NREL
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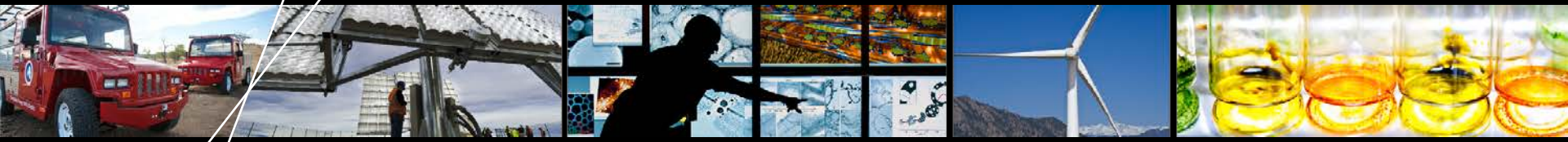
Western Wind and Solar Integration Study Phase 2



EPRI Cycling Webinar

Debbie Lew, Greg Brinkman, Eduardo Ibanez – NREL

Steve Lefton, Nikhil Kumar – Intertek APTECH

Sundar Venkataraman, Gary Jordan – GE Energy

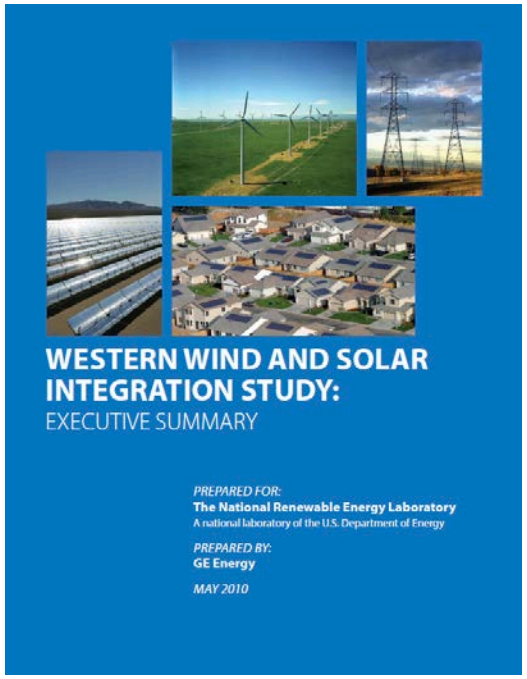
September 11, 2013

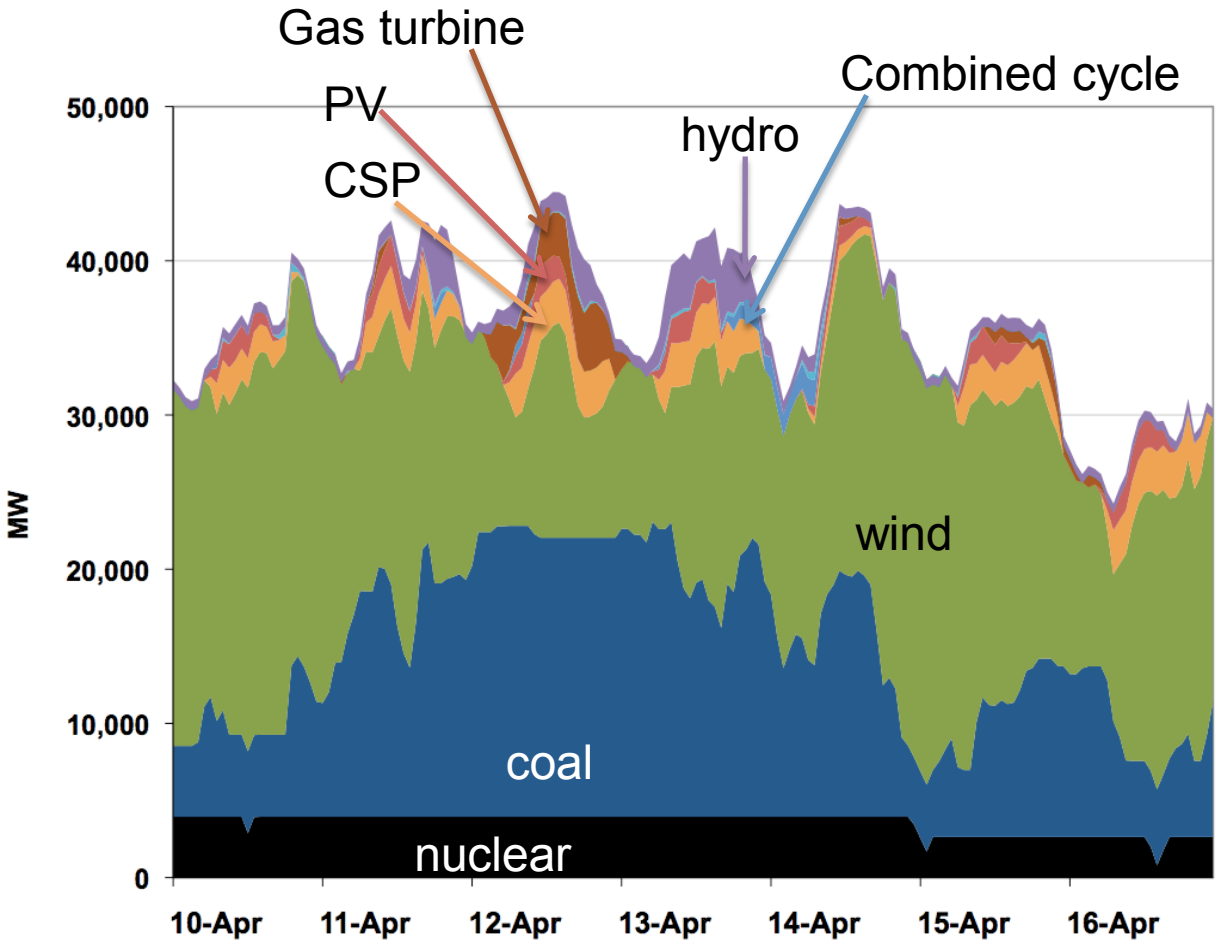
NREL/PR-5D00-60249

Western Wind and Solar Integration Study Phase 1

Can we integrate high penetrations of wind and solar into the Western Interconnection?

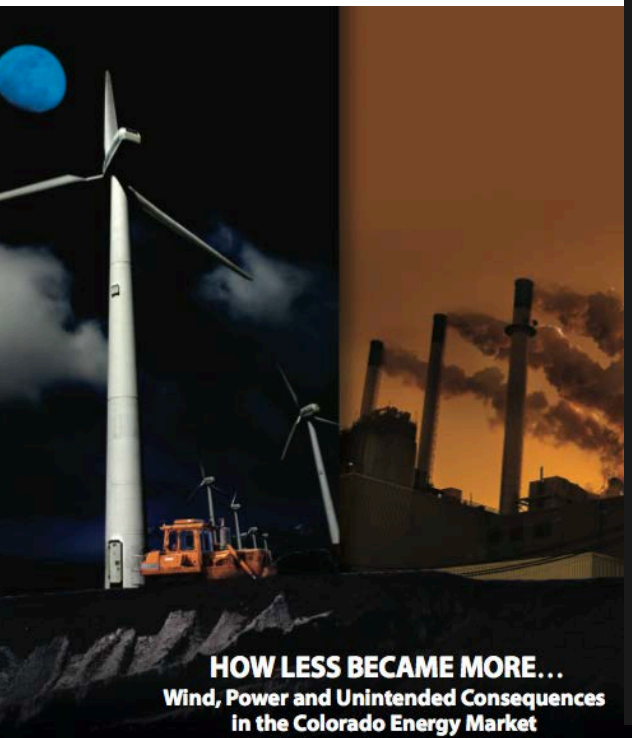
What do we need to do to accommodate this?





WWSIS1: The worst week of three years

Impacts of Solar-/Wind-Induced Cycling



HOW LESS BECAME MORE…
Wind, Power and Unintended Consequences in the Colorado Energy Market

Wind energy promises a clean, renewable resource that uses no fossil fuel and generates zero emissions. Careful examination of the data suggests that the numbers do not add up as expected.

The "must take" provisions of Colorado's Renewable Portfolio Standard require that other sources of generation, such as coal plants, must be "cycled" to accommodate wind power. This cycling makes coal generating units operate much less efficiently… so inefficiently, that these units produce significantly greater emissions.

