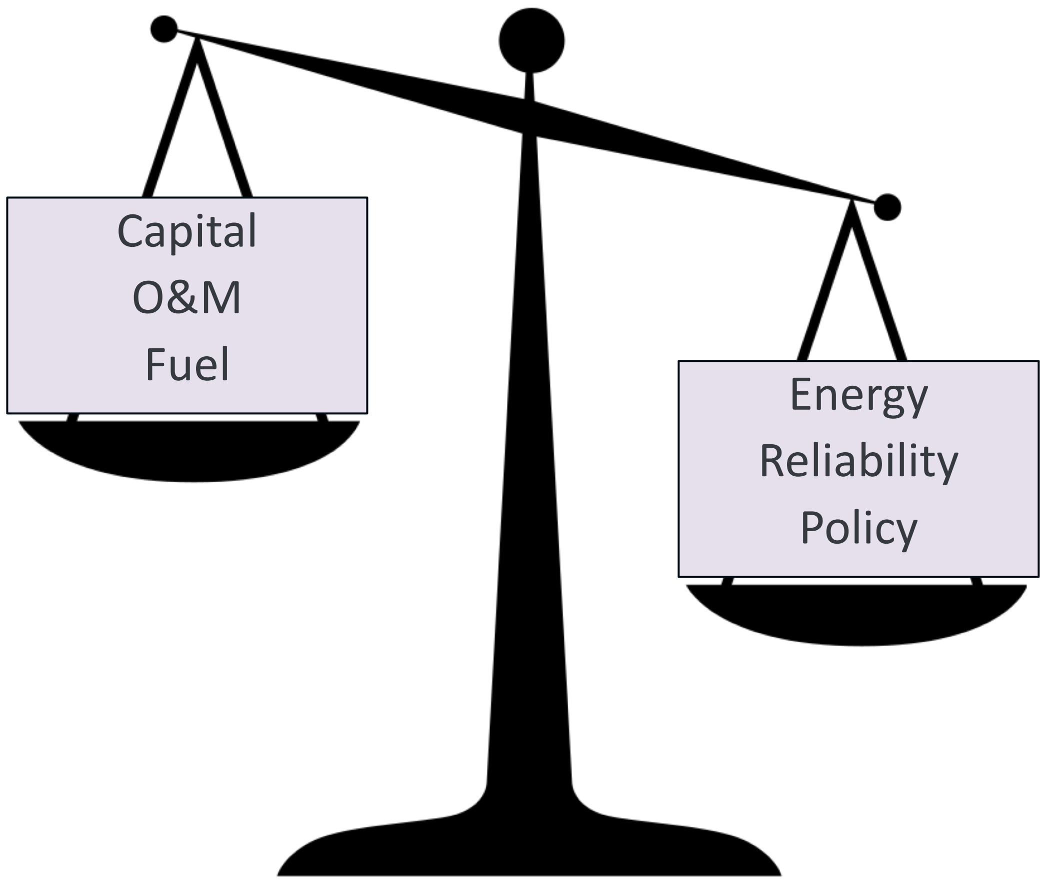

Example CEM: NREL's Regional Energy Deployment System (ReEDS) Model

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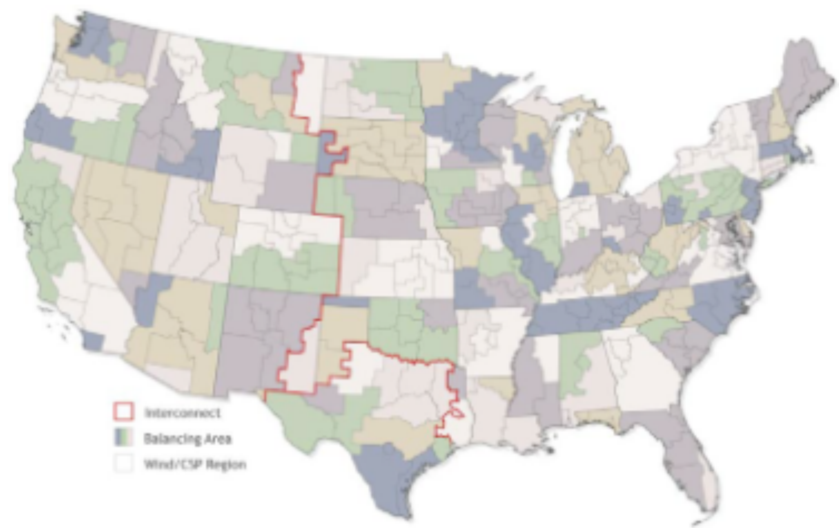
ReEDS is a spatially and temporally resolved CEM that identifies least-cost deployment and reduced form dispatch scenarios for the U.S. electric sector

- High **spatial resolution** to represent both transmission and spatial mismatch of resource and load
- High **temporal resolution** to represent seasonal and diurnal variations in load and resources
- Statistical consideration of **integration issues** due to variability and uncertainty of RE supply



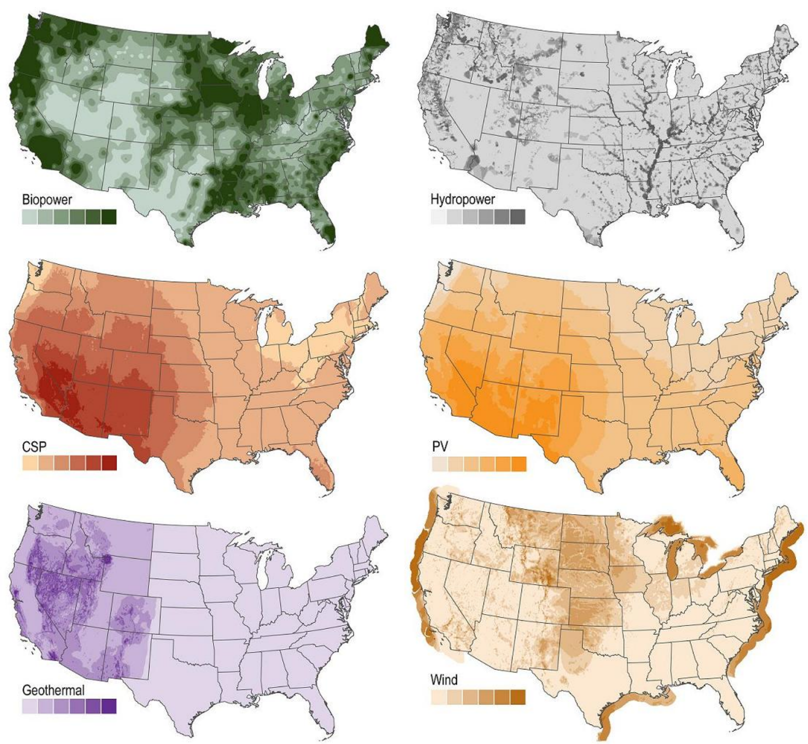
EMPHASIS ON RENEWABLE ENERGY

Highly resolved RE resource representations:

- Resource quality
- Accessibility and other development costs

Intra-timeslice representation of variable resource availability.

- ***Capacity value***: contribution to planning reserves
- ***Induced operating reserves***: additional reserves necessary due to forecast error
- ***Curtailments***: unusable RE due to insufficient load



NREL RE Resource Maps

Can be applied to any location-specific resource

Reliability

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Resource Adequacy – having enough generation supply resource to meet load at all times accounting for outages

Operational Reliability – withstanding sudden disturbances

Resource Adequacy

Approach: Add enough resources (generation, DR, storage, net interchanges, contracts) to supply all demand at a future time and location, with a certain probability of failing to do so

- Often measured based on installed capacity, peak load, and a planning reserve margin (typically 15%)
- No system can be perfectly adequate
- How adequate is adequate enough?
- Quantify the number of times system will be inadequate – often measured as hours/year; days/year (1d/10y ≈ 99.97%)

HOW HAVE WE BEEN MEASURING RESOURCE ADEQUACY?

