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Evaluating the Value of High Spatial Resolution in National Capacity Expansion Models using ReEDS

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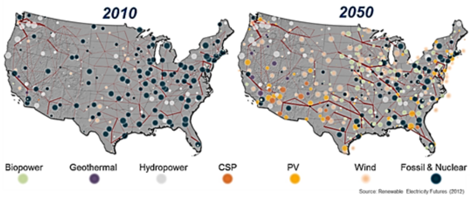
Objective & Key Conslusion

- Power sector capacity expansion models (CEMs) have a broad range of spatial resolutions- e.g., NEMS (22 regions), IPM (64 regions), ReEDS (134 regions), PLEXOS (user defined).
- We use NREL's **Regional Energy Deployment System (ReEDS)** model, a long-term national-scale electric sector CEM for the United States, to evaluate the value of high spatial resolution.
- We perform planning at three different spatial resolutions– 1) **REF**: 134 balancing areas (native ReEDS resolution), 2) **STATE**: 48 contiguous states, and 3) **NERC**: 13 NERC regions
- We evaluate the impact of spatial resolution on renewable capacity deployment and location, associated transmission builds, and system costs.
- ***Spatial aggregation impacts the relative competitiveness of renewables, and higher levels of aggregation led to less solar PV deployment while wind deployment increased.***

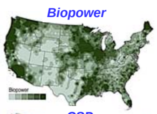
Regional Energy Deployment System (ReEDS) Model - Introduction

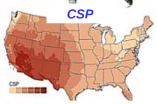
ReEDS finds the regional mix of generation technologies that meet the electric sector requirements at least cost.

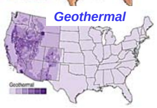


ReEDS output includes:

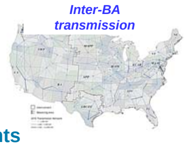
- Capacity and generation evolution of all generator types by region at high geospatial resolution
- Impact of policies on clean energy deployment
- Transmission expansion and inter-regional energy flows
- Emissions, fuel consumption and water consumption
- System costs and electricity prices

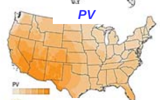


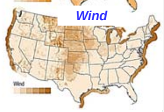




- **134** Balancing Areas (BAs)
- Highly resolved RE resource representations (**356** wind/ CSP regions)
- RE resource accessibility & other development costs
- Transmission (~**300** lines)
  WECC: 35 nodes, 72 AC, 2 DC
  East: 92 nodes, 213 AC lines
  ERCOT: 7 nodes, 12 AC lines
  9 AC-DC-AC interties







Model Constraints

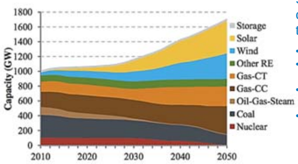
- Regional load, planning reserves & operating reserve requirements
- Federal & state policies (e.g. RPS, CAIR, CSAPR, CPP, RGGI, MATS, AB32)
- Inter-BA transmission constraints
- 17 time-slices (4 seasons x 4 diurnal + 1 super peak)
- Impact of variable resources on capacity value, reserves & curtailments

Study Design

- **REF scenario**: Renewable (RE) resource availability, cost & performance is represented at ReEDS native resolution (356 regions for wind and CSP, 134 regions for all other technologies)
- **STATE scenario**: RE costs and capacity factors were averaged (capacity-weighted) across all the 134 or 356 resource regions within each state, resulting in a common cost and capacity factor within each state
- **NERC scenario**: RE costs and capacity factors were averaged (capacity-weighted) across all the 134 or 356 resource regions within each NERC region, resulting in a common cost and capacity factor within each NERC region
- In all the scenarios, inter-BA transmission limits and distances were respected.
- All three scenarios used the NREL's Annual Technology Baseline (ATB) 2015 mid-case cost and performance assumptions. The ATB is a collection of current and future cost and performance projections for generating units for the U.S. electricity sector.