This study reviews the data that supports this conclusion, outlines mitigation measures which can be used to realize the full potential of wind generation, and provides recommendations for policy makers.

April 16, 2010

BENTEK Energy

Digital Network

Monday, August 23, 2010 As of 12:00 AM New York 57° | 45°

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OPINION | AUGUST 23, 2010

Wind Power Won't Cool Down the Planet

Often enough it leads to higher carbon emissions.

Article | Comments (243)

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BY ROBERT BRYCE

The wind industry has achieved remarkable
provide major reductions in carbon dioxide
true. A slew of recent studies show that win
any reduction in carbon emissions—or that
meaningless.

This issue is especially important now that s
arbitrary amounts of their electricity from re
California will require utilities to obtain 33%
30 states, including Connecticut, Minnesota

SPEAKING OF POWER

Under Siege

As I write this column on Election Day 2012, the polls are still open and both presidential candidates are predicting victory. The next dozen hours or so will prove only one candidate correct. Regardless of the outcome, wind power remains a loser.

The Production Tax Credit (PTC) for wind power expires at the end of this year unless Congress takes affirmative action to renew the law. This expire-renew cycle has occurred seven times since the PTC was first put into effect in 1992. However, unique events are in play this year that signal waning support for its renewal.

Opinions Differ

There is increased squabbling within environmental groups, particularly the Sierra Club, about the consequential environmental damage caused by wind power. "Aviary ing that excluded Exelon. Opposing points of view are clearly not valued by AWEA.

The root cause of the market and economic distortions described by Exelon is the PTC. The PTC pays the owner approximately $22/MWh for energy (not firm capacity) sold into a market. In some regions wind farm owners bid into the electricity market at a zero or negative power cost up to the value of the PTC in order to stay first in the production queue. The market distortion is particularly prevalent during periods of low power demand and excess electricity supply, where these artificially low power prices force baseload plants to operate at less-efficient part load.

The economic distortion is exacerbated in states with a renewable portfolio standard (RPS), where mandated power purchase agreements pay two to three times the marginal power cost. Not only does the to reduce CO_2. Intuition is not a substitute for empirical studies.

Over the past few years a large number of studies have been conducted in the U.S. and the European Union that conclude the fossil-fueled equipment used to balance the grid ("chase" wind because of its limited and unpredictable supply), and the loss in efficiency of baseload plants forced to operate off design, produce about zero net change in CO_2 emissions. Some studies predict a little more, some a little less. I also find it interesting that many utilities with large amounts of wind generation steadfastly refuse to release operating data for analysis. I suspect to do so would mean the release of empirical data to build the opposition's case for insignificant CO_2 reduction and poor operating economics. I was unable to find one study of existing wind energy installations that found the CO_2 reductions predicted by AWEA.

The number of grassroots organizations opposed to government-mandated and -supported utility-scale wind power projects is growing rapidly. The Industrial Wind Action Group maintains a growing list of organizations (more than 150

Regardless of the outcome, wind power remains a loser.

Study Scope

Goal - Examine costs of cycling, emissions impacts of cycling, and compare wind and solar impacts

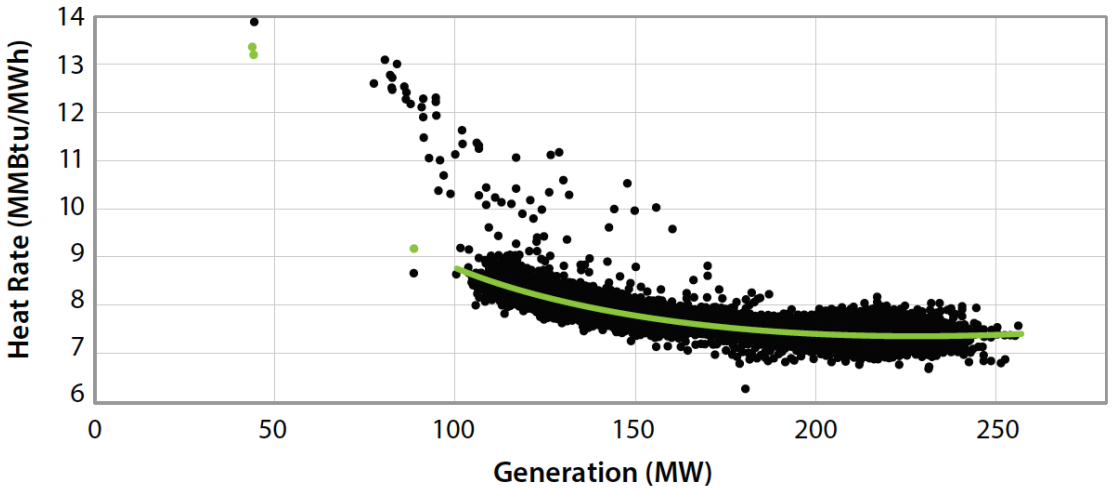
- **We model the western grid based on transmission planning models and methodologies of the Western Electricity Coordinating Council (TEPPC 2020)**
  - Results are *specific* to the grid and generator characteristics of the west
- **We examine grid *operations***
  - This is not a transmission planning study
  - Reliability and stability are being examined in WWSIS-3
- **Used commercial software PLEXOS to model grid operations on 5 minute basis for year 2020**

