Capacity Expansion Models (CEM) and the National Energy Modelling System (NEMS): Modelling Variable Renewable Energy (VRE)

For

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By

Cara Marcy, Renewable Energy Analyst

Outline

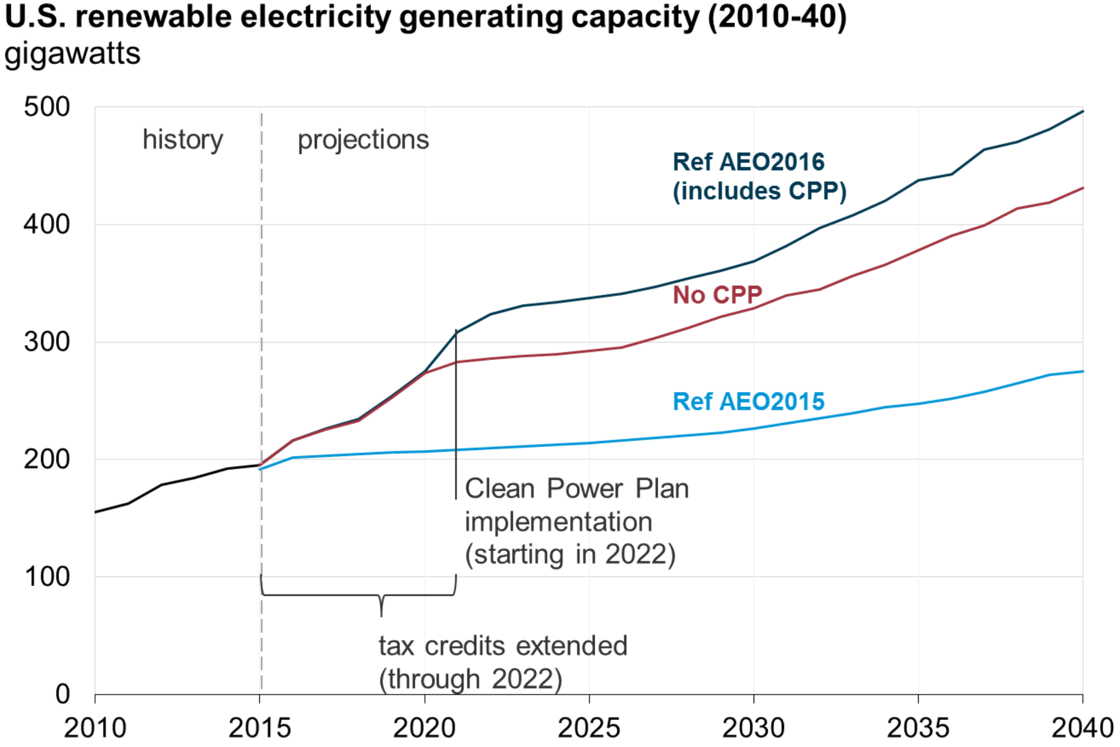
1. Capacity Expansion Model (CEM) overview
2. National Energy Modelling System (NEMS) overview
3. Electricity Market Module (EMM) overview
4. Constraints that lead to demand for new capacity
5. Variable renewable energy (VRE) modelled (overview)
6. VRE impact on meeting/contributing to primary constraints
7. Factors that impact deployment/performance of VRE
8. What's next?

Today's discussion of CEM is focused around national models, but can also be applied to utility-scale models

- CEM are used to inform policy-making and to provide quantitative analysis of the power system typically over a long-term multi-decade scope