In real systems

- No universal resource adequacy target – each planning area sets its own target, often imposed somewhat arbitrarily by policy
  - Peak load plus some reserve margin
  - Loss of load probability (LOLP)-based metric (1d/10yr)
- In North America, NERC annually assesses, but does not enforce, seasonal and long-term reserve margins

In planning models (e.g., CEMs like ReEDS)

- Planning reserve margin (PRM) constraint with derating of capacity based on performance metrics → **capacity value**

  Σ (Derated Capacity) ≥ PRM * Peak Load
- Ongoing work to improve this aspect of models
  - e.g., improve temporal resolution of CV methods; embed reliability model within CEM to effectively remove need for PRM constraint

Are There Metrics For System Adequacy?

Loss of load probability (LOLP)

- Probability of insufficient generation to cover load

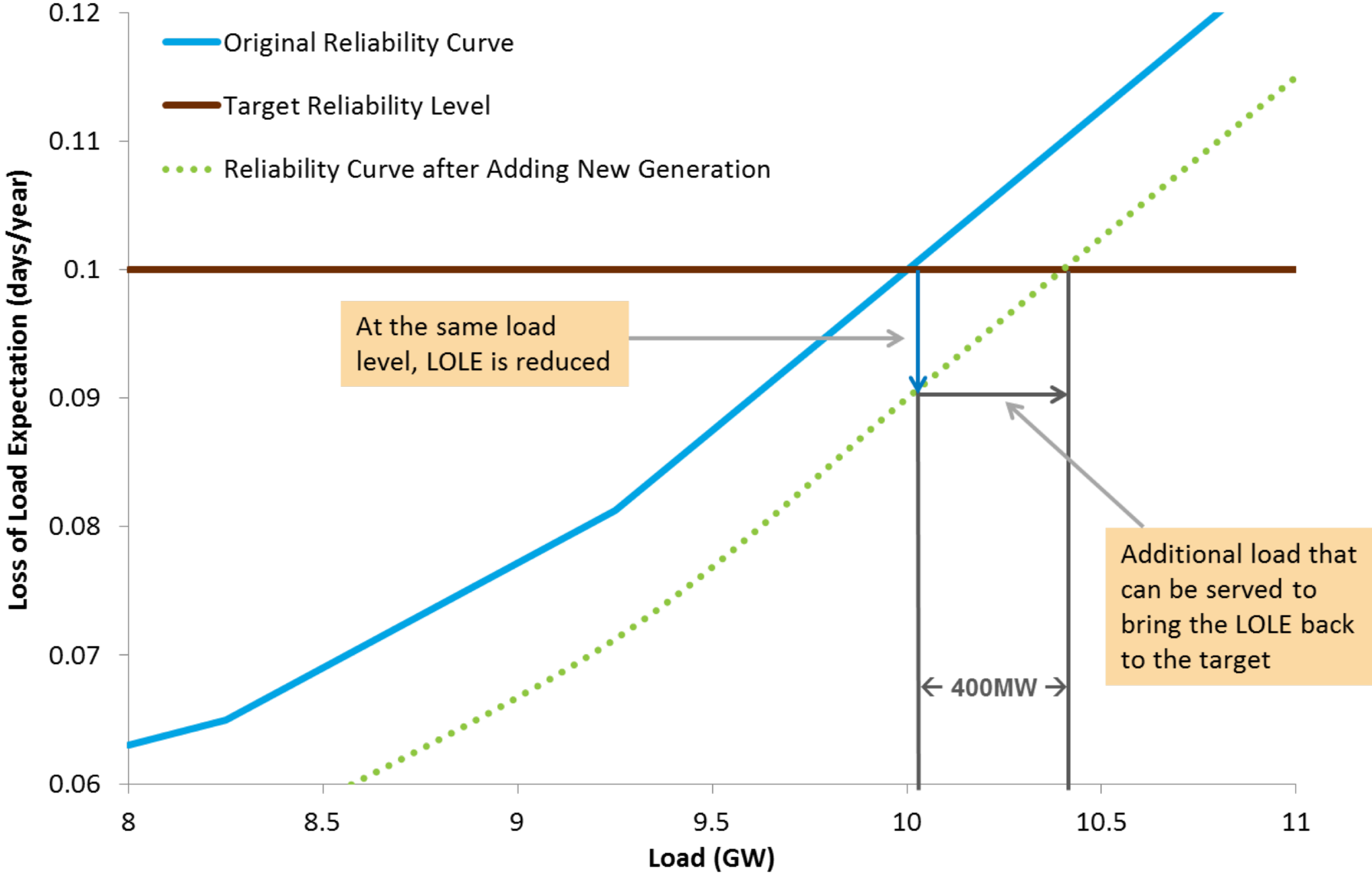
Loss of load expectation (LOLE) = probability x time

Expected unserved energy

- Measures the *amount* of potential shortfall, not just the likelihood

All of these measures capture varying levels of risk – something that is missing from fixed planning reserve margin approaches unless they have been 'trued up' with reliability results

PREFERRED RESOURCE ADEQUACY METRIC (AND CV METHOD) IS BASED ON LOLP



= ELCC (Effective Load Carrying Capability)

Milligan et al. 2016

RECOMMENDED APPROACHES FOR RESOURCE ADEQUACY

- Adopt a reliability target *such as* 1d/10y
- Derive the percentage reserve margin that corresponds to the reliability target
- Use ELCC to determine any generator's contribution
  - Wind and solar from net load time series → **CV**
  - Conventionals with forced outage rates
- Use multiple years of data, and revisit as more data becomes available
- Interconnection or regional analysis
- Ideally account for storage/DR

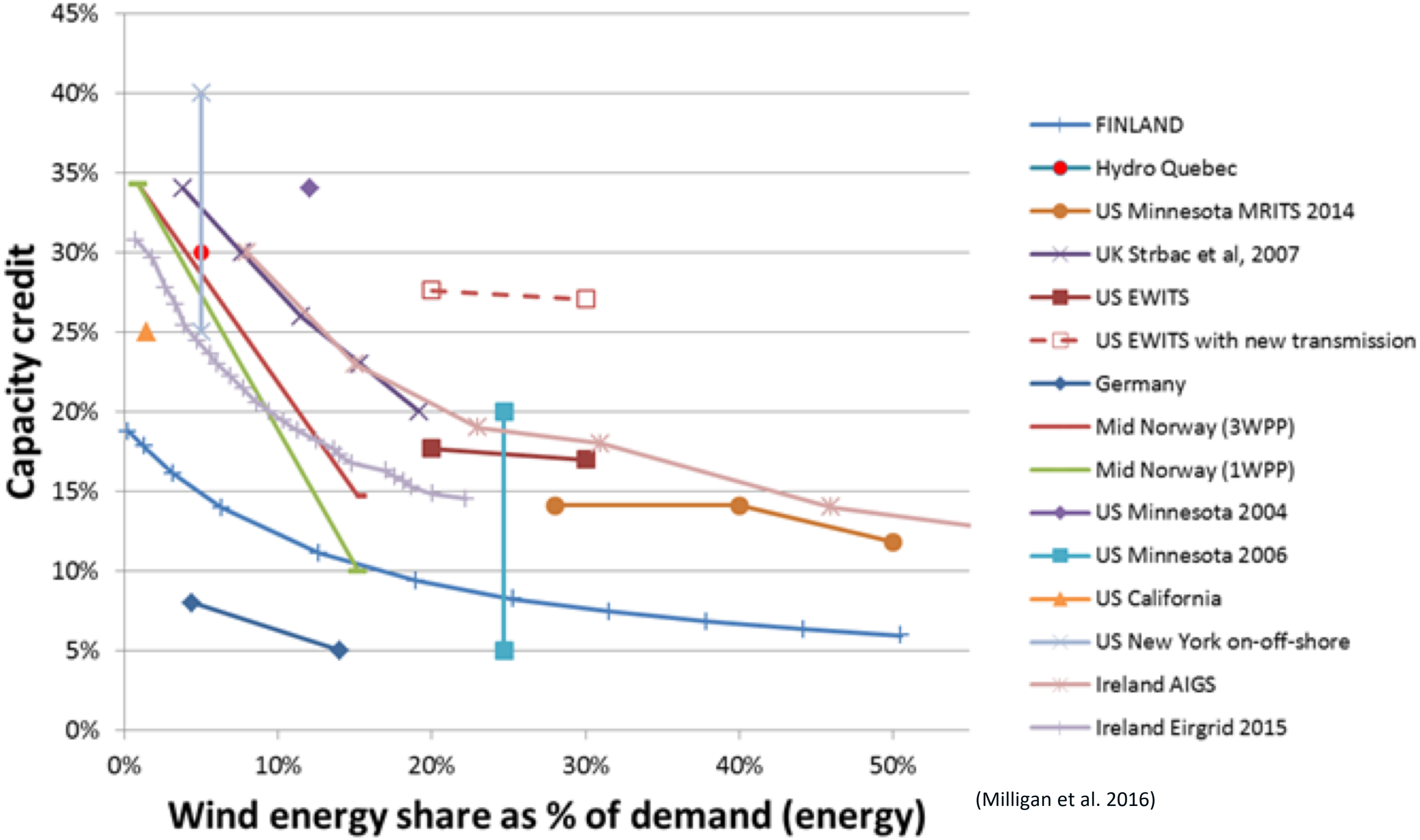
WHAT IS CAPACITY VALUE (CV)?