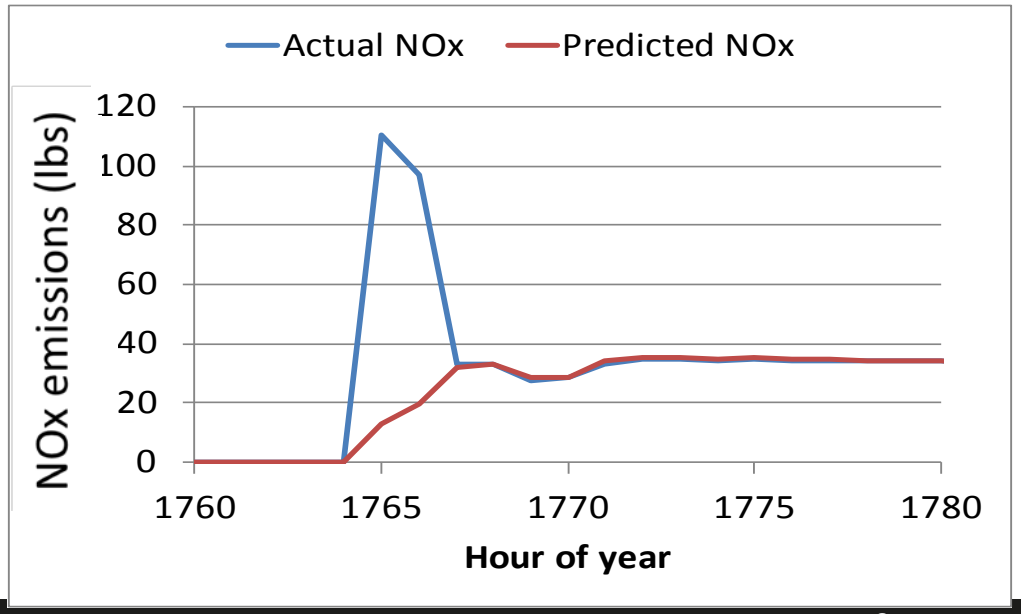
Ensured Technical Rigor

- **Technical Review Committee met every 2 months**
  - Western Electricity Coordinating Council, Western Governor's Association
  - DOE and other labs (Sandia, LBNL, NETL)
  - EPRI
  - Utilities (SRP, APS, PNM, TriState, WAPA, Xcel, Pacificorp, CAISO, BPA, NV Energy, ISO-NE, etc)
  - Other industry (NextEra, Energy Exemplar)
- **Working groups**
  - Hydro (input from BPA, WAPA)
  - Reserves (input from reserve sharing groups)
  - Others
- **Nevertheless, any grid modeling has limitations**

