Air quality benefits of replacing coal with wind and solar in Texas

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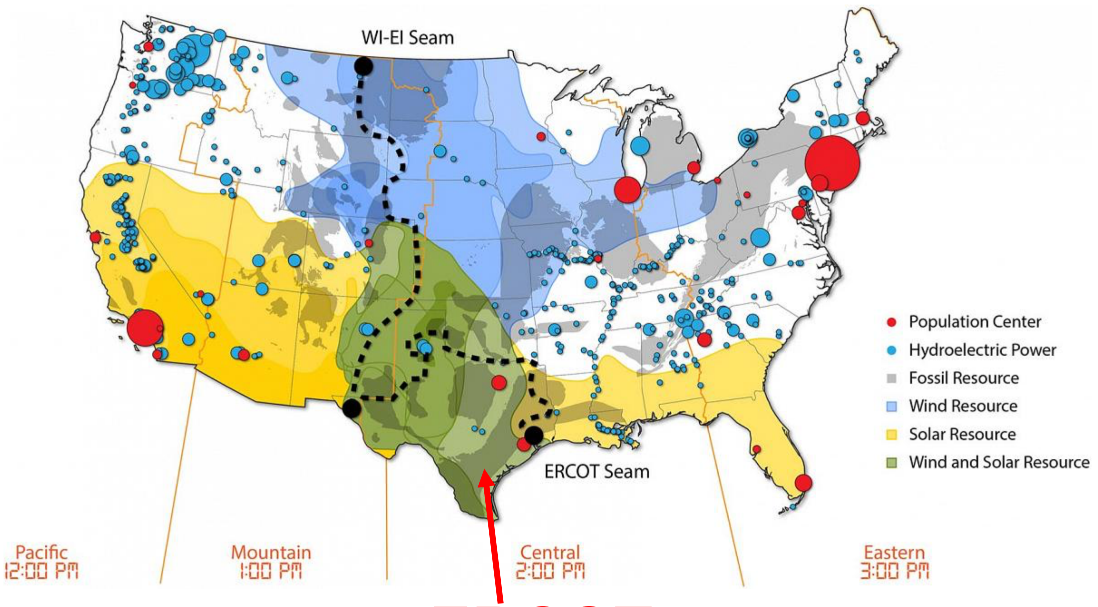
CMAS Conference, October 2020

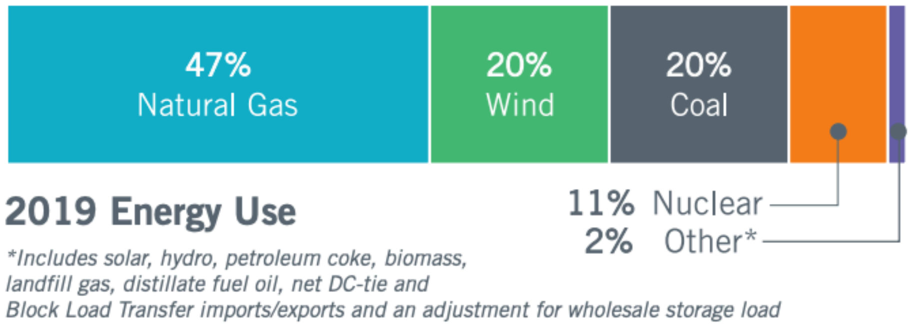
RICE

Motivation: Electricity in ERCOT

- Isolated power grid
- Texas #1 in coal, gas, and wind
  - Solar is small but growing fast
- Texas #1 in CO_2, NO_x & SO_2
  - Climate, ozone, $PM_{2.5}$, regional haze, and health impacts
  - Hundreds of mortalities per year
- Motivating question: Can wind and solar displace coal throughout the year?