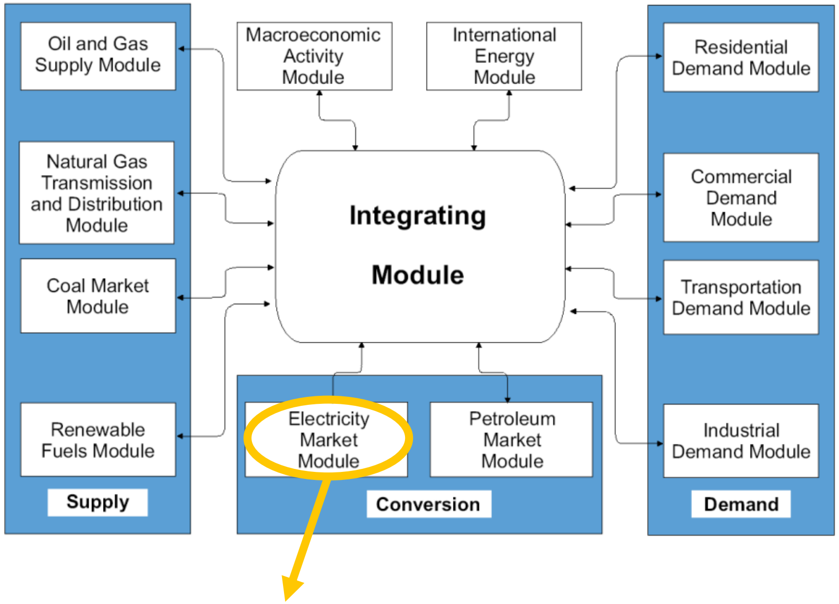
- They model investments in generation and transmission capacity, given assumptions about the future, such as electricity demand, fuel prices, & policy/regulation

- The complexity necessitates tradeoffs between detail and computational tractability



National Energy Modelling System (NEMS) provides projections (not predictions) to 2040

- NEMS is a computer-based, energy-economy modeling system of U.S. through 2040
- It projects energy:
  - production
  - imports
  - conversion
  - consumption
  - prices
- Based on assumptions about:
  - Macroeconomic/financial factors
  - world energy markets
  - resource availability and costs
  - behavioral and technological choice criteria
  - cost and performance characteristics of technologies

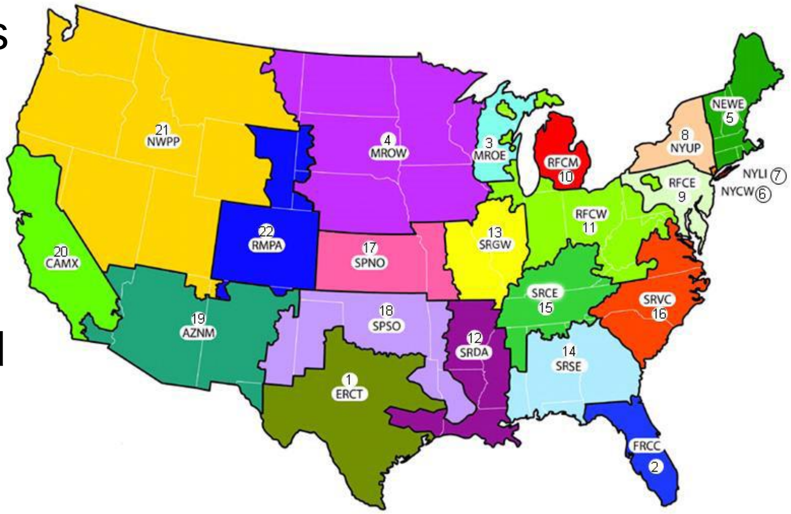


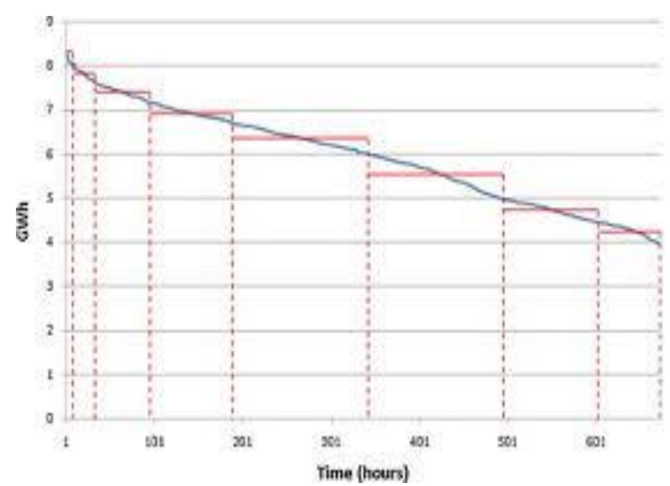
- Electricity Market Module (EMM):
  - Electricity Load and Demand
  - Electricity Capacity Planning
  - Electric Fuel Dispatch
  - Electricity Finance and Pricing