- Fraction of the installed capacity that reliably contributes to meeting load **during times when the system has the highest probability of not meeting load**

- Sometimes called **capacity credit** (where capacity value then refers to the monetary value of that capacity)

- For VRE, key inputs are load and VRE profiles

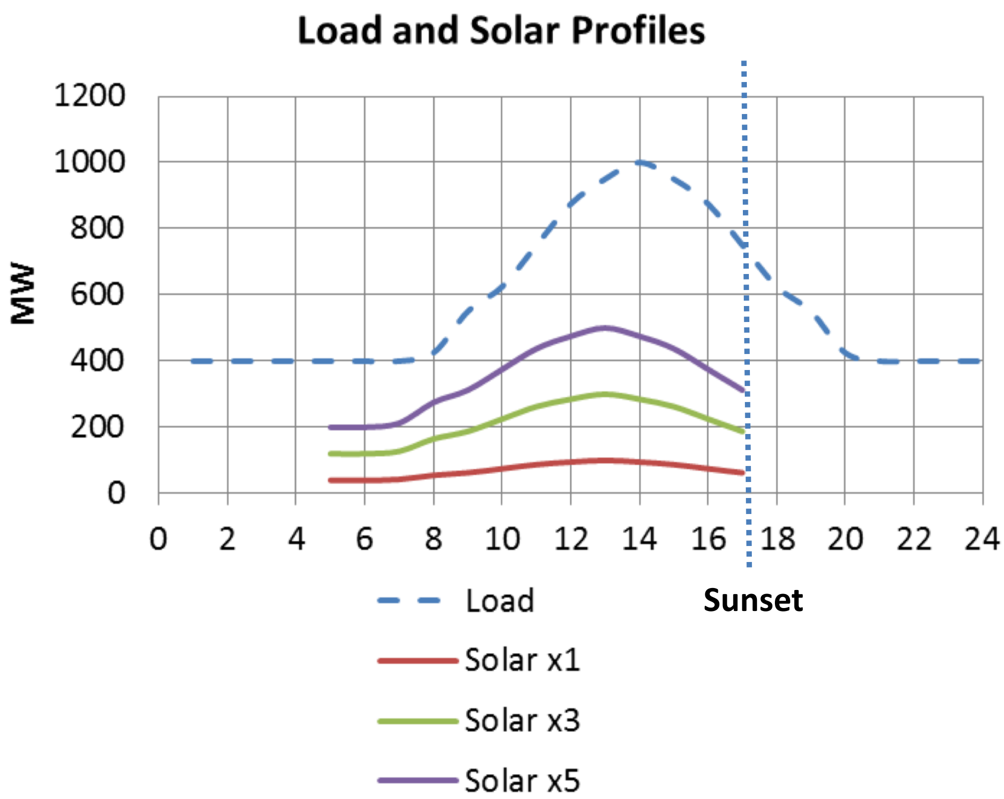
CV DECLINES WITH VRE PENETRATION LEVEL



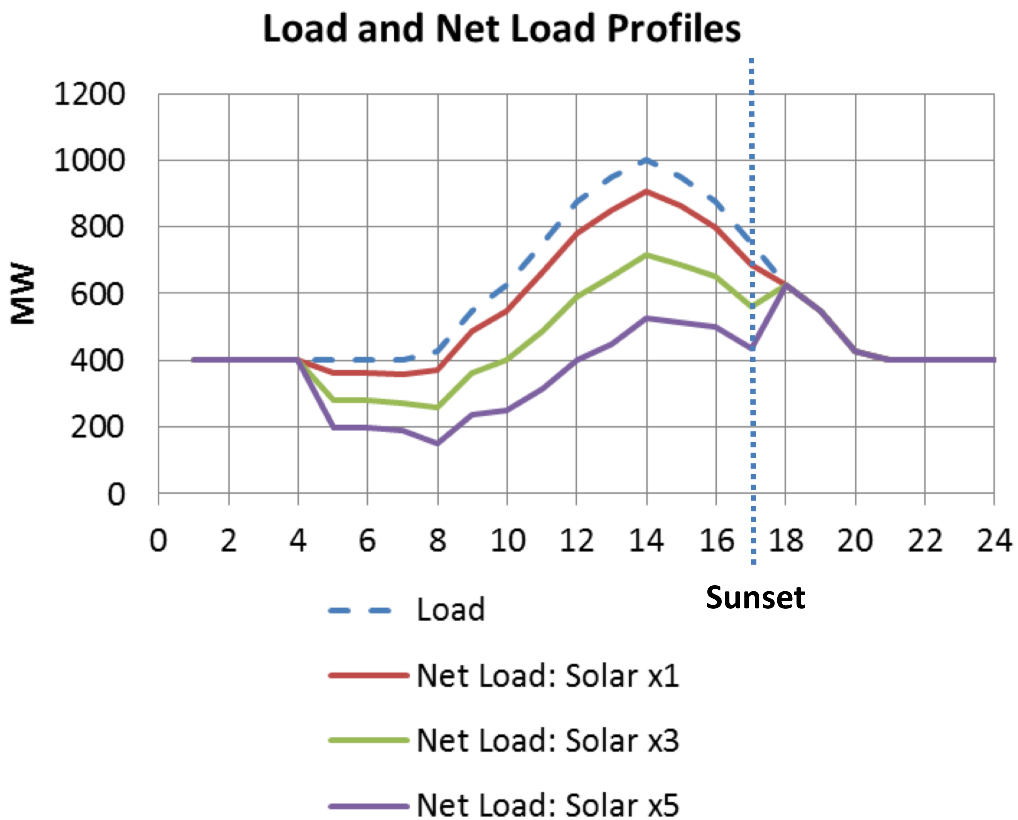
(Milligan et al. 2016)

Solar PV sees a similar decline, with marginal capacity values approaching 0 around 20% energy penetration (e.g., Munoz and Mills 2016)