Impact of Spatial Resolution on Renewable Deployment & Planning Costs

REF scenario – cumulative installed capacity



Scenarios revealed appreciable changes primarily in three technologies **with lower resolution**:

- **Solar PV capacity decreases**
- **Wind capacity increases** in response to the decrease in PV capacity
- **Gas-CC capacity increases** to compensate for PV decrease
- Additionally, slight changes in gas-CT and storage capacities in some years- driven by varying degrees of variable renewable curtailments

TABLE I COMPARISON OF NATION-WIDE WIND, PV, GAS-CC CUMULATIVE CAPACITY & TRANSMISSION AT DIFFERENT SPATIAL AGGREGATION

Year	2010			2020			2030			2040			2050		
Scenario	REF	STATE	NERC	REF	STATE	NERC	REF	STATE	NERC	REF	STATE	NERC	REF	STATE	NERC
PV (GW)	0.8	0.8	0.8	21.5	21.6	22.9	77.1	70.3	52.8	186.4	167.1	95.0	300.1	268.1	190.3
Wind (GW)	39.7	39.7	39.7	89.7	90.5	89.1	134.7	126.2	127.6	224.9	224.4	241.8	343.2	346.0	354.8
Gas-CC (GW)	204.1	204.1	204.1	245.1	245.1	245.1	253.0	255.4	252.6	265.6	268.3	268.7	380.9	383.6	397.9
Inter-BA transmission (10^3 GW-miles)	82.4	82.4	82.4	86.5	86.5	86.5	95.3	94.5	94.0	104.9	103.0	105.0	119.7 (757GW)	118.5 (752GW)	117.7 (749GW)
Intra-BA -Solar (10^6 MW-miles)	0.0	0.0	0.0	0.5	0.5	0.5	0.9	0.8	0.8	1.4	1.3	1.3	3.2	2.5	2.1
Intra-BA -Wind (10^6 MW-miles)	0.7	0.7	0.7	2.3	2.3	2.2	3.2	3.3	3.4	6.4	7.1	8.3	11.3	12.6	12.5

Effect of spatial aggregation of RE resource parameters:

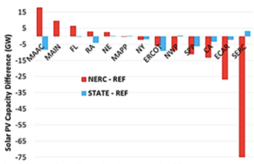
- As in the case of PV resources, low cost high performance (high capacity factors and capacity value during peak periods) resources may be "missed" by the model as a result of averaging with other higher cost lower performance resources
- On the other hand, as in the case of wind resources, averaging the parameters of a remote "good" resource that needs transmission with a local "poor" resource that does not need transmission may improve the "poor" resource's attractiveness

Impact on system planning cost & regional PV deployment

TABLE II COMPARISON OF SYSTEM PLANNING COSTS (NPV)

Category (2015$)	REF	STATE	NERC
Conventional Capital	349.61	356.05	355.79
Conventional O&M	840.02	843.66	846.05
Conventional Fuel	2159.78	2190.40	2234.83
Renewable Capital	613.64	598.38	570.43
Renewable O&M	238.54	236.18	237.01
Renewable Fuel	24.19	23.82	25.14
Storage Capital	2.54	2.18	2.11
Storage O&M	9.26	9.12	9.11
All Transmission	60.73	63.10	66.13
Water	0.02	0.02	0.02
TOTAL	4298.33	4322.92	4346.61
Difference		24.59	48.28

Note: planning horizon – 2010 to 2050; discount rate – 3%



Impact on System Planning Cost (2015$):

- With anticipated lower cost solar PV resources available to the high-resolution CEM models (this study assumed hitting $1/W SunShot target in 2030s), lower resolution CEM models which misses these low cost PV sites due to aggregation will over estimate the system planning costs.
- This is because lower resolution CEM models under-invest in low cost PV resources and instead invest in other expensive generating options.
- Relative to REF scenario, in the table we observe a ~$25B and ~$50B increase under STATE and NERC resolution scenarios.

Impact on regional PV capacities:

- Aggregation of the cost and performance metrics at the state-level has a relatively limited overall effect on solar PV deployments, while aggregation at the NERC level has a substantial impact, especially in SERC and ECAR (see right side figure on capacity difference).

Summary & Conclusions

- An overview of the ReEDS electricity system capacity expansion model that optimizes the generation portfolio along with transmission expansions from 2010 to 2050.
- ReEDS has high spatial resolution in terms of representing the U.S. electric sector using 134 BAs, with generation technology cost and performance data at the same or higher resolution (356 regions for wind and PV).
- The paper assessed the impact of two degrees of model aggregation by averaging the cost and performance of RE resources at 48 state and 13 NERC region levels.
- Results revealed that **spatial aggregation** of RE resources **impacts the competitiveness of RE resources** (which need transmission access).
- Lower quality resources may appear better when aggregated with higher-quality resources, and vice versa, leading to differences in the relative competitiveness of renewable technologies and the consequent investment in capacity.
- The scenarios indicated that **solar PV was the most sensitive to the level of aggregation**. Higher levels of aggregation led to less PV deployment while wind deployment increased.

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