Sub-Modules

EMM represents the U.S. electricity market across 22 regions and over 9 annual time slices

- Least cost optimization model examines costs over a 3-period planning horizon of 30 years:
  - Current year
  - Next year
  - the final 28 years of cost recovery period
- Decisions are made at a 22 regional level and are for the next model year include:
  - New capacity builds
  - Environmental retrofits
  - Retirements
- Demand is characterized by a load curve of 9 time slices, solved simultaneously:
  - 3 season
    - summer
    - winter
    - fall/spring
  - 3 time segments
    - peak
    - shoulder
    - base

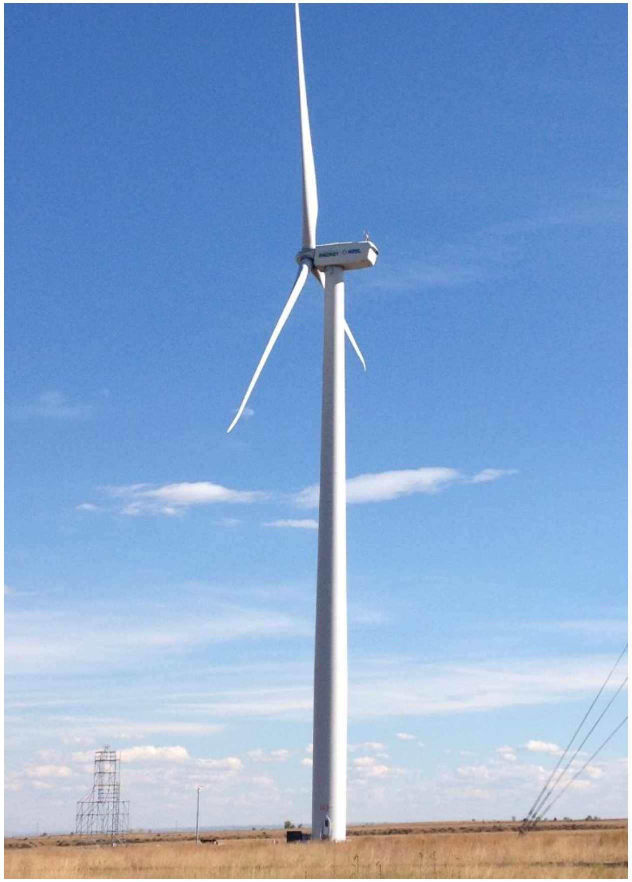




Eight different utility-scale renewable electricity technologies are represented in the model

- Renewable electricity technologies represented in NEMS include:
  - Conventional hydropower
  - Biomass-Wood
  - Biomass-Municipal solid waste/ Landfill gas
  - Geothermal
  - Solar-thermal
  - Solar-photovoltaic
  - Wind-onshore
  - Wind-offshore

Variable Renewable Energy e.g. non-dispatchable (Solar-thermal, Solar-photovoltaic, Wind-onshore, Wind-offshore)



The model decides to build capacity based on requirements set by demand projections

- **Load/energy requirements**
  - *Energy market by region, season, and time slice* – Ensure that there is sufficient energy available in order to satisfy regional demand throughout the year. Load is adjusted for items such as imports/exports and own use generation.
- **Reserve margin requirements**
  - *Capacity market by region, peak time slice* – Ensure that planning decisions that increase supply by adding new capacity are sufficient to satisfy regional reliability requirements.
- **Spinning reserve requirements**
  - *Capacity market by region, season, and time slice* – Capacity that must be committed to operate to provide load but also is available to contribute to the spinning reserves.