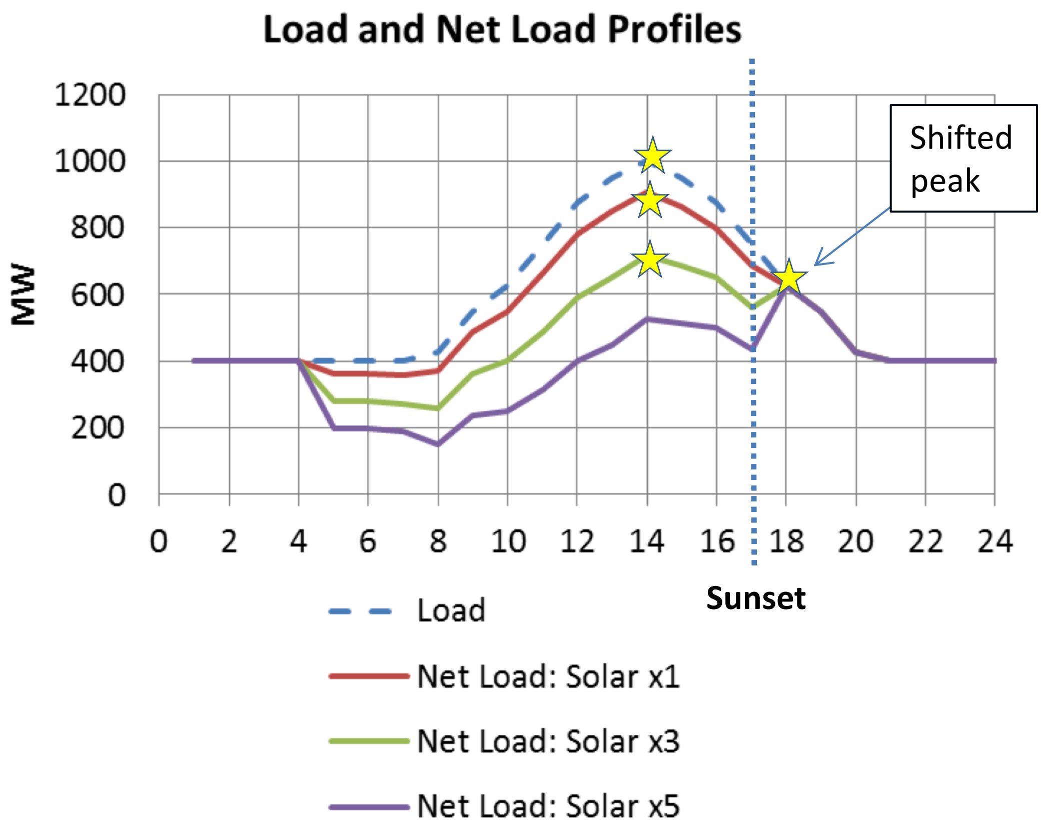
VRE DECLINING CV: SIMPLE EXAMPLE



VRE DECLINING CV: SIMPLE EXAMPLE



VRE DECLINING CV: SIMPLE EXAMPLE



How to estimate CV for variable renewable energy (VRE) resources

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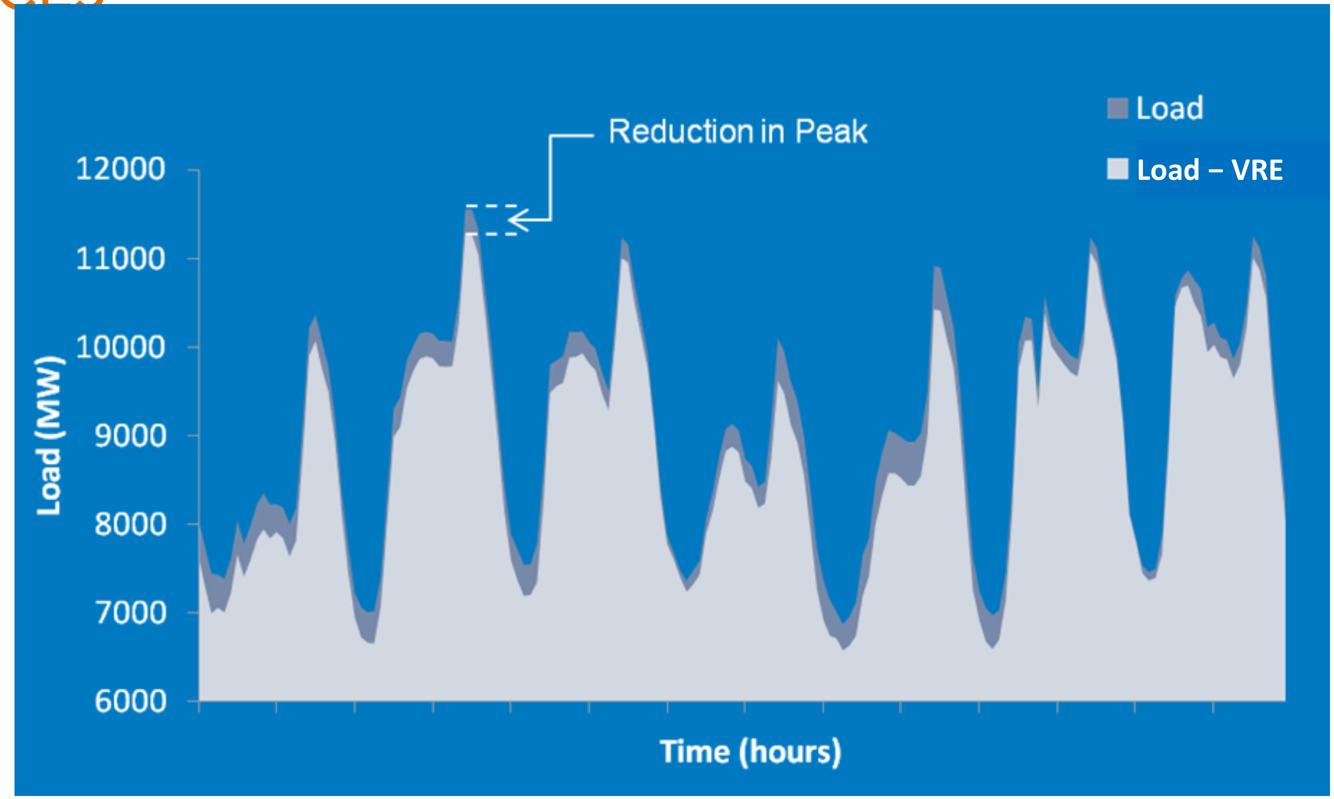

- Could explicitly back out (or embed) CV with enough data (above)
- Otherwise, the preferred approach is to calculate CV as the ELCC

A LITTLE BIT MORE ABOUT ELCC

What ELCC is *Not*

- A minimum generation value
- A schedule or forecast for solar or wind
- Unique to wind and solar

ELCC *is*

- Measure of solar or wind (or other resource's) contribution to overall system adequacy (e.g., PRM)

How Does ELCC Work?