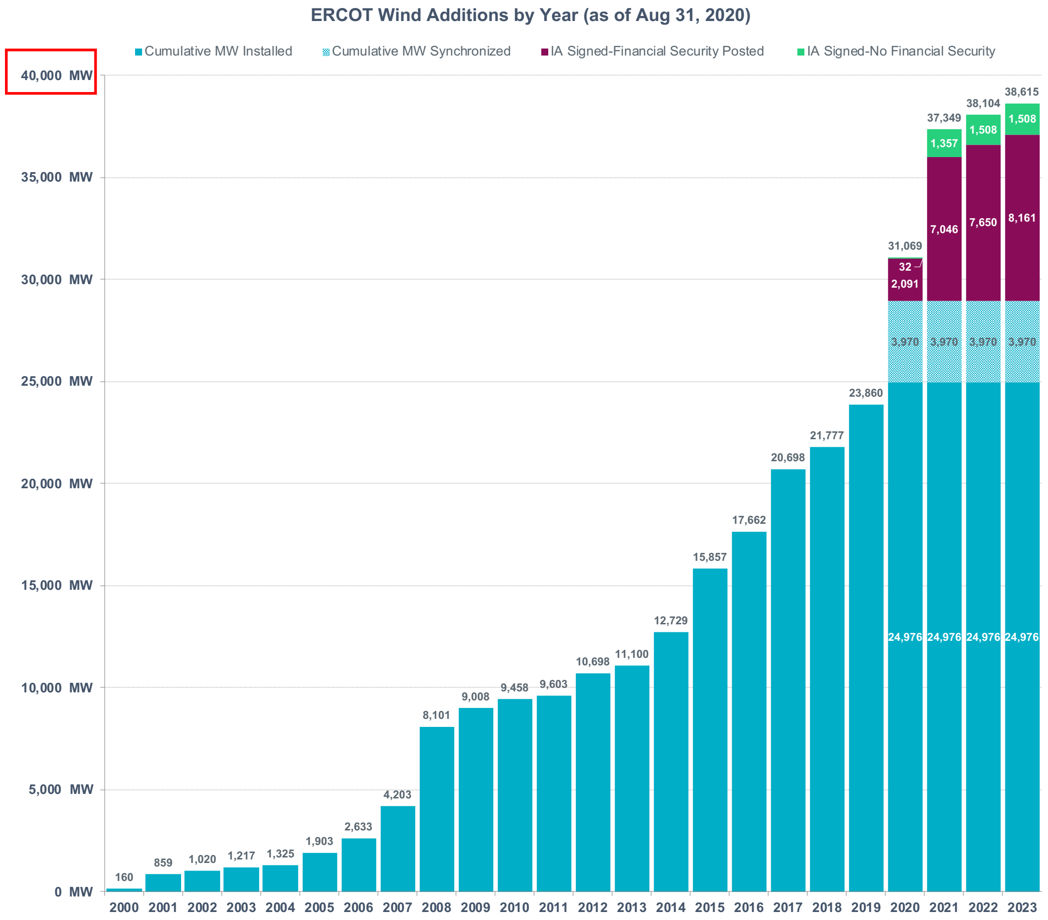
ERCOT



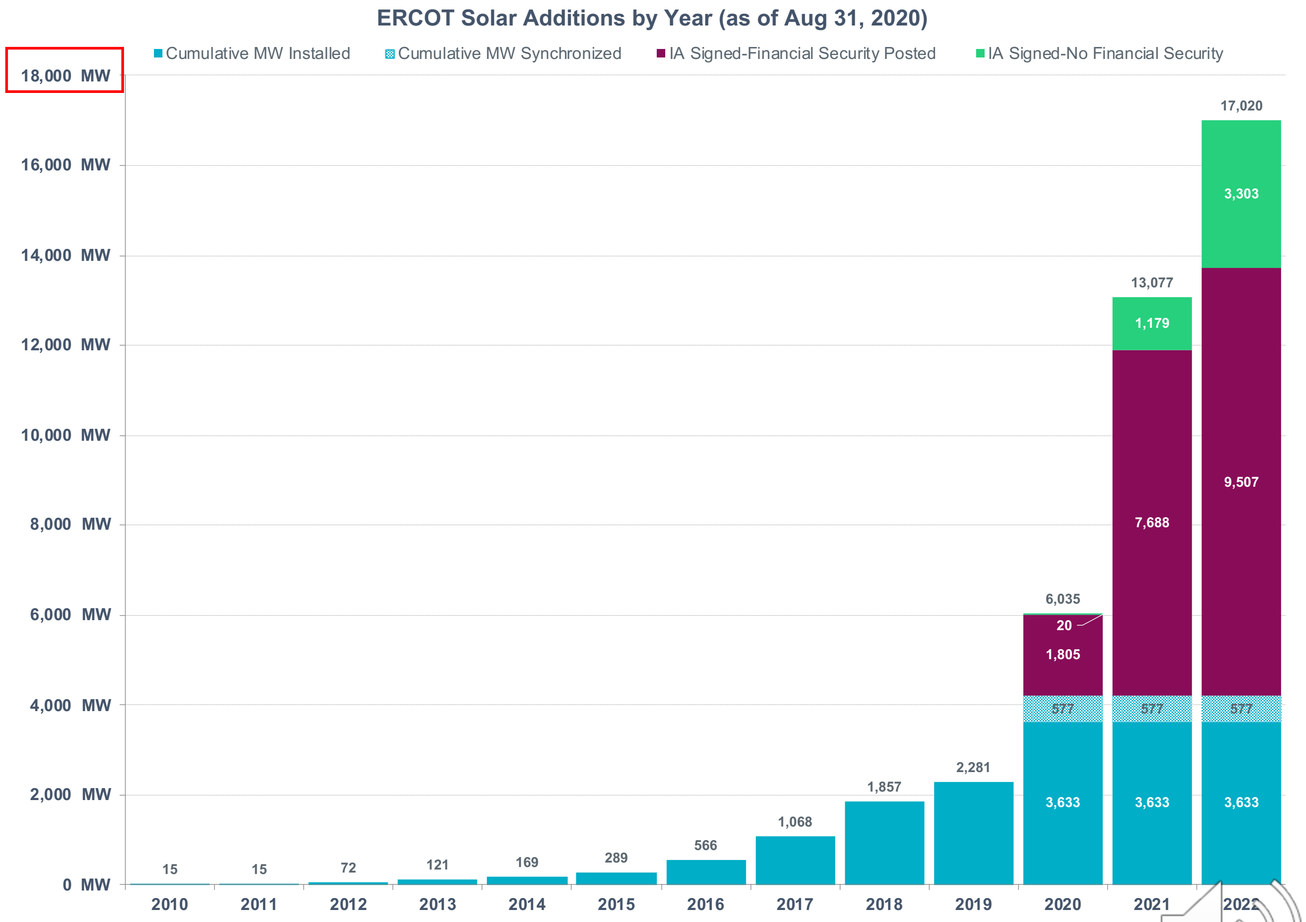
ERCOT fact sheet; NREL seams study

Rapid growth in wind and solar

Wind



Solar

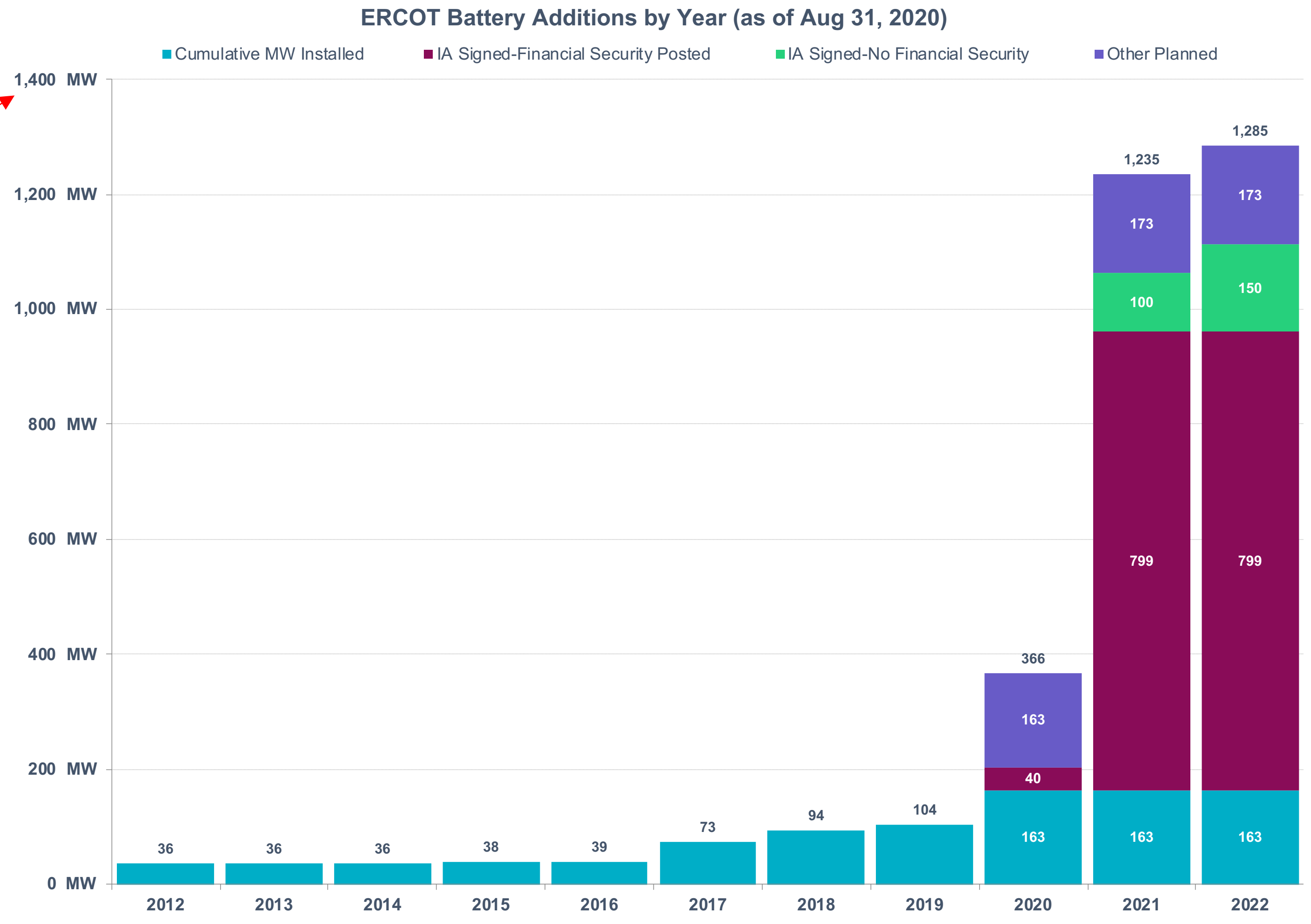


Note: Larger scale for wind than solar;
ERCOT peak demand ~75,000 MW

http://www.ercot.com/gridinfo/resource

Not much battery storage yet

Note: Small relative to 75,000 MW peak demand



http://www.ercot.com/gridinfo/resource

Prior research: Air quality and health impacts of Texas coal power plants

JOURNAL OF THE AIR & WASTE MANAGEMENT ASSOCIATION
https://doi.org/10.1080/10962247.2018.1537984

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Air quality and health benefits from potential coal power plant closures in Texas

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Department of Civil and Environmental Engineering, Rice University, Houston, TX, USA

ABSTRACT

As power production from renewable energy and natural gas grows, closures of some coal-fired power plants in Texas become increasingly likely. In this study, the potential effects of such closures on air quality and human health were analyzed by linking a regional photochemical model with a health impacts assessment tool. The impacts varied significantly across 13 of the state's largest coal-fired power plants, sometimes by more than an order of magnitude, even after normalizing by generation. While some power plants had negligible impacts on concentrations at important monitors, average impacts up to 0.5 parts per billion (ppb) and 0.2 μg/m^3 and maximum impacts up to 3.3 ppb and 0.9 μg/m^3 were seen for ozone and fine particulate matter ($PM_{2.5}$), respectively. Individual power plants impacted average visibility by up to 0.25 deciviews in Class I Areas. Health impacts arose mostly from $PM_{2.5}$ and were an order of magnitude higher for plants that lack scrubbers for SO_2. Rankings of health impacts were largely consistent across the base model results and two reduced form models. Carbon dioxide emissions were relatively uniform, ranging from 1.00 to 1.26 short tons/MWh, and can be monetized based on a social cost of carbon. Despite all of these unpaid externalities, estimated direct costs of each power plant exceeded wholesale power prices in 2016.

Implications: While their CO_2 emission rates are fairly similar, sharply different NO_x and SO_2 emission rates and spatial factors cause coal-fired power plants to vary by an order of magnitude in their impacts on ozone, particulate matter, and associated health and visibility outcomes. On a monetized basis, the air pollution health impacts often exceed the value of the electricity generated and are of similar magnitude to climate impacts. This suggests that both air pollution and climate should be considered if externalities are used to inform decision making about power-plant dispatch and retirement.

Table 5. Results of the six main impact metrics (maximum MDA8 ozone, average MDA8 ozone, maximum DA24 $PM_{2.5}$, average DA24 $PM_{2.5}$, mortality from ozone, mortality from $PM_{2.5}$) for each of the 13 power plants of interest in CAMx/BenMAP modeling.

	Maximum MDA8 ozone (ppb)	Average MDA8 ozone (ppb)	Maximum DA24 $PM_{2.5}$ (μg/m^3)	Average DA24 $PM_{2.5}$ (μg/m^3)	Ozone health (deaths)	$PM_{2.5}$ health (deaths)
Big Brown	2.1	0.04	0.5	0.031	1	81
Coleto Creek	1.7	0.03	0.2	0.009	0	22
Fayette Power Project	2.2	0.06	0.1	0.003	1	7
J K Spruce	0.7	0.02	0.1	0.001	1	5
J T Deely	0.7	0.03	0.1	0.009	1	29
Limestone	1.8	0.05	0.2	0.014	1	41
Martin Lake	2.9	0.06	0.5	0.020	1	42
Monticello	4.4	0.06	1.0	0.033	1	76
Oak Grove	1.6	0.05	0.2	0.005	1	15
San Miguel	1.2	0.02	0.1	0.003	0	7
Sandow	1.4	0.02	0.6	0.015	1	44
W A Parish	1.0	0.03	1.2	0.062	1	177
Welsh	2.2	0.03	0.2	0.008	0	18

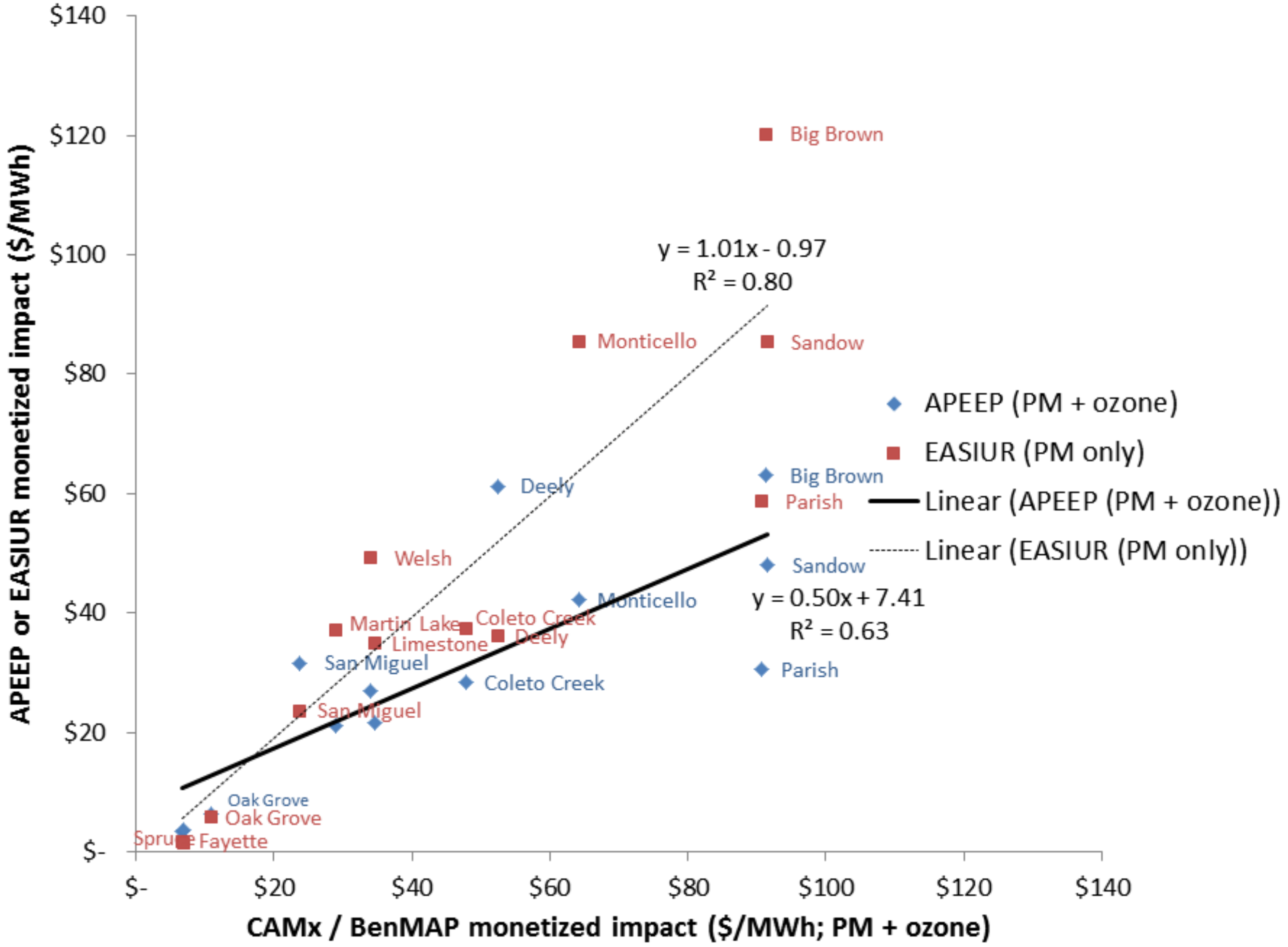
Note. Maximum refers to the grid cell with the maximum impacts after averaging over all days.