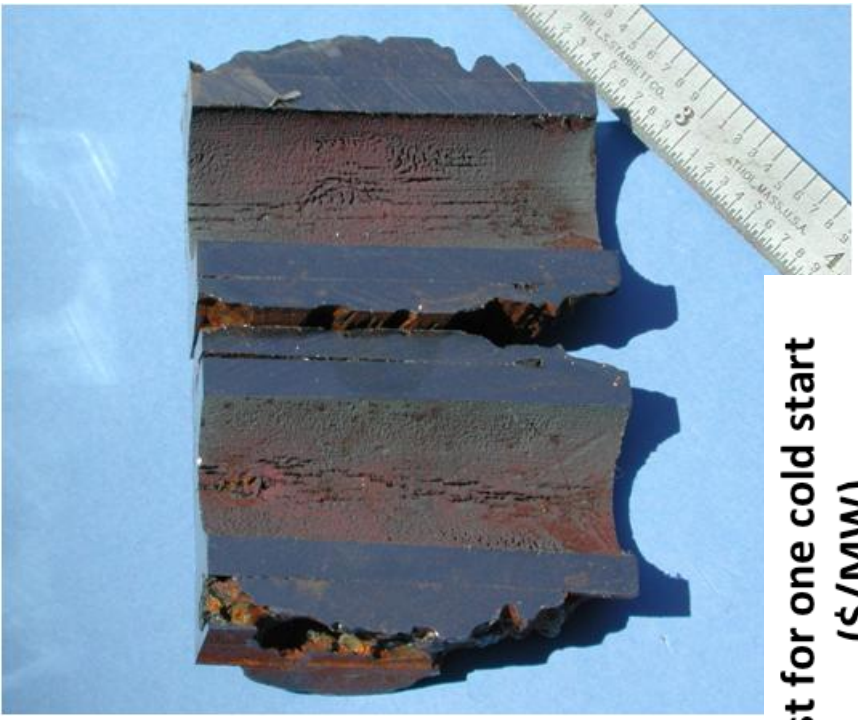
Developed Emissions Data Set

- **Measured hourly emissions from each fossil-fueled plant in the U.S. for 2008**
- **CO_2, NO_X, SO_2**
- **For each plant:**
  - Emissions rate as a function of generation
  - Additional emissions due to starts and ramps