- Holds the system at constant annual risk level with/without the generator of interest (wind, solar)
- Utilizes reliability/production simulation model
  - Hourly loads
  - Generator characteristics (capacity, planned and forced outages)
  - Network characteristics (line outage rates)
  - VRE generation pattern (hourly for >= 1 year) time-synchronized with load
  - Calculates hourly LOLP (loss of load probability)
- The hourly LOLP calculation finds high-risk hours: risk can be caused by
  - Peak loads or net loads
  - Unit unavailability (planned maintenance, forced outage)
  - Interchange and hydro schedules/availability
- Most hours/days have LOLP=0 so are discarded: only high-risk/peak hours remain in the calculation of ELCC
- For conventional units, ELCC is function of forced outage rate

ELCC REVISITED

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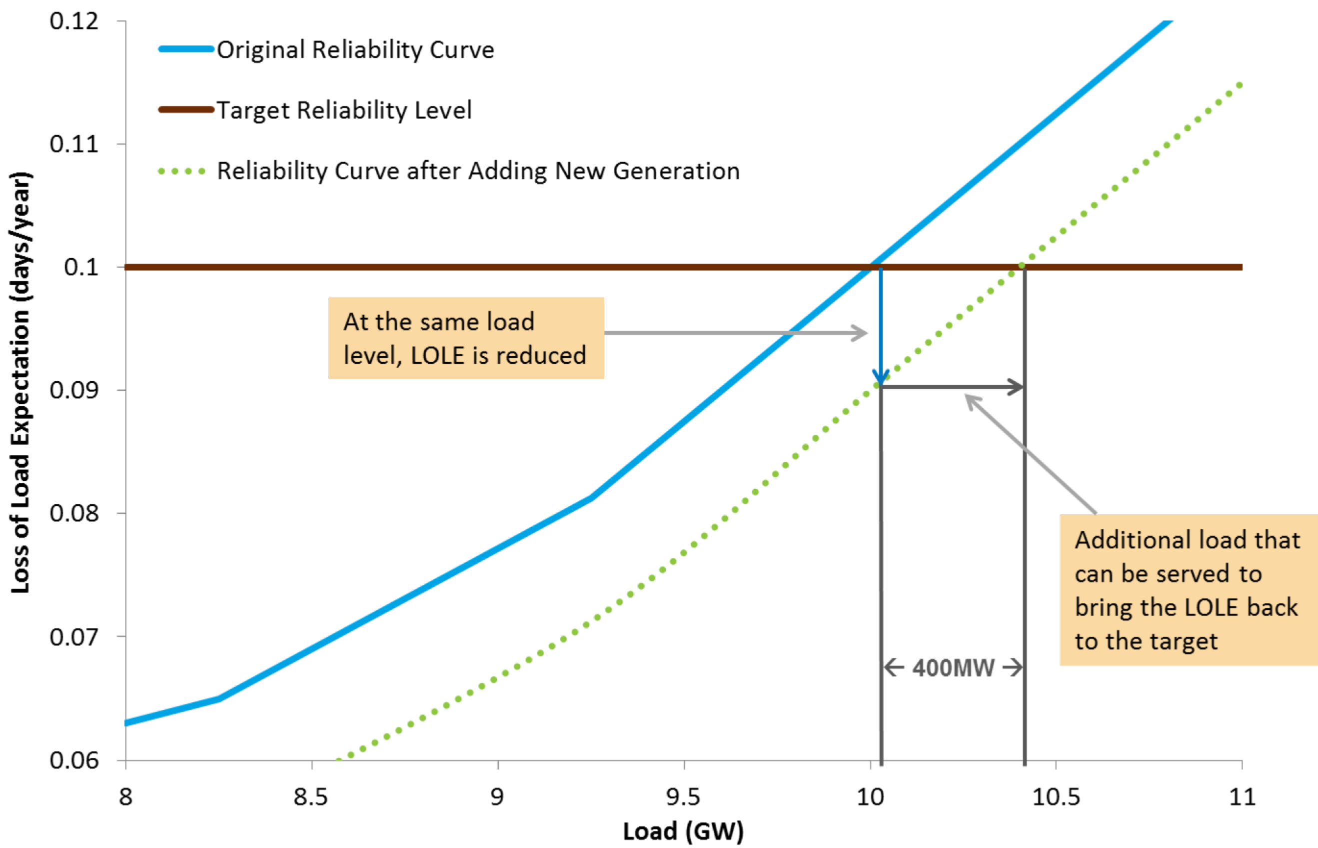


= ELCC
(Effective Load Carrying Capability)

Milligan et al. 2016

However, CV is often approximated

ELCC estimations

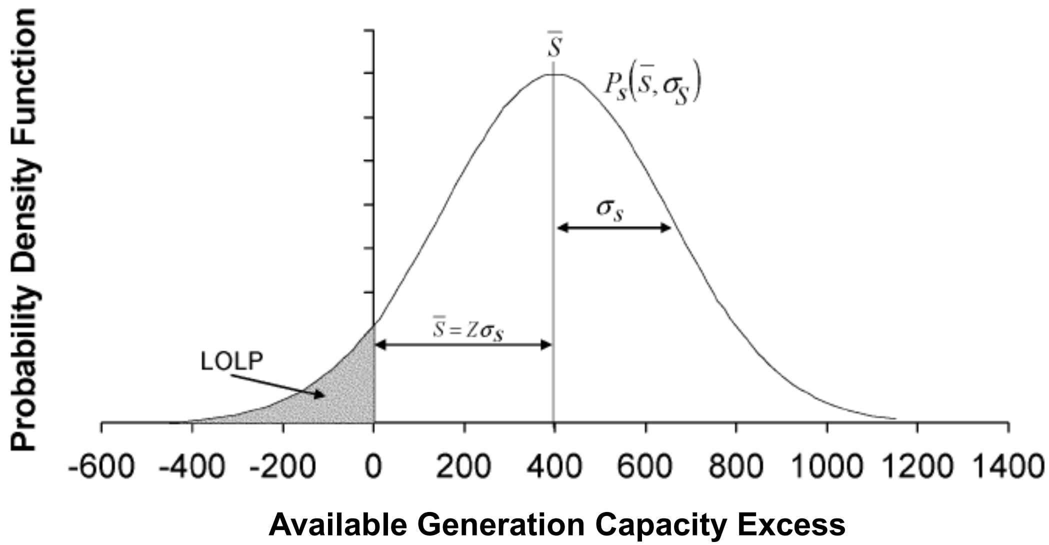
- Approximate the relationship between capacity additions and LOLP
- e.g., Z-method (Dragoon and Dvortsov 2006), Garver's method (Garver 1966), and Garver's method extended to multistate generators (D'Annunzio and Santoso 2008)

Capacity factor proxy

- Applied to "high risk" hours (e.g., Milligan and Parsons 1999 for wind, Madaeni et al. 2013 for solar)
- Ad-hoc rule of thumbs
- Applied to top load hours in load duration curve (LDC)

One example: Statistical "Z-method"

CV: additional load that can be served (ELCC) by an additional unit of capacity (e.g., VRE) while maintaining the same level of reliability (LOLP)



Source: Dragoon and Dvortsov (2006)