Hundreds of deaths per year, mainly due to SO_2 → $PM_{2.5}$

Strasert et al., 2018

Comparison of CAMx / BenMAP, APEEP, and EASIUR health impact estimates

Reduced-form models



[Strasert et al., 2018]

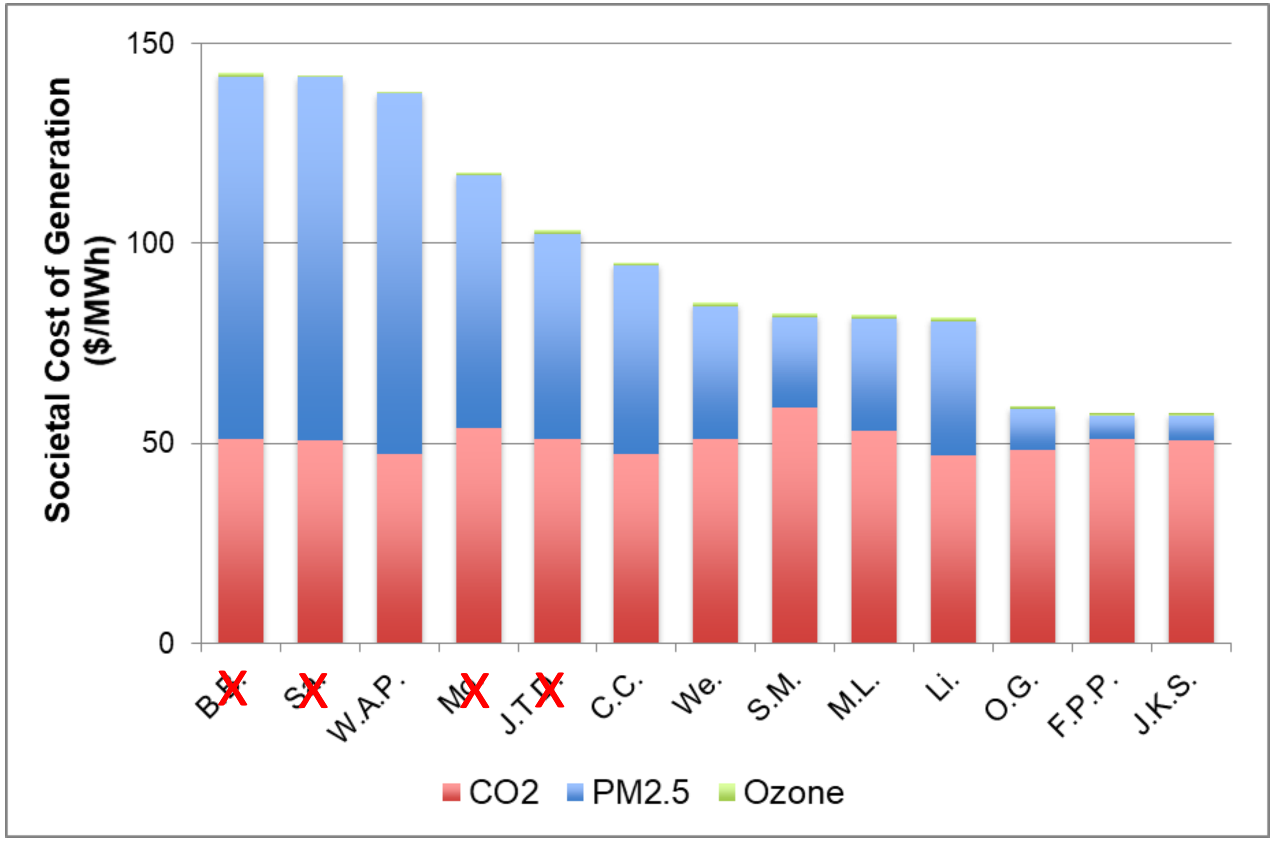
CAMx / BenMAP

Direct costs and externalities of coal electricity

Direct variable O&M

	Variable O&M ($/MWhr)
~~Sandow~~	~~17.41~~
Coleto Creek	25.11
Oak Grove	19.75
Limestone	20.88
~~Big Brown~~	~~24.03~~
Martin Lake	19.98
~~J T Deely~~	~~33.62~~
San Miguel	43.67
Welsh	31.42
~~Monticello~~	~~26.52~~
J K Spruce	31.93
Fayette	26.65
W A Parish	25.99

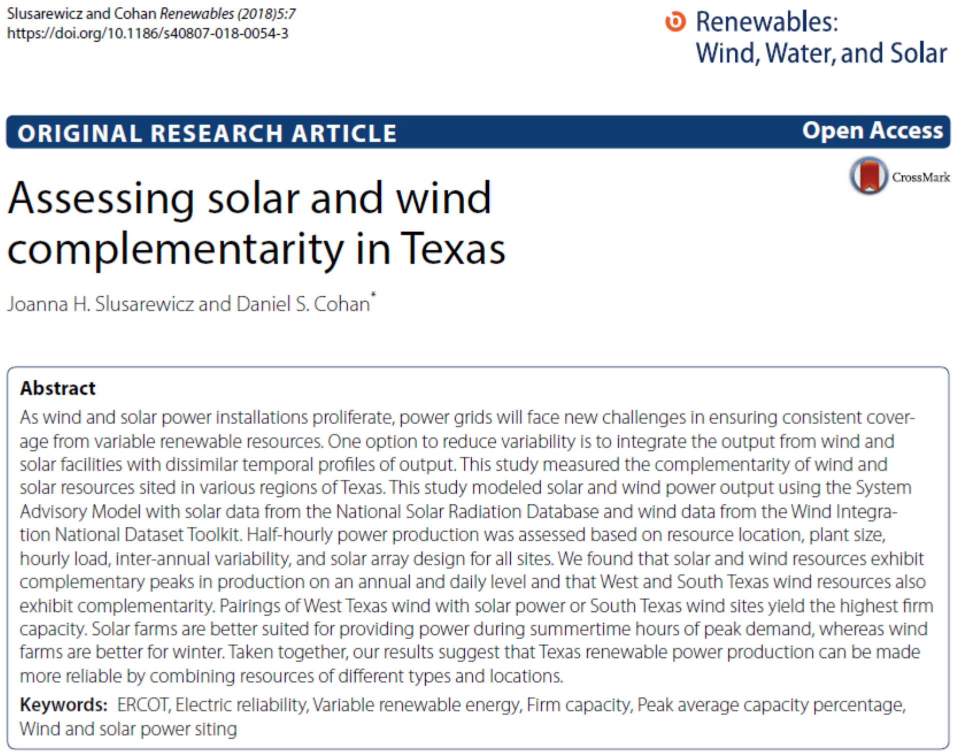
Externalities to climate and mortality



Average direct O&M + air & climate externalities for plants remaining open in 2019: $111.67/MWh
(Neglects capital costs and externalities to water and haze)
(~~Retired sites~~ denoted by **X**)

Strasert et al., 2018

Prior research: Complementarity of wind and solar resources in Texas


Slusarewicz and Cohan *Renewables* (2018)5:7
https://doi.org/10.1186/s40807-018-0054-3

Renewables: Wind, Water, and Solar

ORIGINAL RESEARCH ARTICLE Open Access

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Assessing solar and wind complementarity in Texas

Joanna H. Slusarewicz and Daniel S. Cohan*

Abstract

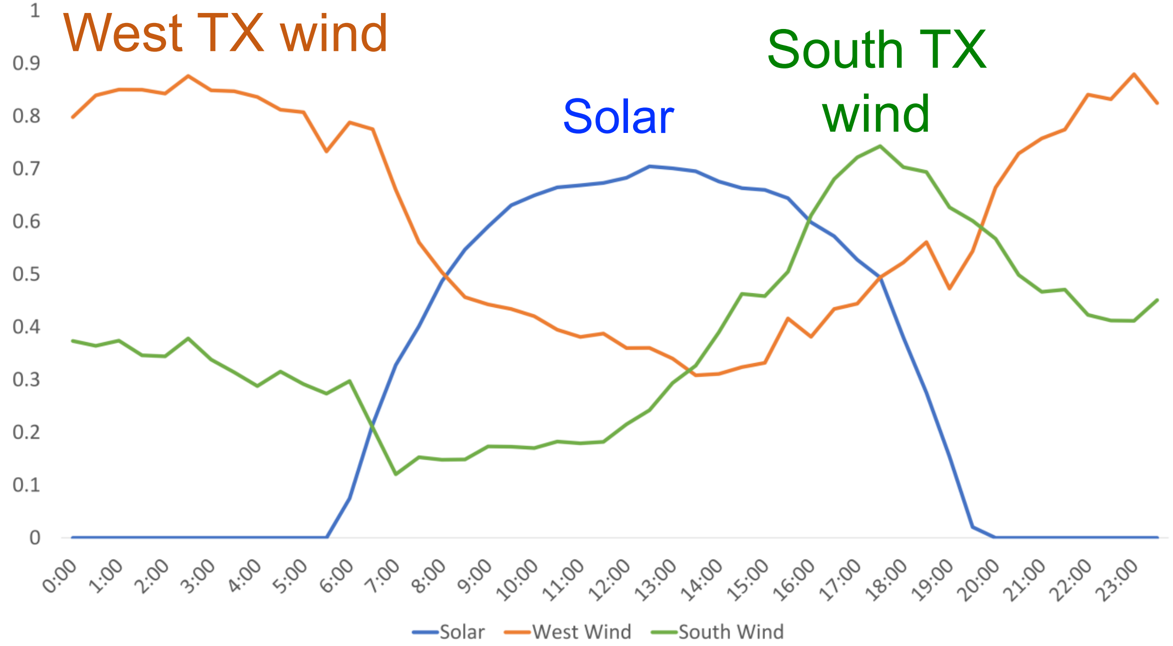
As wind and solar power installations proliferate, power grids will face new challenges in ensuring consistent coverage from variable renewable resources. One option to reduce variability is to integrate the output from wind and solar facilities with dissimilar temporal profiles of output. This study measured the complementarity of wind and solar resources sited in various regions of Texas. This study modeled solar and wind power output using the System Advisory Model with solar data from the National Solar Radiation Database and wind data from the Wind Integration National Dataset Toolkit. Half-hourly power production was assessed based on resource location, plant size, hourly load, inter-annual variability, and solar array design for all sites. We found that solar and wind resources exhibit complementary peaks in production on an annual and daily level and that West and South Texas wind resources also exhibit complementarity. Pairings of West Texas wind with solar power or South Texas wind sites yield the highest firm capacity. Solar farms are better suited for providing power during summertime hours of peak demand, whereas wind farms are better for winter. Taken together, our results suggest that Texas renewable power production can be made more reliable by combining resources of different types and locations.