VRE contribution to load requirement is limited to a load segment based on the availability of the resource

- EIA uses NREL datasets to develop wind/solar resource data
  - Hourly resource data is aggregated at the regional level and then at each of the 9 time slices for use in planning
  - Wind resource data is also broke up into 5 wind resource classes
- The marginal value of energy at each region/timeslice declines as more zero-fuel-cost renewable resources participate in the market

Capacity factor for solar PV, by hour/month, example region

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0%	0%	0%	0%	0%	0%	0%	3%	22%	46%	53%	55%	56%	56%	56%	51%	43%	19%	1%	0%	0%	0%	0%	0%
2	0%	0%	0%	0%	0%	0%	0%	4%	31%	48%	54%	57%	59%	59%	59%	56%	49%	30%	3%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	11%	39%	50%	56%	61%	61%	61%	61%	58%	50%	32%	3%	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%	4%	21%	47%	56%	60%	63%	64%	63%	62%	58%	51%	30%	4%	1%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	1%	6%	24%	45%	54%	58%	60%	61%	61%	60%	56%	48%	28%	7%	1%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	2%	9%	26%	48%	55%	58%	59%	59%	59%	58%	54%	48%	31%	9%	3%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	1%	7%	23%	49%	56%	59%	60%	60%	60%	58%	54%	48%	32%	9%	3%	0%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	5%	22%	48%	57%	61%	61%	60%	59%	57%	53%	45%	29%	5%	1%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	1%	21%	46%	55%	58%	61%	61%	61%	59%	55%	46%	24%	1%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	1%	18%	44%	54%	57%	60%	60%	59%	58%	52%	42%	14%	0%	0%	0%	0%	0%	0%
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12	0%	0%	0%	0%	0%	0%	0%	4%	26%	46%	51%	54%	55%	54%	52%	47%	36%	9%	0%	0%	0%	0%	0%	0%
1	0%	0%	0%	0%	0%	0%	0%	7%	35%	50%	55%	57%	57%	56%	54%	52%	43%	15%	0%	0%	0%	0%	0%	0%
2	0%	0%	0%	0%	0%	0%	0%	7%	41%	52%	58%	61%	62%	59%	55%	54%	48%	27%	1%	0%	0%	0%	0%	0%
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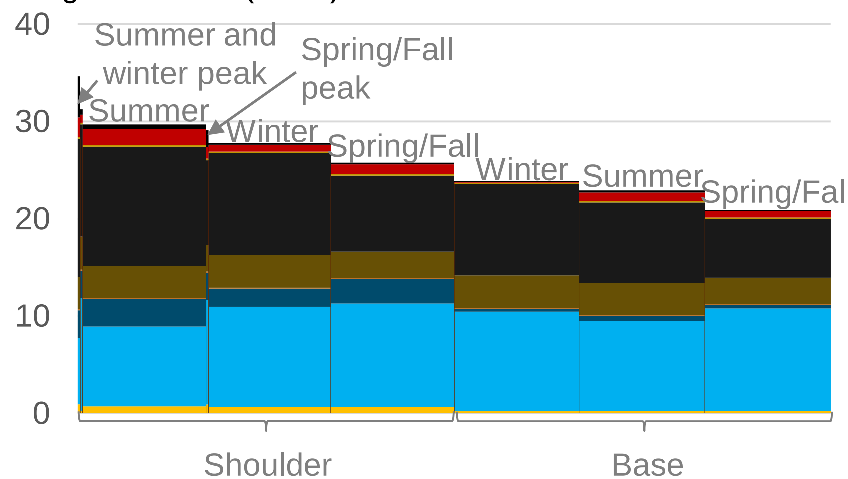
4	0%	0%	0%	0%	0%	0%	2%	29%	53%	60%	64%	65%	65%	64%	62%	59%	51%	27%	4%	0%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	1%	5%	32%	54%	59%	62%	62%	60%	60%	57%	54%	45%	24%	9%	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	1%	6%	27%	46%	52%	53%	53%	53%	49%	49%	45%	36%	20%	7%	0%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	7%	24%	47%	54%	55%	55%	53%	51%	47%	41%	33%	19%	5%	0%	0%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	3%	24%	48%	56%	56%	56%	54%	52%	48%	42%	34%	18%	3%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	1%	22%	44%	51%	54%	54%	53%	51%	46%	41%	33%	14%	0%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	2%	23%	47%	54%	57%	58%	58%	56%	53%	49%	37%	7%	0%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	0%	14%	44%	55%	58%	59%	58%	55%	52%	47%	33%	3%	0%	0%	0%	0%	0%	0%
12	0%	0%	0%	0%	0%	0%	0%	8%	36%	48%	52%	53%	53%	52%	49%	45%	33%	5%	0%	0%	0%	0%	0%	0%