Another example: CV estimated as capacity factor during top hours in LDC

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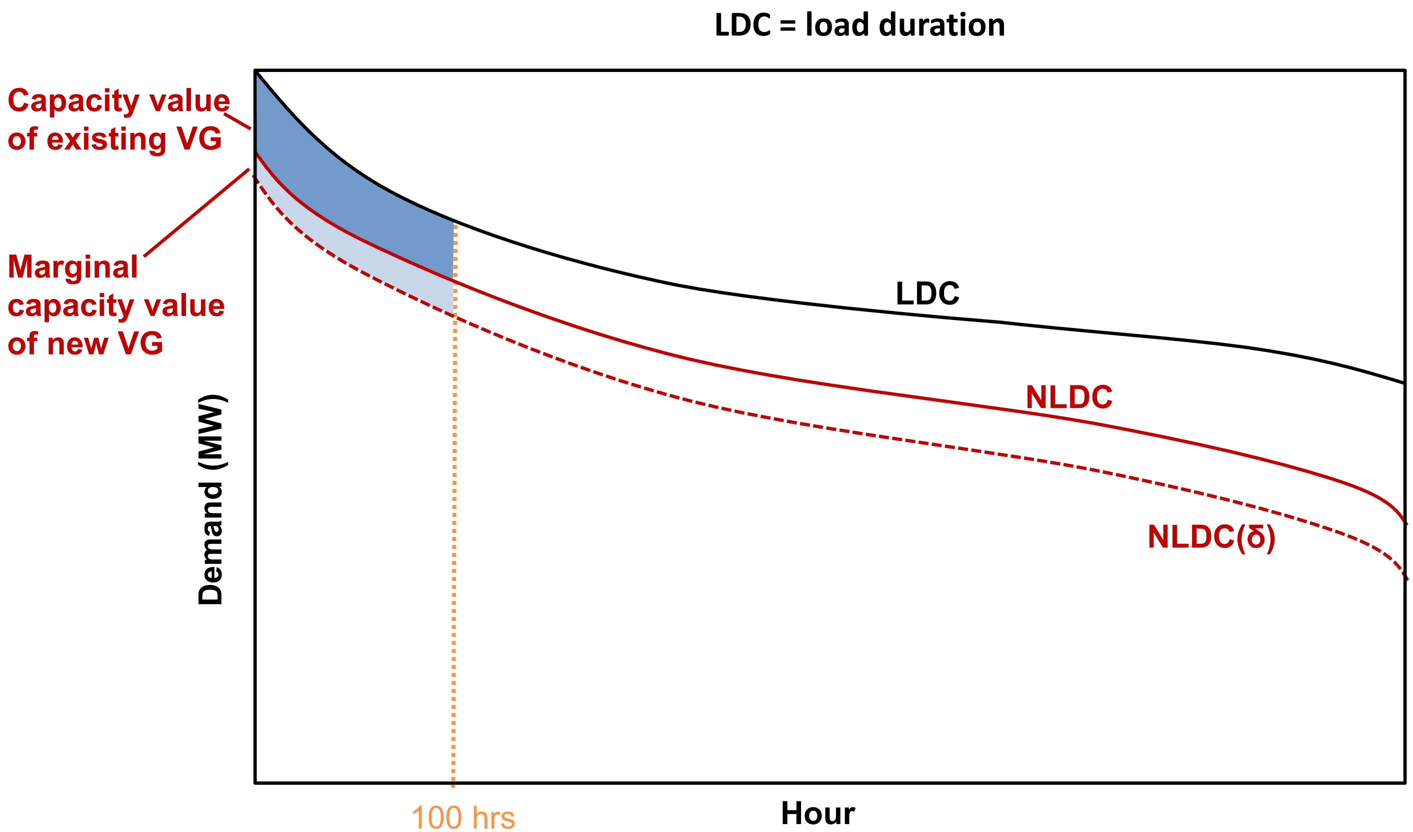
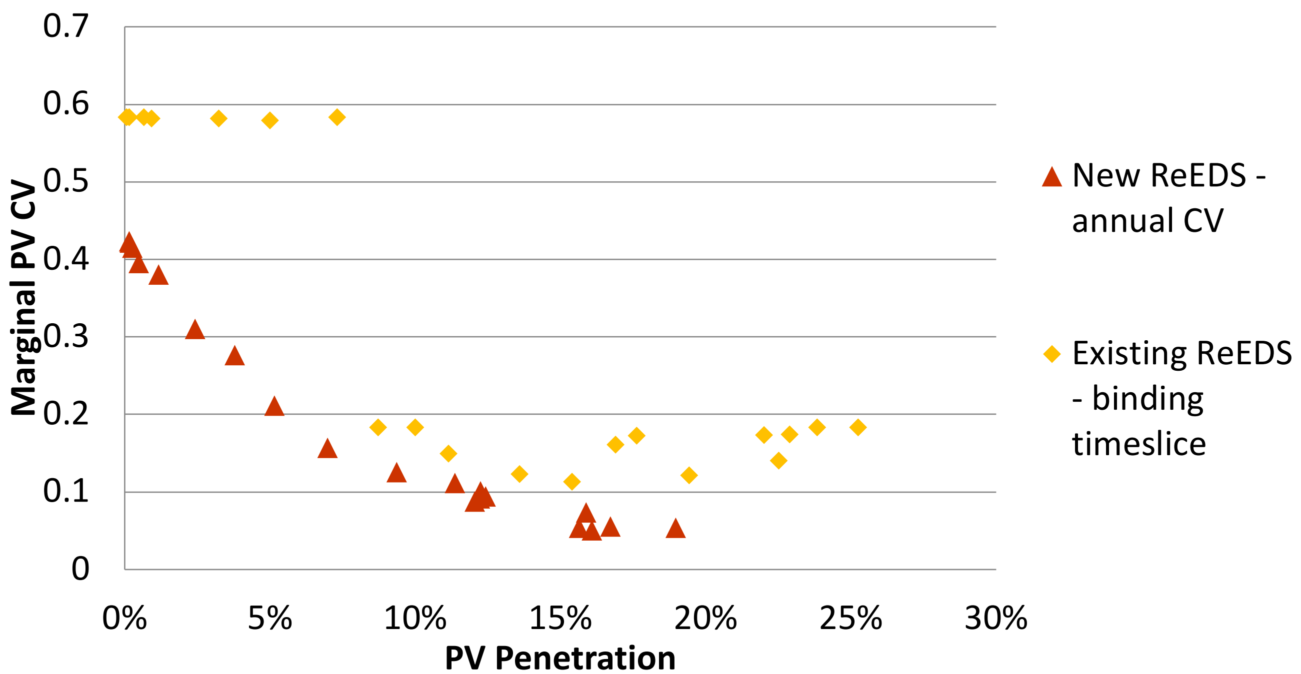


Move from time-slice based CV to annual 8760-hourly method
Consistent methodology with NREL's RPM model (Hale et al. 2016)

LDC method better captures declining CV than statistical method in ReEDS



Incremental PV CV in the Austin, Texas region (p64)

Frew et al. 2017

IN PRACTICE, CF APPROXIMATIONS ARE OFTEN USED FOR CALCULATING CV

Operator	Geographic Resolution	Sampling Period	Intra-annual distinction	Historical Window
CAISO	Site-specific	Summer afternoons, Winter evenings	Monthly	3 years
ERCOT	System-wide (solar), Coastal vs non-coastal (wind)	Top 20 load hours	Summer, Winter	3 years (solar) 10 years (wind)
MISO	Nodal disaggregated from system-wide	Top 8 load hours	Annual	11 years (wind)
NE-ISO	Site-specific	Summer afternoons, winter evenings, shortage events	Summer, Winter	5 years
PJM	Site-specific	Summer afternoons	Summer only	3 years

Note: CV is also used in operating regions with capacity markets to determine the eligible portion of capacity