Keywords: ERCOT, Electric reliability, Variable renewable energy, Firm capacity, Peak average capacity percentage, Wind and solar power siting

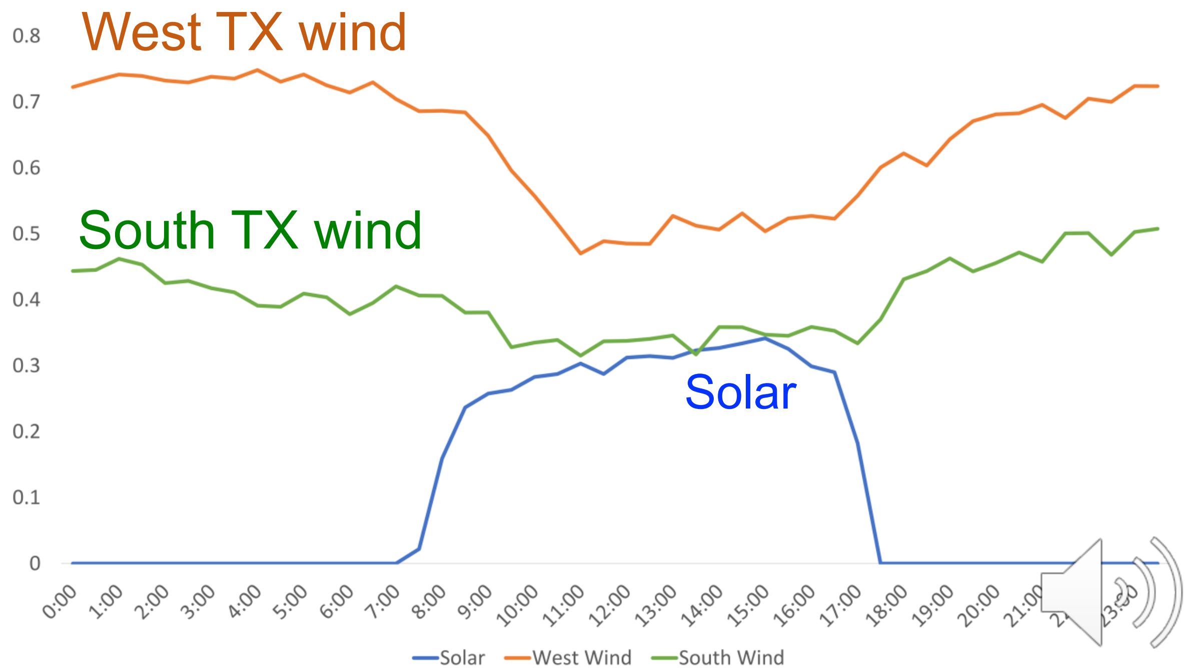
Considered only a dozen sites; did not compare to coal output

[Slusarewicz and Cohan, 2018](#)

Summer



Winter

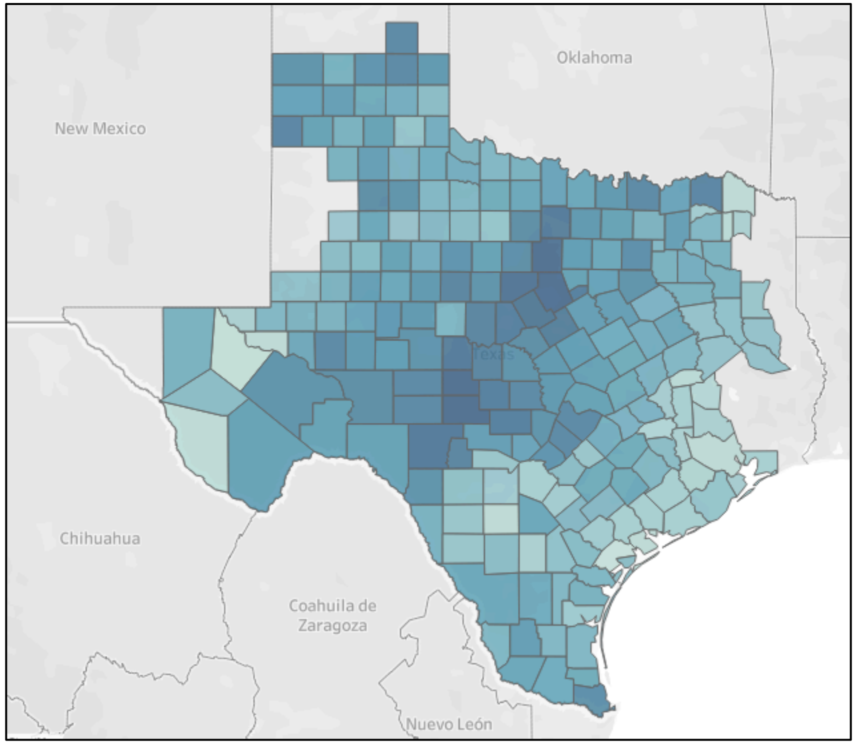


Approach

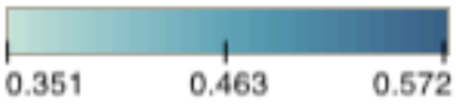
- Wind and solar projects in ERCOT interconnection queue
- NREL System Advisor Model and WIND toolkit database to simulate solar and wind power output
  - Meteorology data for 2009 – 2011
- ERCOT coal output and systemwide load data for 2019
- Treat system as single region (no transmission constraints)
- Mixed-integer optimization to select least-cost set of new wind and solar projects to display >90% of coal output
  - Can create surpluses at other times if zero-out coal

Average capacity factors by county
(Simulations with 2009-2011 meteorology)

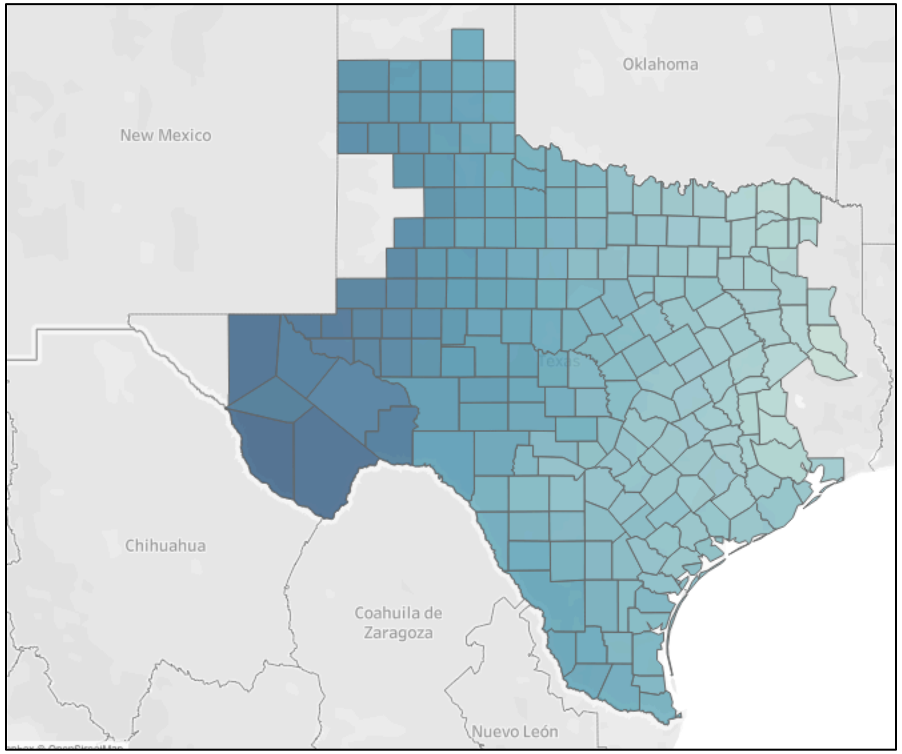
Wind



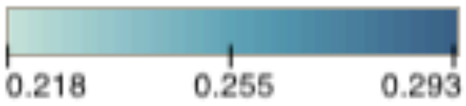
Wind CF Scale



Solar



Solar CF Scale

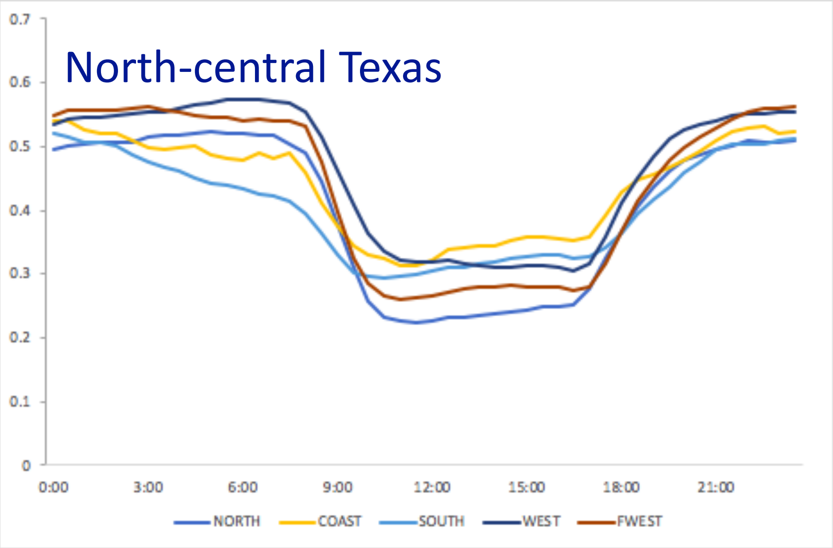


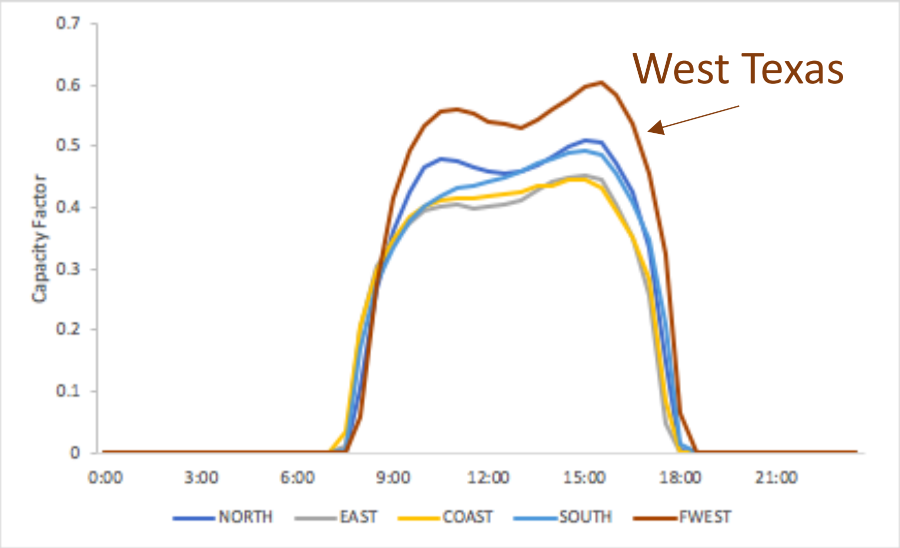
Capacity factors by month, hour, and region