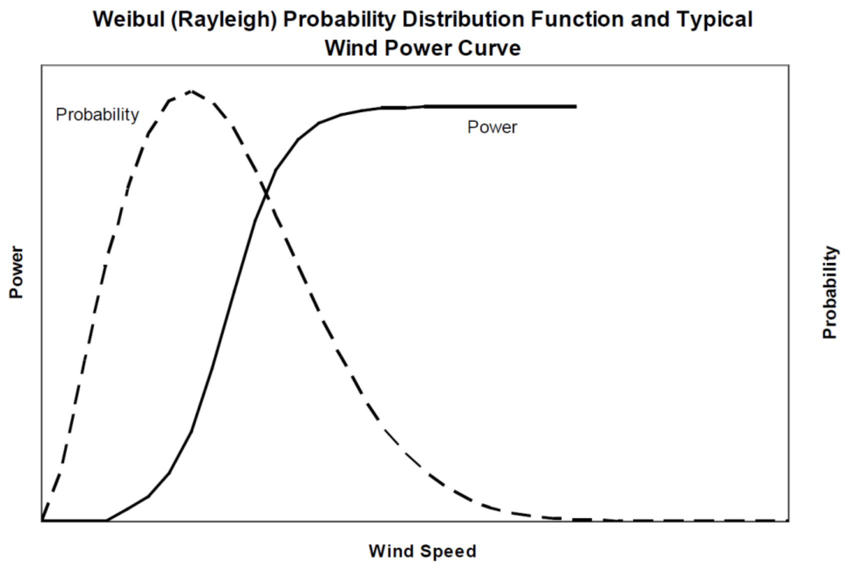
Hourly Generation by Dispatch Order, example region
megawatthours (MWh)



Capacity credit for VRE determines the amount of capacity available for the reserve margin requirement

- **Capacity credit:** estimated portion of capacity that will be available during peak generation

- **System reliability:** goal of five 9's (99.999% = 1 hour per 10 years)
  - Peak load = 1.56%
    = 137 hr/yr
  - Reliability goal is = 99.93%
    = 1 hr in 137 hr/yr x 10 yrs



- Despite being non-dispatchable, there is a probability that some degree of VRE generation will be available during times of peak demand

- The marginal effective load carrying capacity of VRE declines as additional capacity is added to the market until it reaches a "saturation" point

Spinning reserves address the volatility of VRE and the uncertainty in meeting demand

- **Spinning reserves:** available reserve capacity that is ready to meet load quickly in order to maintain grid stability during unforeseen load swings

- At higher penetrations, the non-dispatchable nature of VRE increases the need for spinning reserves

- In NEMS, the level of this requirement is based on:
  - a percent of the load height in each the slice
  - a percent of the distance between load of the timeslice and the seasonal peak
  - a percent of the available intermittent capacity within a timeslice

- Non-spinning reserves are currently not represented within the model

Some factors within the model impact the ability/value of VRE used towards meeting these requirements

- **Variable/Intermittency Bound**
  - *By region, by year,* the fraction of VRE generation permitted to be built
  - Initially the bound is set to 20%, increases by 5 percentage-point intervals
  - The total amount of VRE is limited to a **maximum of 40%** per year/region

- **Capacity Factor Learning (wind only)**
  - *National, by wind class,* for every doubling of capacity installed in the US, the capacity factor for wind increases asymptotically

$$C = C_u e^{-b/G} \quad b = G_i \ln {}^{C_i}/_{C_u}$$

- **Curtailment**
  - *By region, by timeslice,* a reduction in the output of VRE from what it could otherwise produce given available resources

$$W_{Crit} = L_{g,t} - (D_{coal} * O_{coal} * C_{coal} + D_{nuclear} * O_{nuclear} * C_{nuclear})$$

EIA is always looking for new ways to enhance NEMS representation of the energy sector

- Earlier this year EIA published a report that reviewed EIA's past performance of modelling wind and solar technologies:

  Wind and Solar Data and Projections from the U.S. Energy Information Administration: Past Performance and Ongoing Enhancements

- Potential future enhancements to NEMS/EMM:
  - Update regionality
  - Extended planning horizon (2050)
  - Include utility-scale energy storage
  - Include other renewable technologies, such as low speed wind