RULE OF THUMB CV METHODS ARE INCONSISTENTLY INACCURATE

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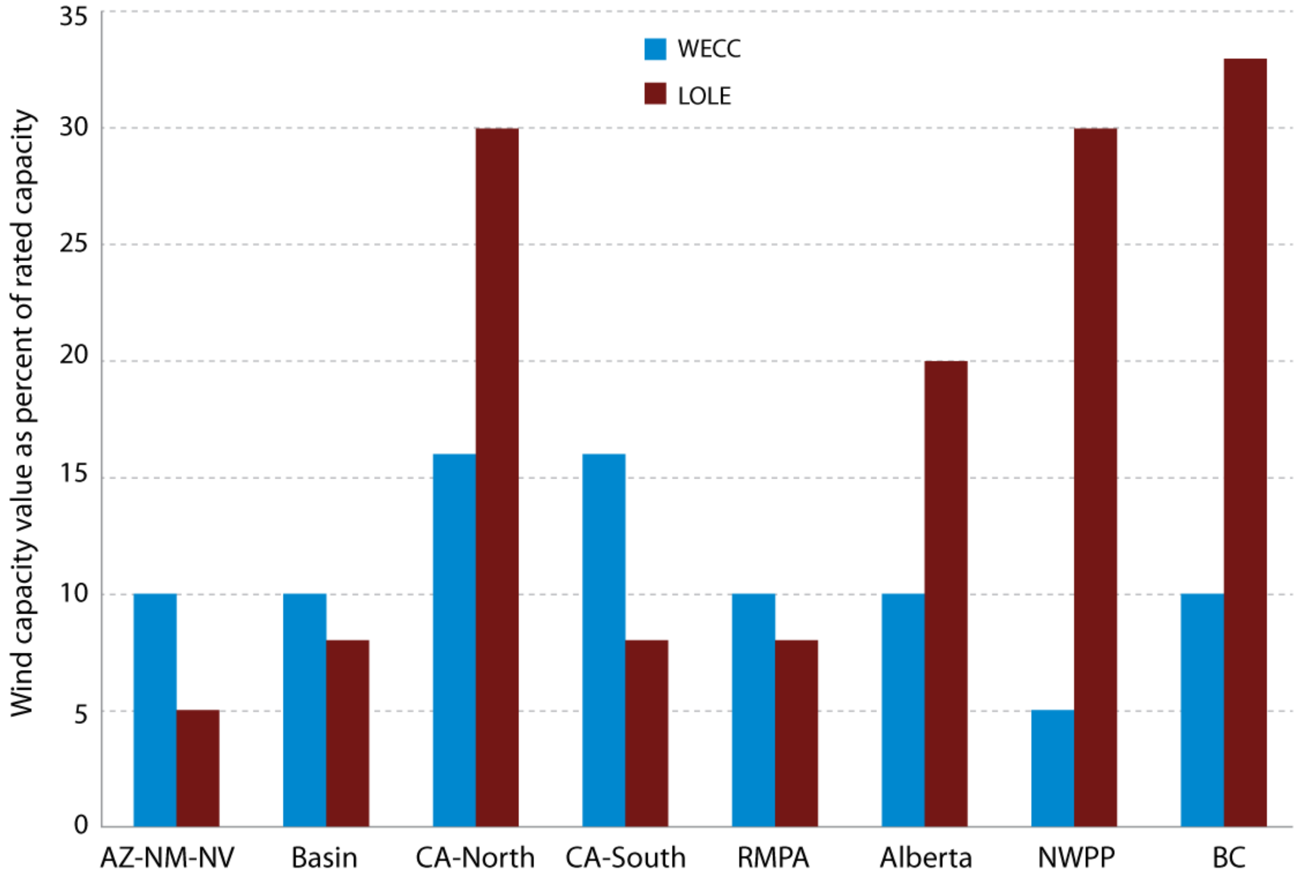

Western Electricity Coordinating Council (WECC) rules of thumb versus full reliability model

Milligan et al. 2016

OTHER CONSIDERATIONS…SINGLE-YEAR CAPACITY VALUE IS NOT ADEQUATE FOR ANY TYPE OF PLANT

- Conventional plant uses long-term forced outage rate for that type and size of plant
  - Long-term adequacy question
- Resource supply must be robust against any single unit or probable multiple unit failures at critical times
- Example: Thermal plant, 100 MW, 0.10 FOR. Expected capacity value is approximately 90% (90 MW).
  - In outage year plant has 0 capacity value
  - In "normal" years plant has 100 MW capacity value

ACHIEVE MORE ROBUST CV RESULTS WITH MULTIPLE-YEAR DATA SETS

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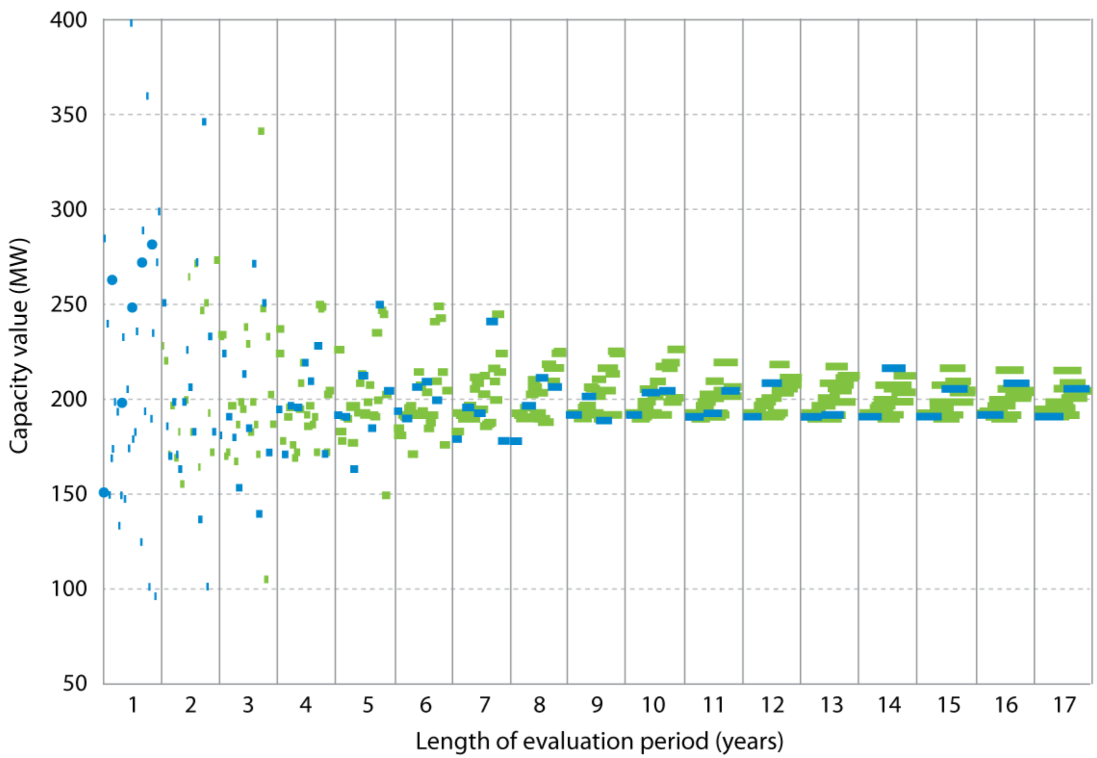

Studies suggest 8-9 years to converge on long-term value, which is key for planning decisions