Wind

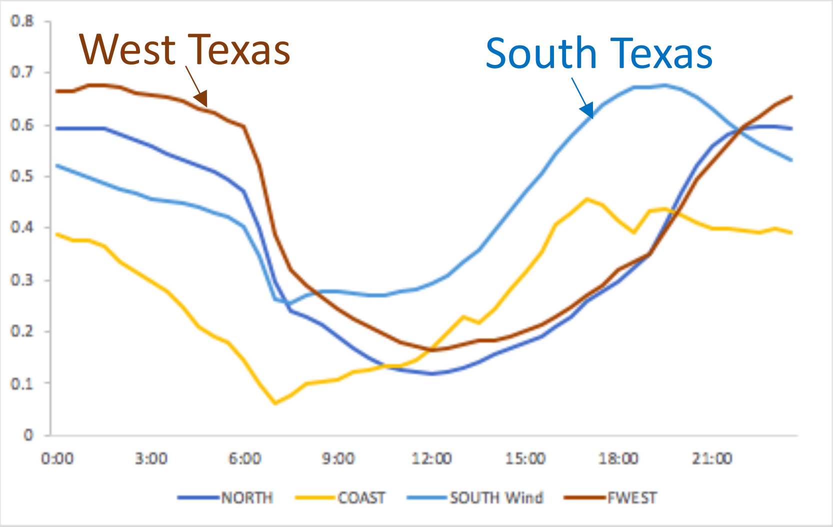
Solar

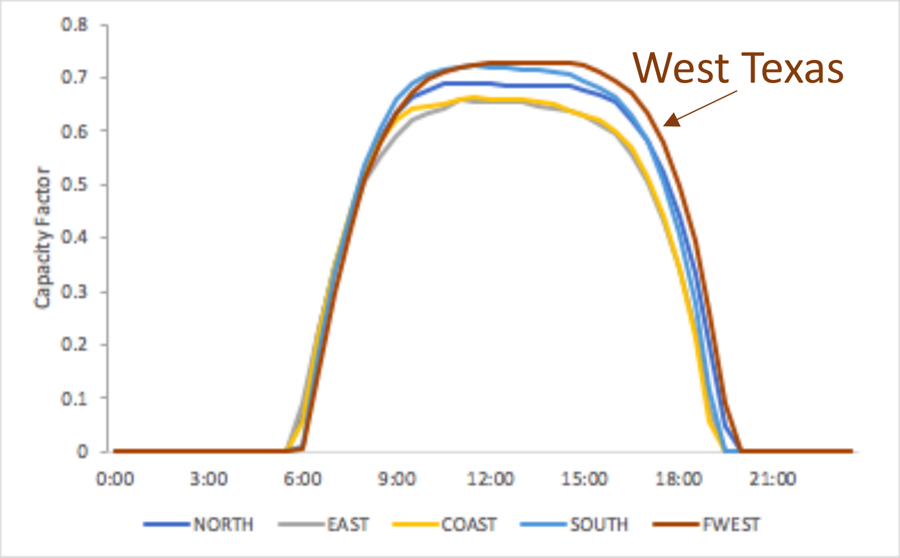
January



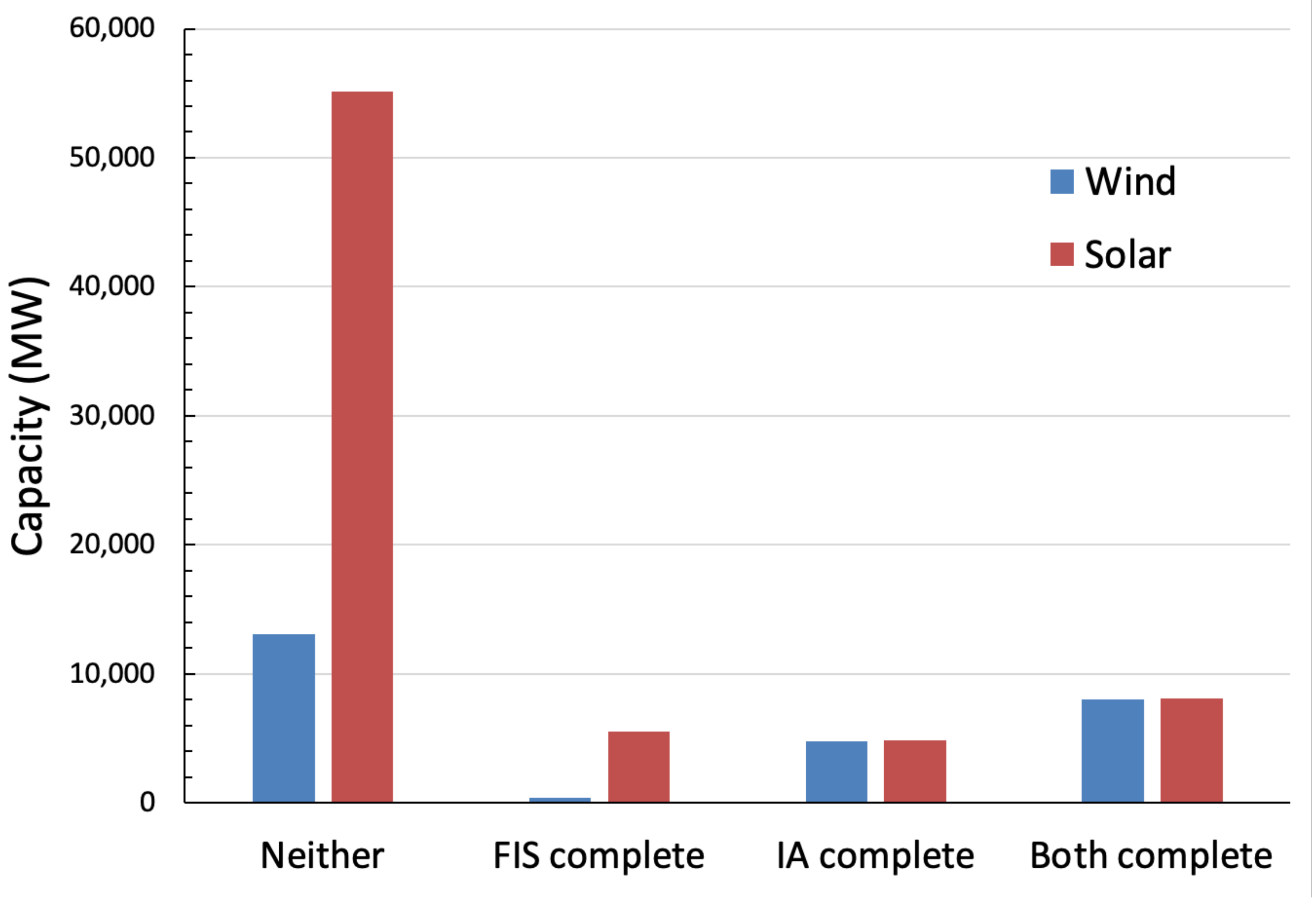


July





Proposed wind and solar projects by status

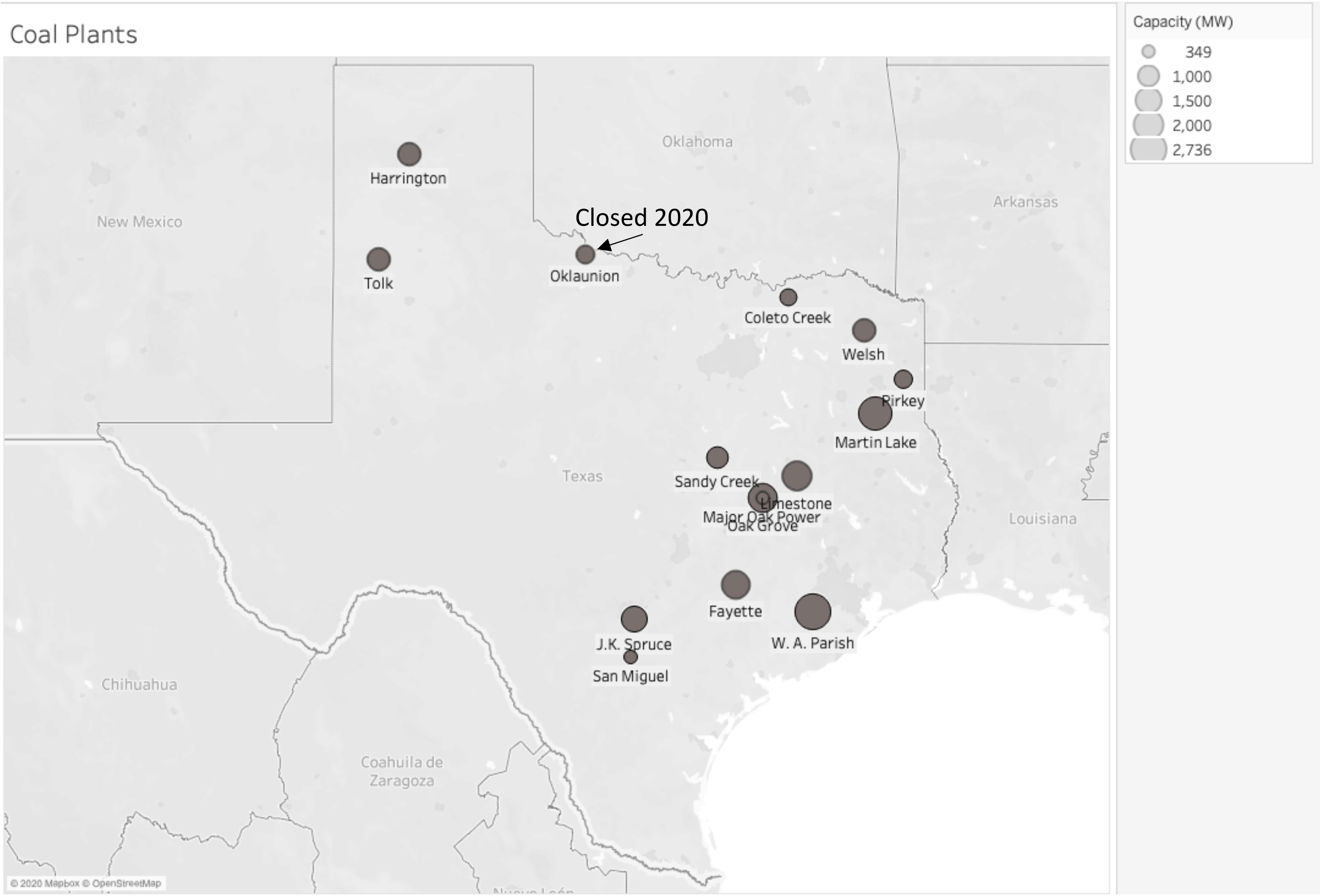


FIS: Full Interconnection Study

IA: Interconnection Agreement

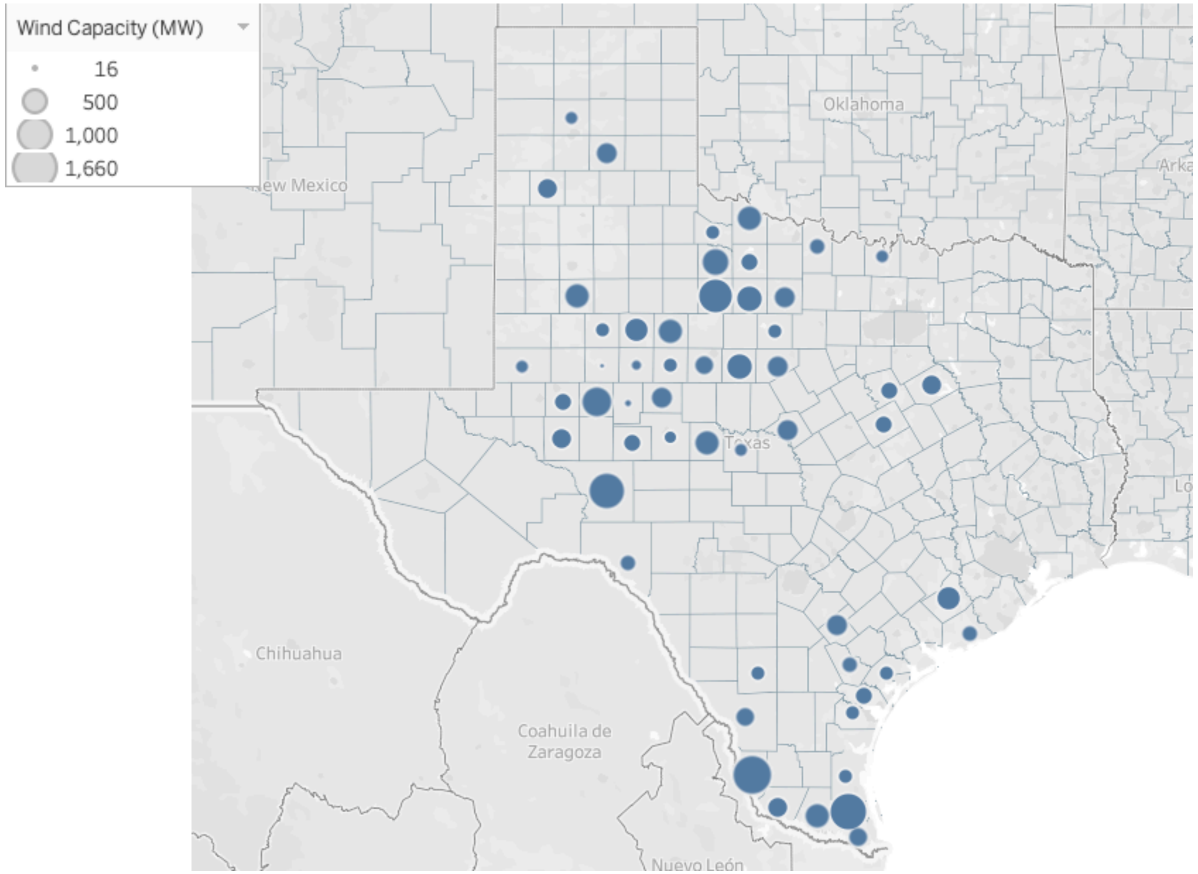
ERCOT June 2020 Generator Interconnection Status Report

Remaining coal plants in ERCOT (15,065 MW)

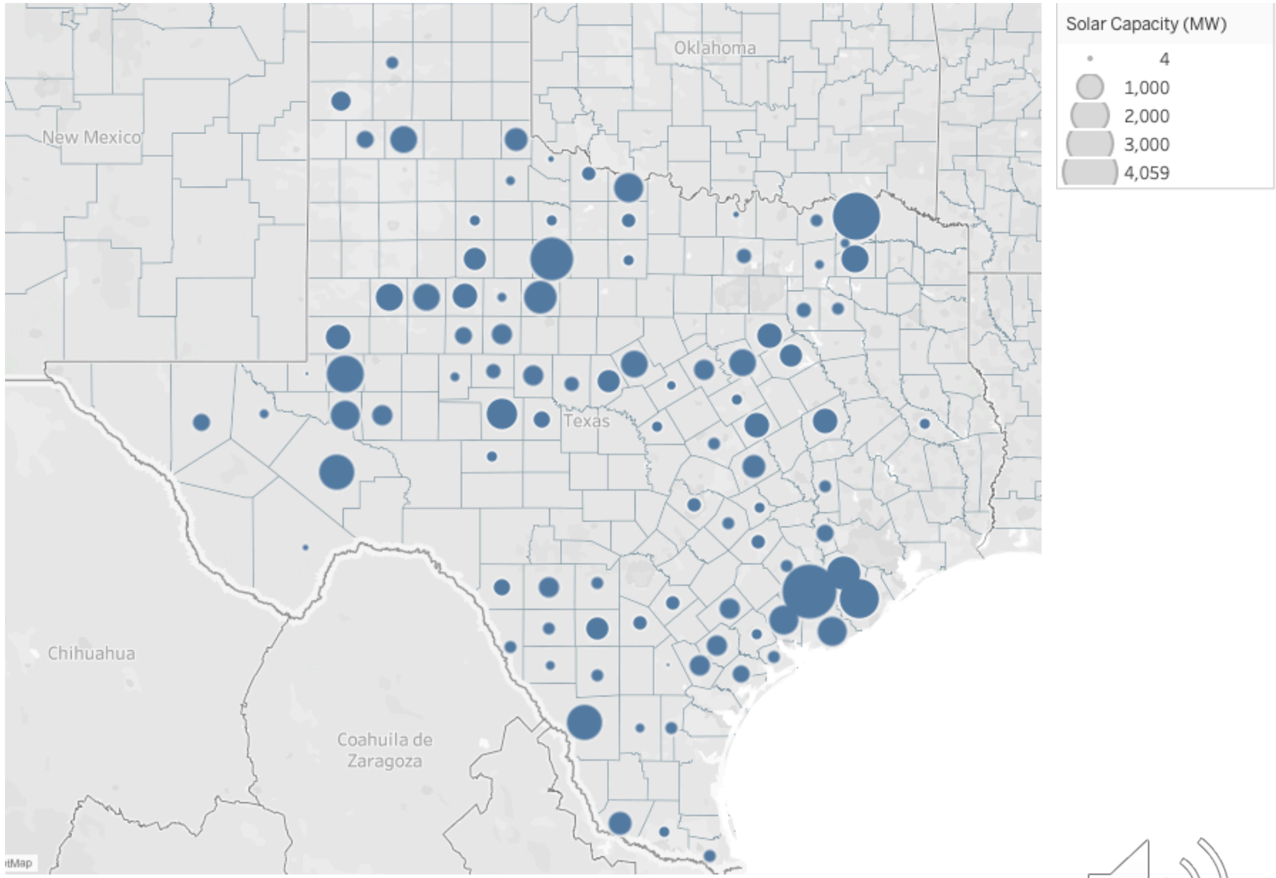


Proposed wind and solar projects

Wind (108 sites; 26,272 MW)