Milligan et al. 2016

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TRANSMISSION ASSUMPTIONS IMPACT RESOURCE ADEQUACY LEVEL

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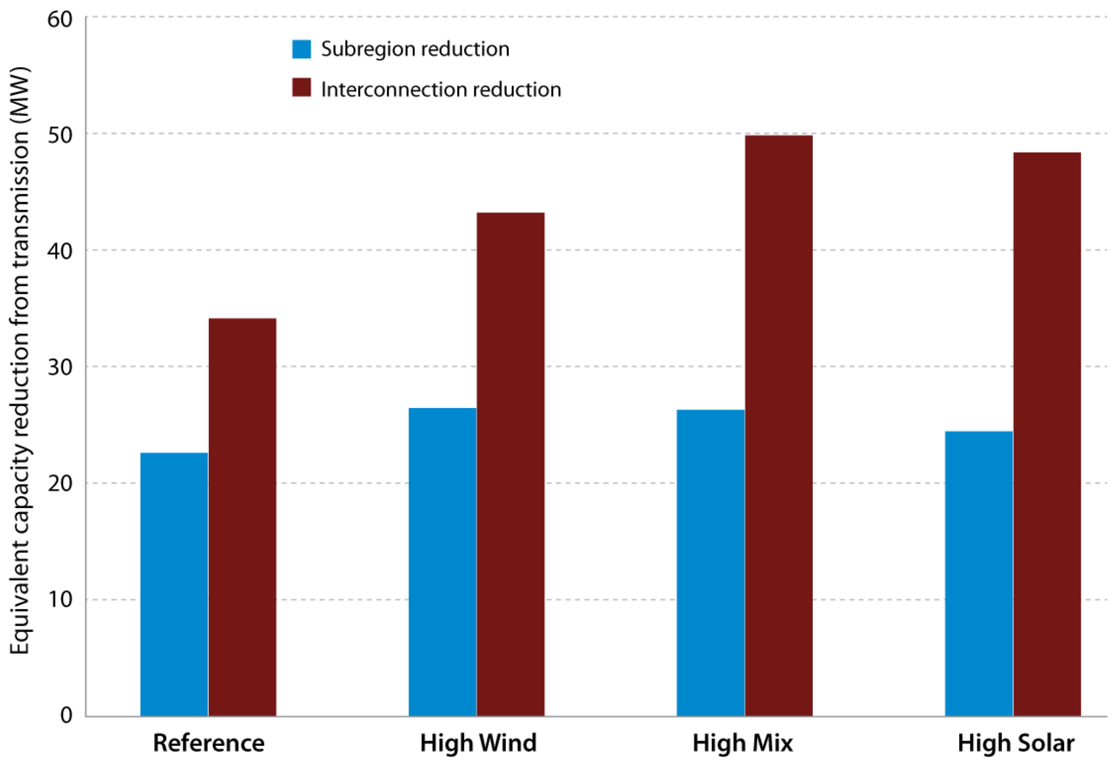
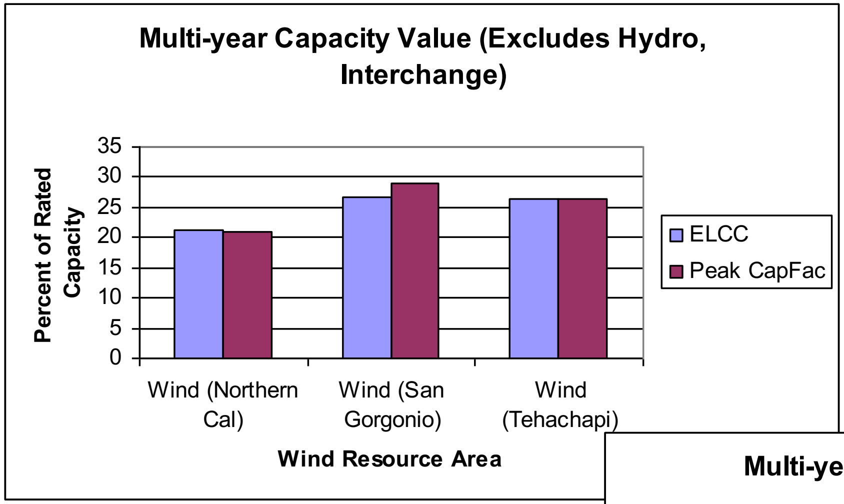


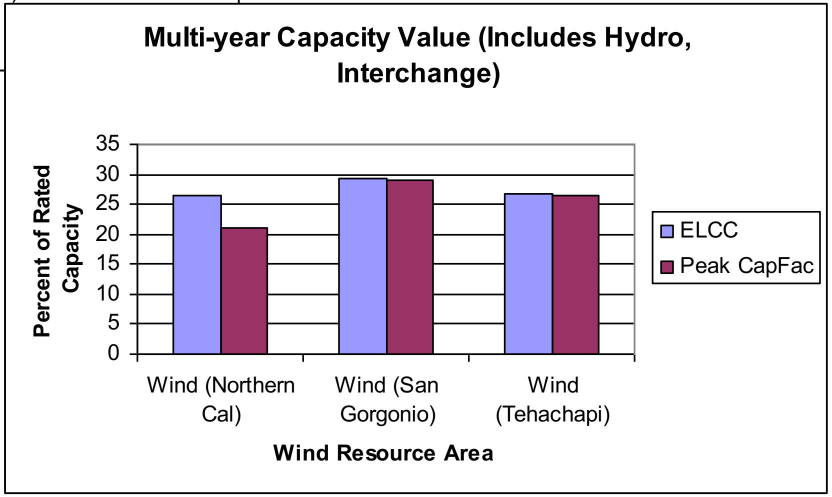
Greater reduction in required ELCC for reliability target is achieved with increasing degrees of interconnection

Milligan et al. 2016

California: Impact of Hydro, Transactions



3-year Averages



CAPTURING SYSTEM-WIDE INTERACTIONS IS INCREASINGLY IMPORTANT WITH MORE VRE

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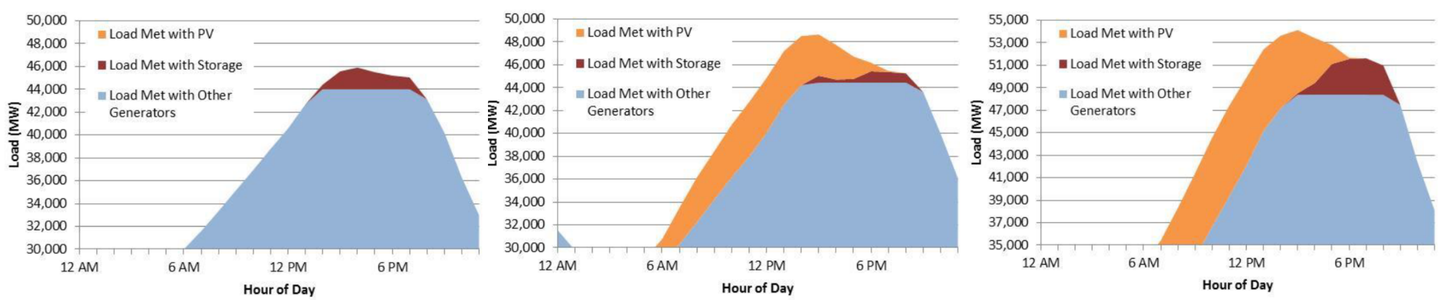
- Supply AND demand side
- Capacity AND energy constraints
- Network impacts
- Correlated or common mode failures
- Changes in net load (load minus VRE) profile:



a) Zero PV (October 12) b) 5% PV (June 30) c) 10% PV (September 9)

Impact of PV on net load profile and 4-hour storage effective market potential in California in 2015
(Denholm and Margolis)

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STORAGE IS PARTICULARLY COMPLEX

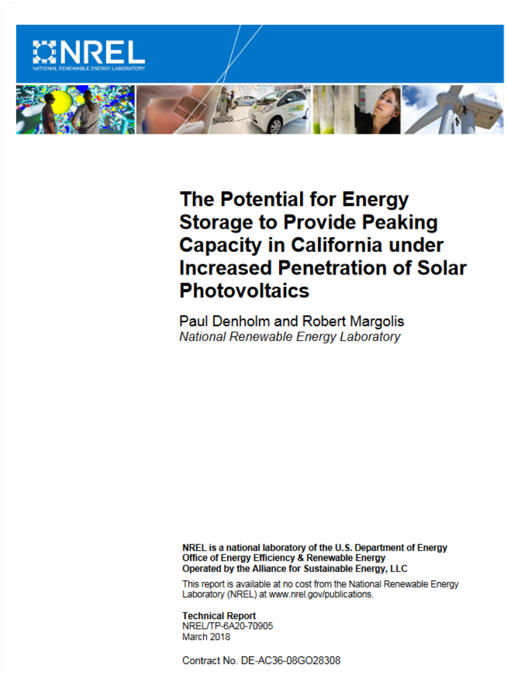
Capacity and energy constraints

- Ideally requires chronological tracking

Depends on interaction with many other system components

- Amount of existing PV
- Amount of existing storage
- Duration of storage

New storage CV method in ReEDS: functional form to capture peak net load reduction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The Potential for Energy Storage to Provide Peaking Capacity in California under Increased Penetration of Solar Photovoltaics

Paul Denholm and Robert Margolis
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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QUESTIONS?

Thank you!

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