Solar (262 sites; 73,655 MW)



ERCOT June 2020 Generator Interconnection Status Report

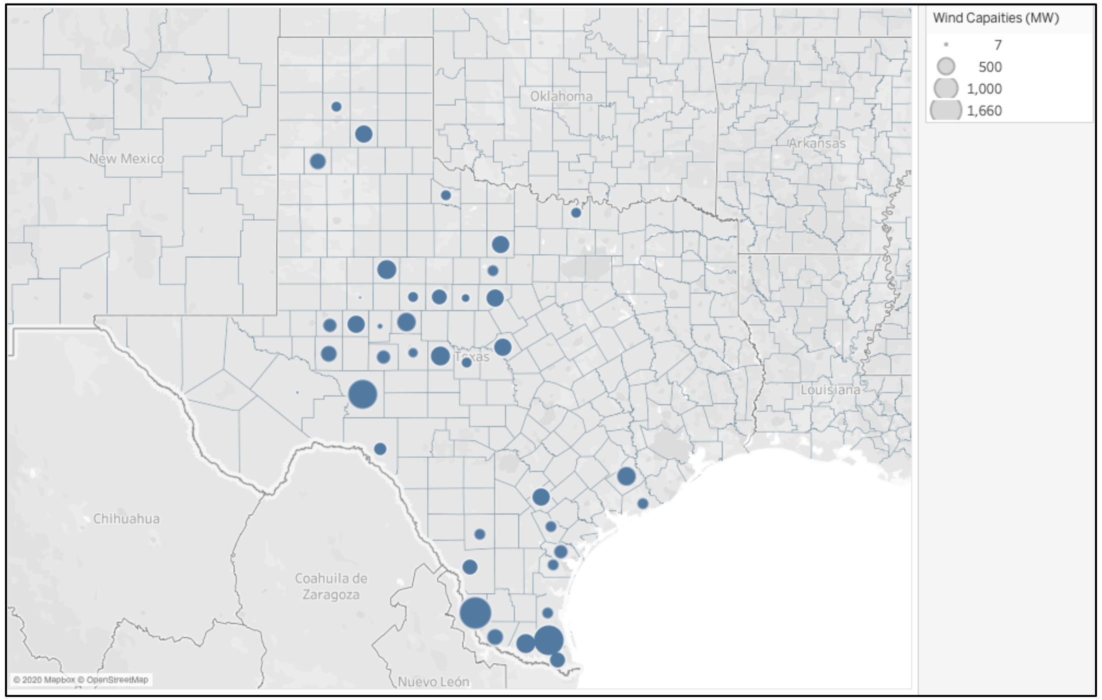
Optimization modeling

- Building all 370 projects would cover 96.5% of coal load and yield surpluses at other times, but be costly
- Mixed-integer model: Minimize cost to satisfy p% of coal load
- Costs: Computed from NREL 2020 Annual Technology Baseline
  - Wind: \$118.48 per kW capacity per year
  - Solar: \$92.50 per kW capacity per year
  - Coal: \$111.67 per MWh (Strasert et al. 2018, direct + externalities)

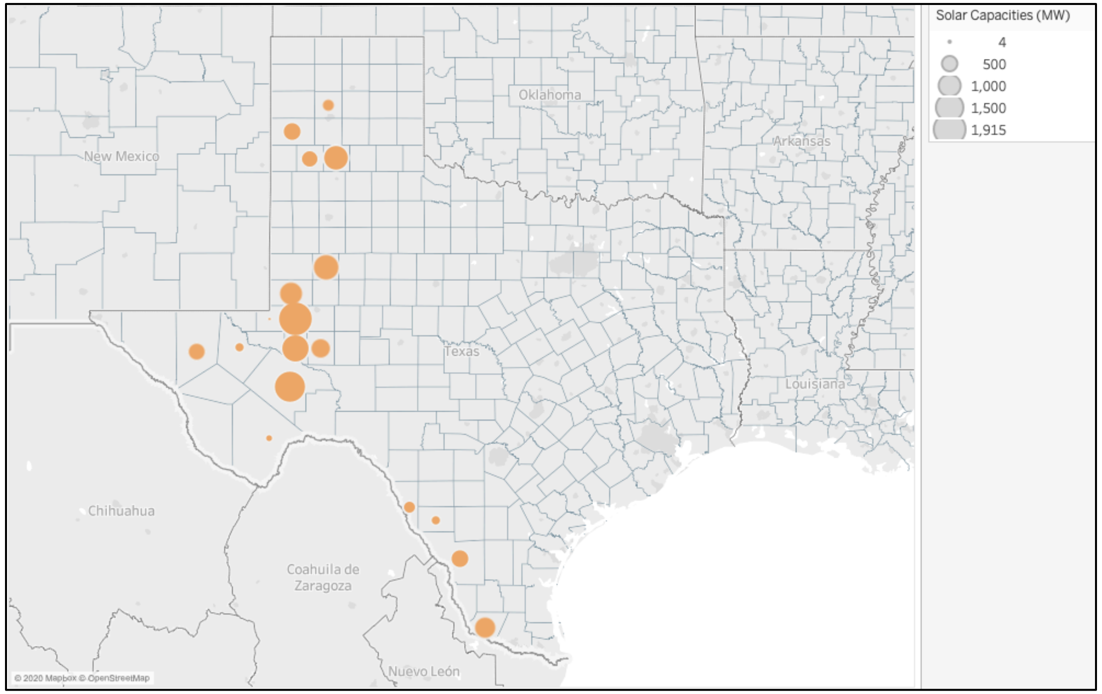
$$
\begin{array}{llcll}
\min\limits_{s,w,slack} & c_s s + c_w w & & & \\
\text{s.t.} & P_j^s s + P_j^w w & \geq & coal - slack_j & \forall j \in Y \\
& \sum\limits_{j \in Y} \sum\limits_{k=1}^{h} (slack_j)_k & \leq & (1-p)(3 \sum_{k=1}^{h} coal_k) & \\
& (slack_j)_k & \geq & 0 & \forall j \in Y, \forall k \in \{1, ..., h\} \\
& s_i & \in & \{0,1\} & \forall i \in \{1, ..., sn\} \\
& w_j & \in & \{0,1\} & \forall j \in \{1, ..., wn\}
\end{array} \qquad (1)
$$

Cost-optimized solar and wind sites to replace 90% of coal output

Wind (76 out of 108 sites)



Solar (51 out of 262 sites)

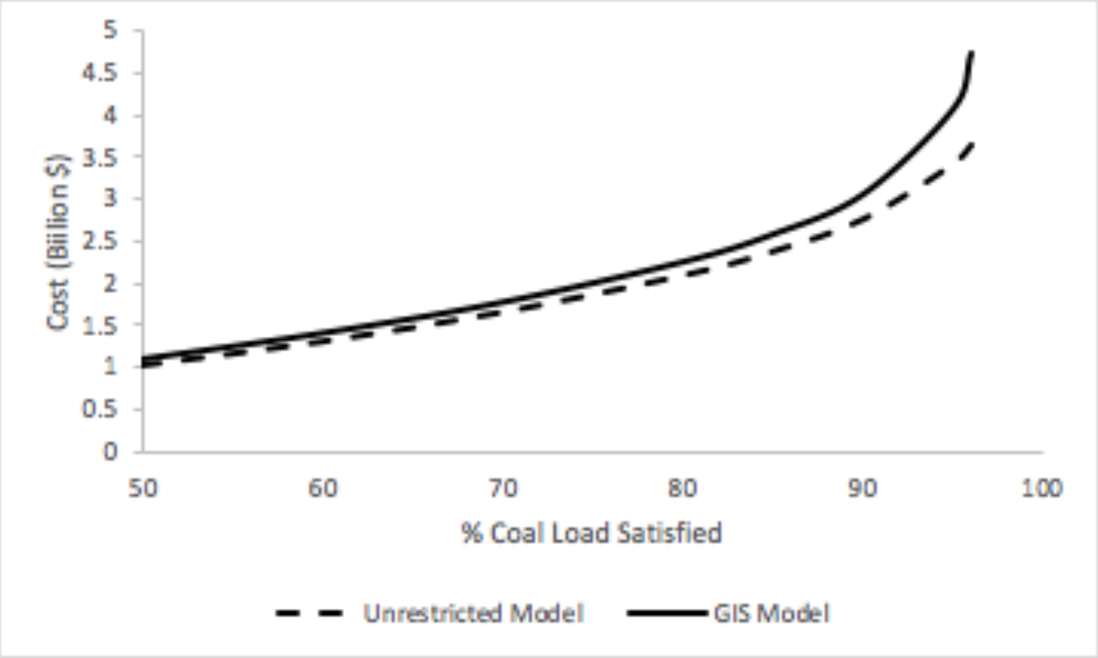


$3.05 billion/year cost for new wind and solar

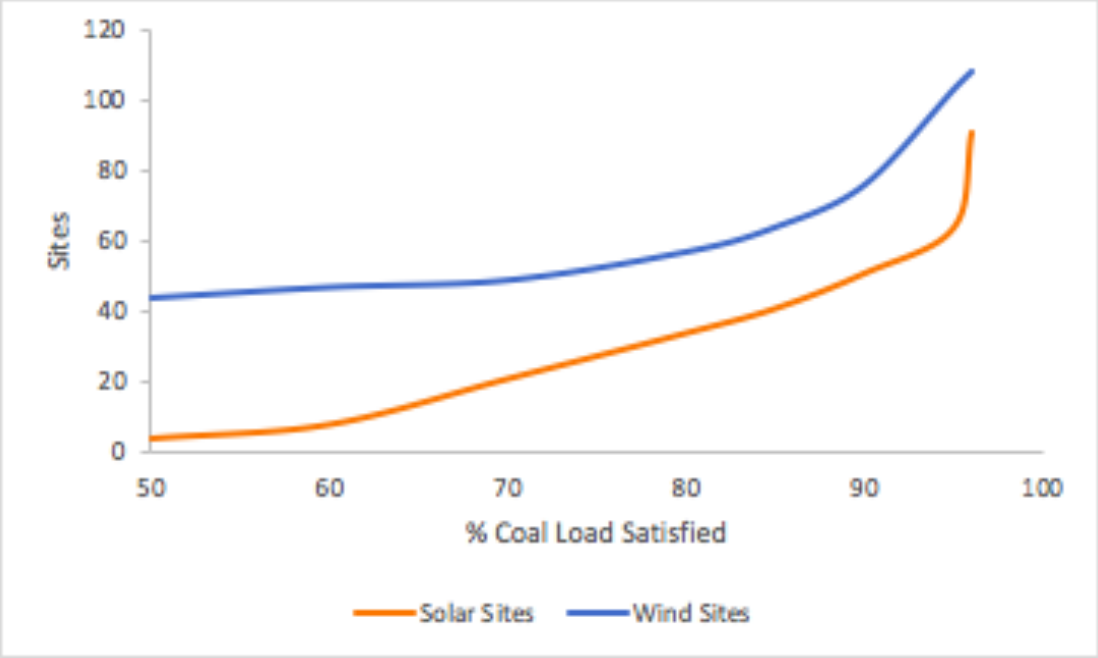
$7.83 billion in averted direct costs + externalities from coal (if $111.67/MWh)

Optimization results

Costs to displace coal increase linearly until ~90% is displaced

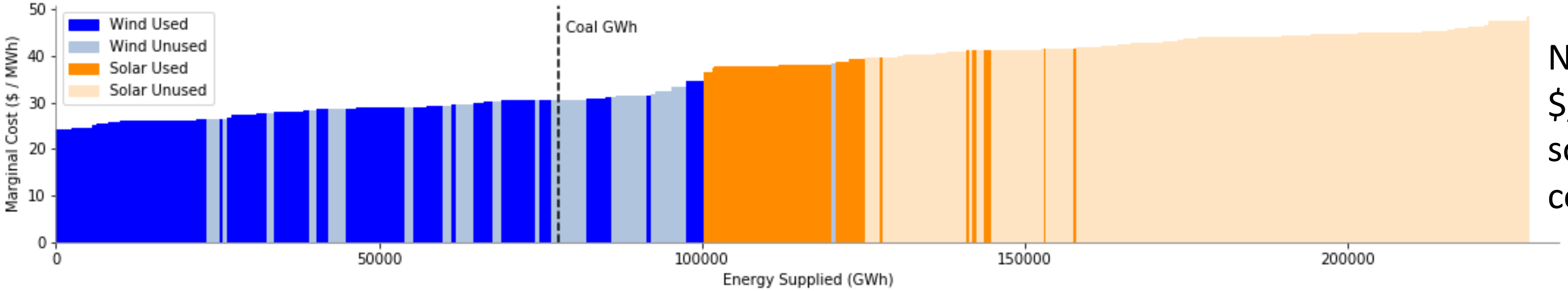


Wind sites chosen first; Solar added to cover more coal load*

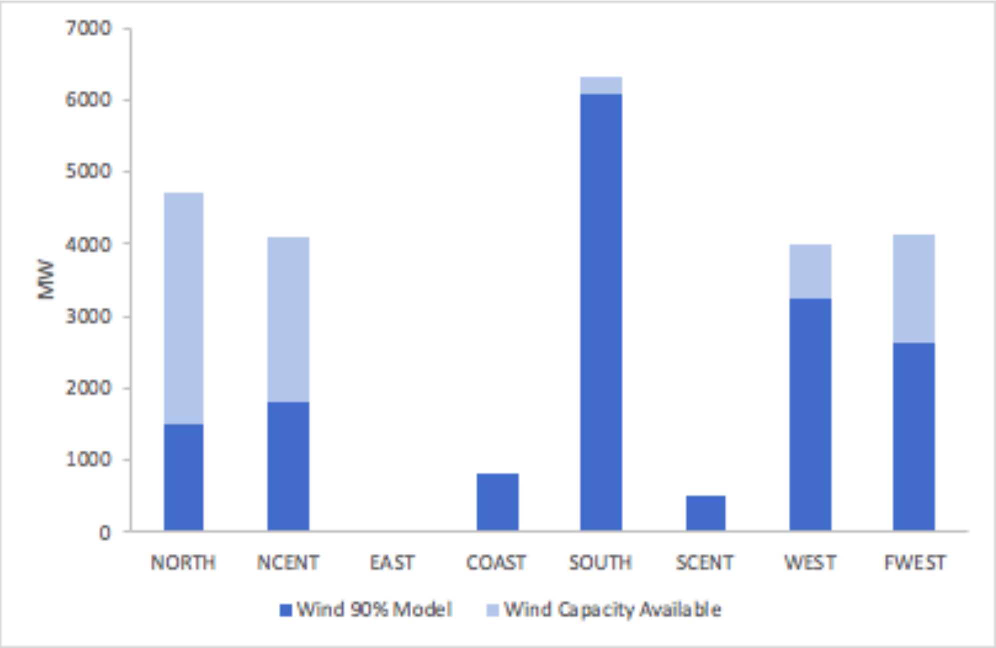


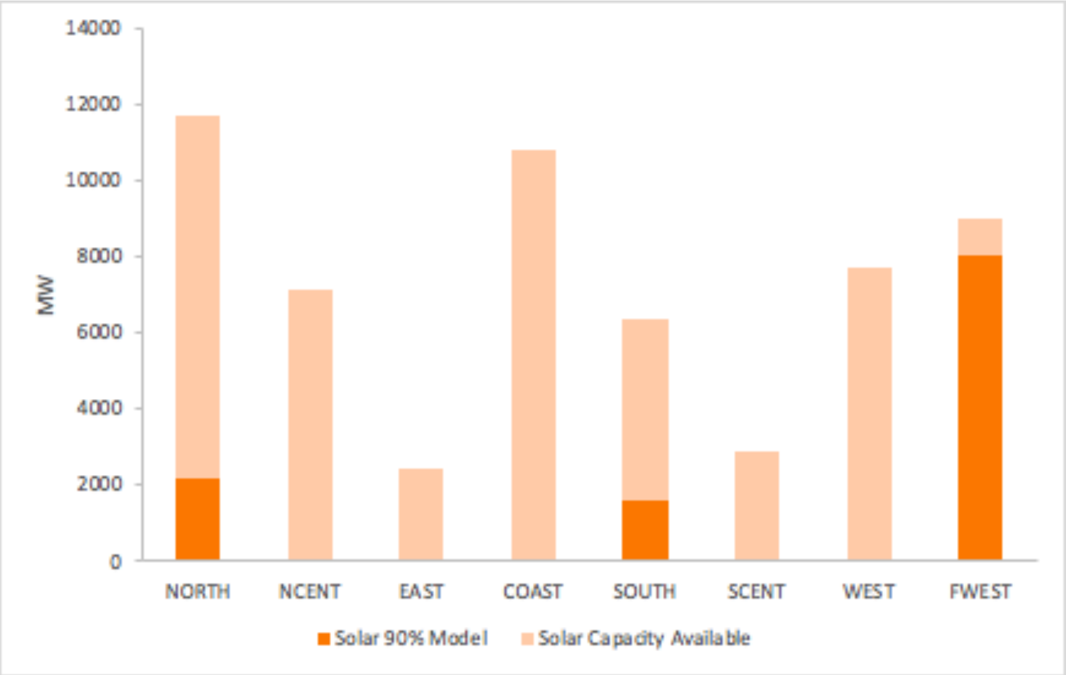
*Note: Our optimization does not consider time-varying price of electricity, which would tend to favor solar

Sites chosen by 90% optimization

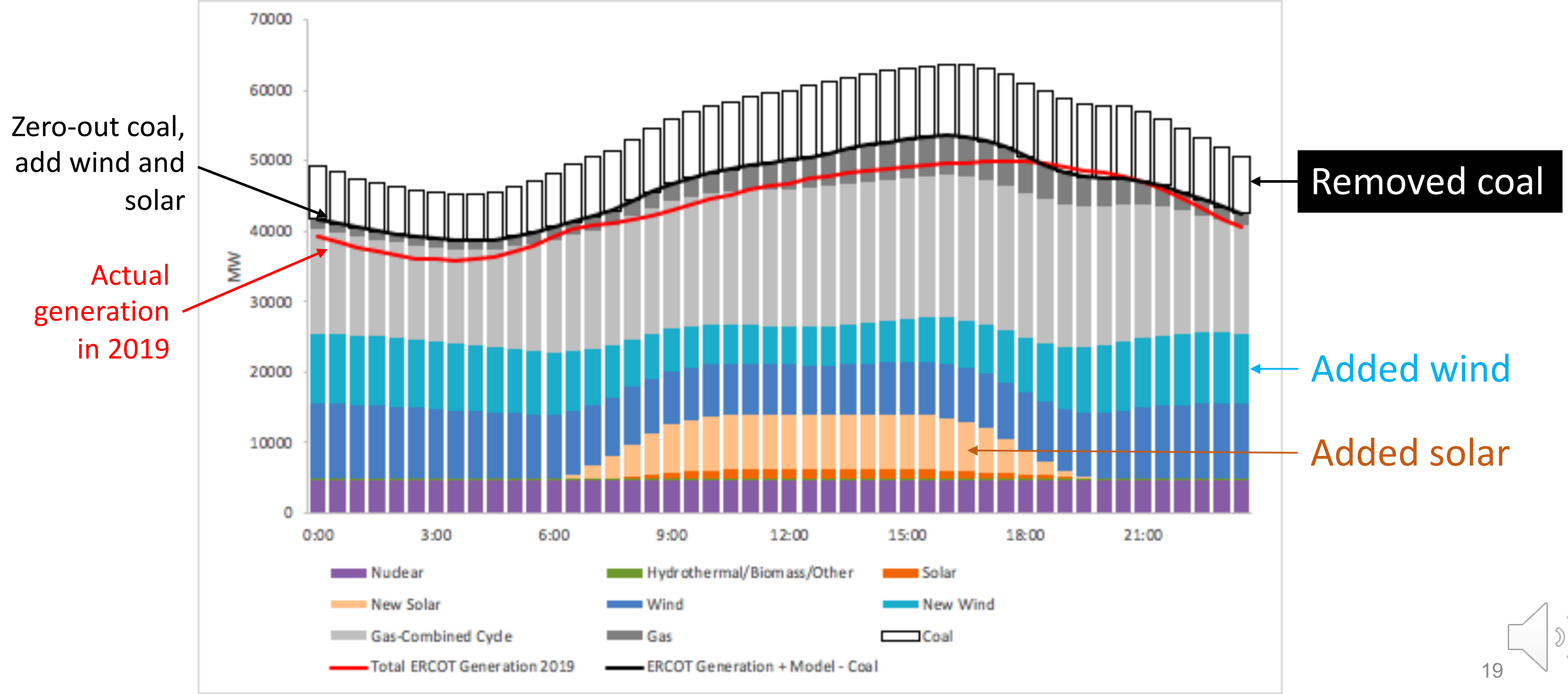


Note: Wind has lower $/MWh cost, but some solar is chosen for complementary timing



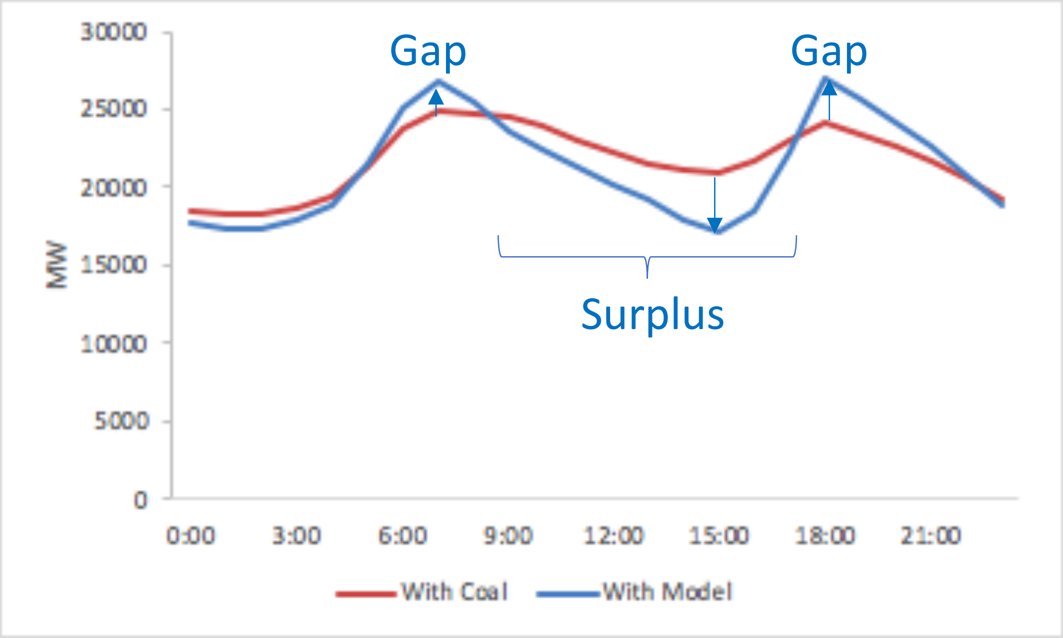


Generation in 90% optimization case

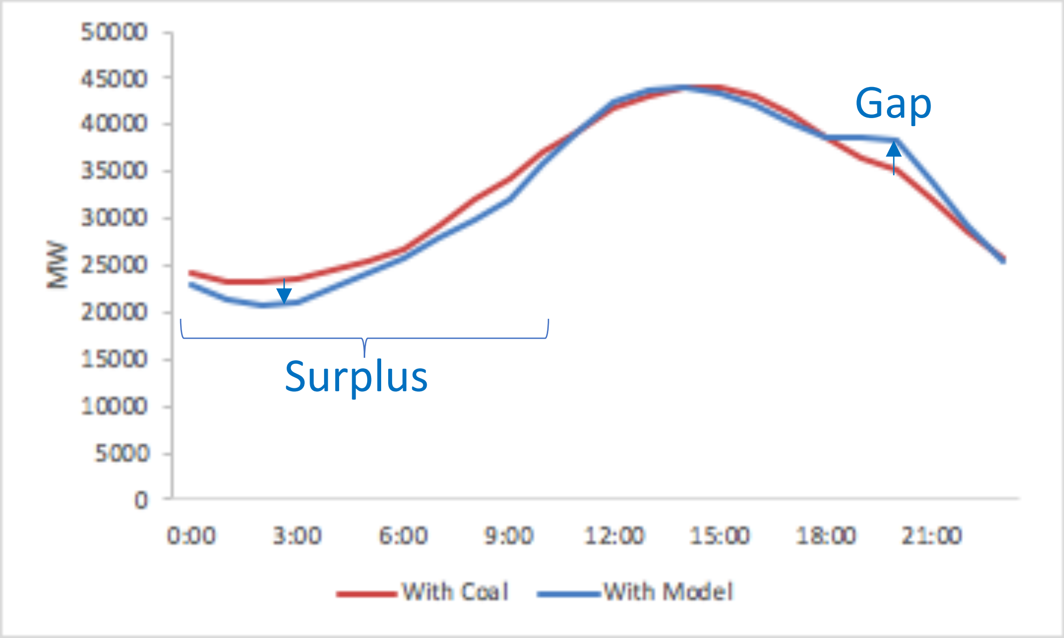


Load left for other sources (not wind, solar, or coal) to cover

January



July



Red: Status quo

Blue: Zero out coal, add wind and solar from 90% optimization

Note: Needs become spikier (mild duck curve) in January; little change in July

Conclusions

- Substantial health impacts from coal in Texas
- Wind and solar provide output at complementary times
- Projects already in interconnection queue can displace coal
- Optimization identified least-cost path to displace 90% of coal
- No severe gaps in output if zero out coal, add wind and solar
- Future research will examine transmission and storage

Acknowledgment: Funding from Energy Foundation