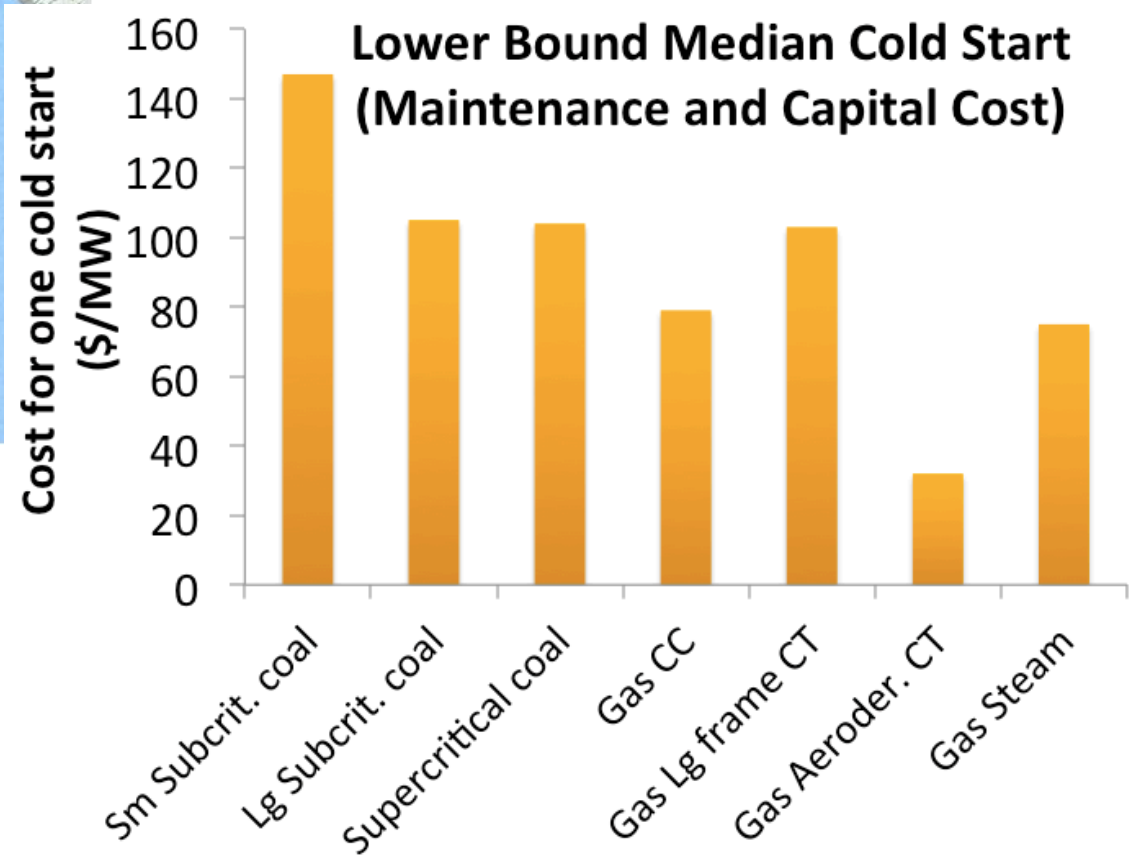




Developed Wear-and-Tear Cost Data Set

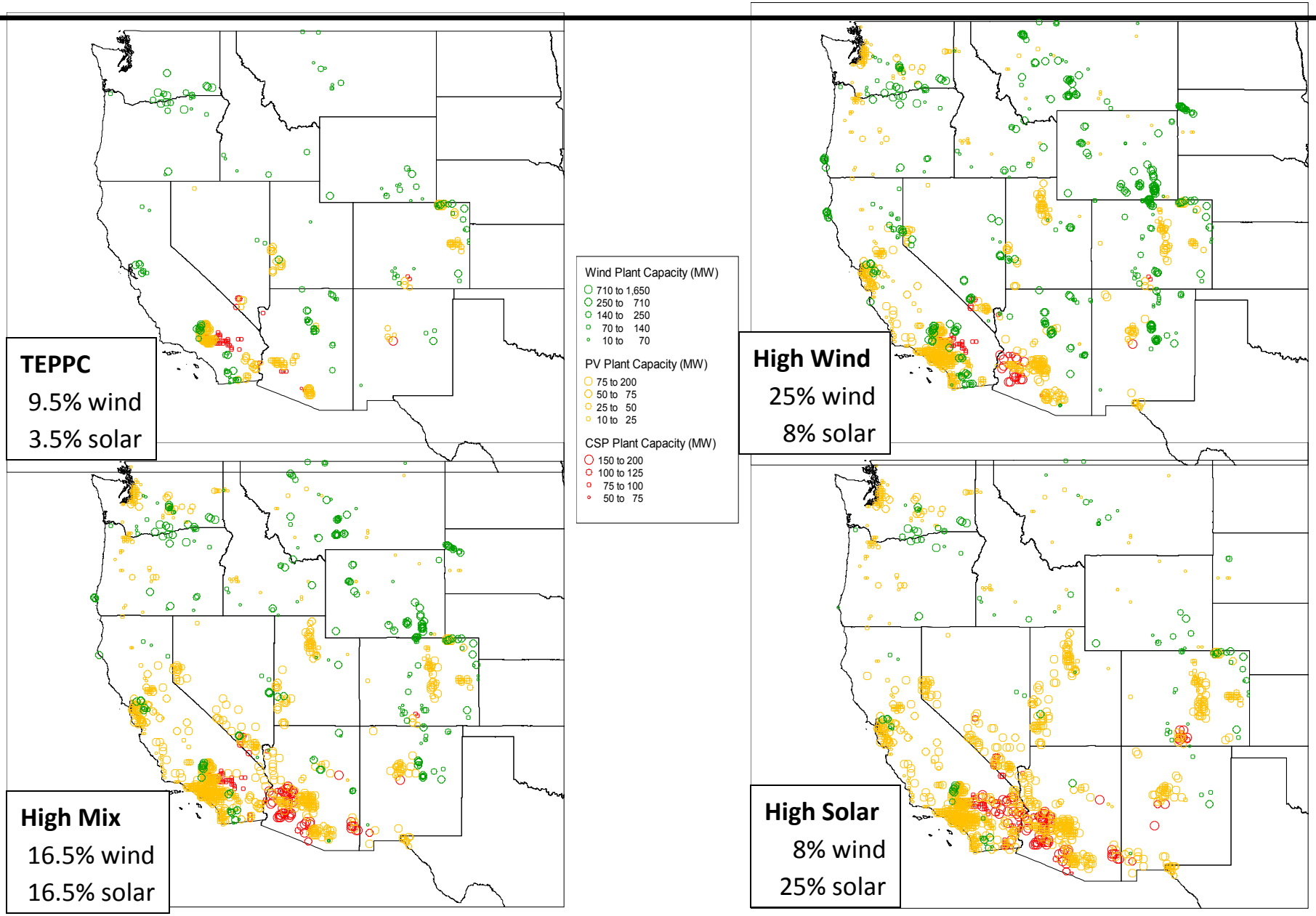


Upper and lower bounds developed for costs to reflect uncertainty ranges



Source: Kumar 2012, www.nrel.gov/docs/fy12osti/55433.pdf

Scenarios Compare Wind and Solar



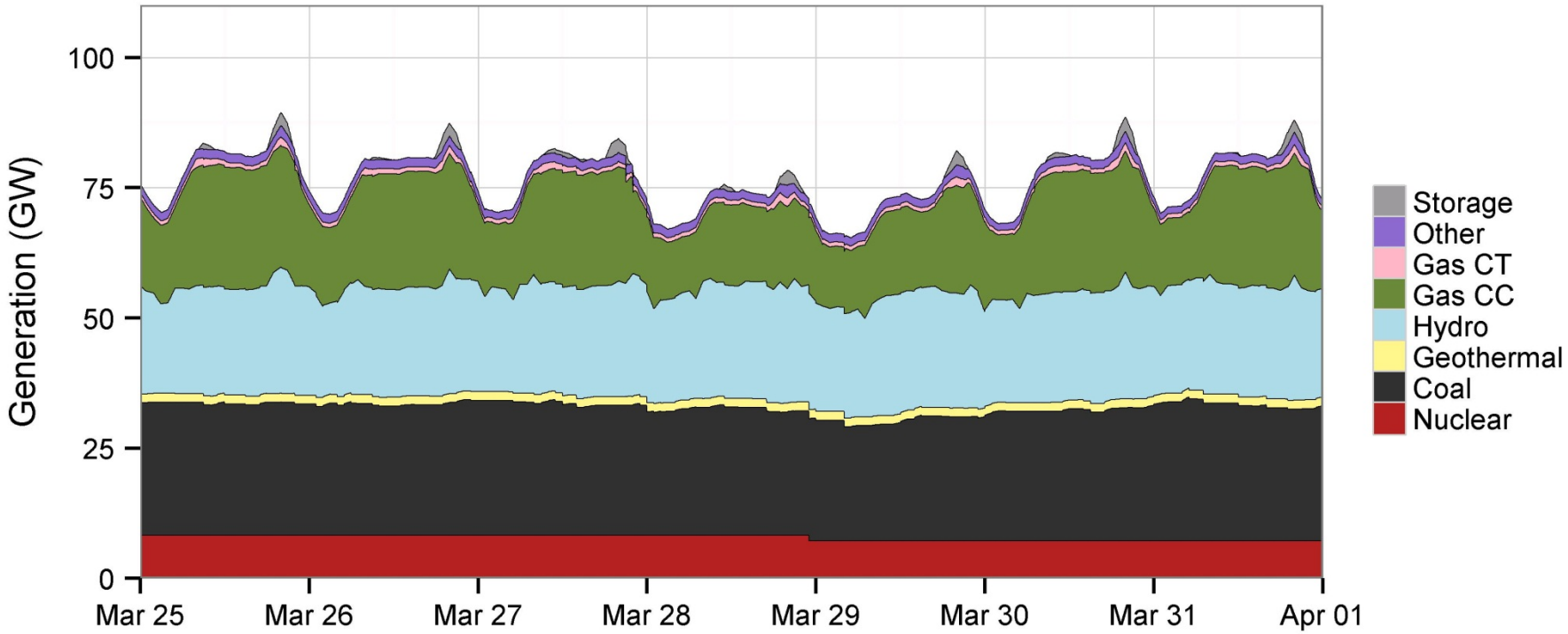
Adding ~100,000 MW of Wind/Solar

	PV (MW)	CSP (MW)	Wind (MW)	Total (MW)
TEPPC (9.5% wind, 3.5% solar)	7,074	4,352	27,900	39,326
High Wind (25% wind, 8% solar)	20,064	6,536	63,840	90,439
High Mix (16.5% wind, 16.5% solar)	40,374	13,997	43,118	97,489
High Solar (8% wind, 25% solar)	61,941	21,526	23,357	106,824

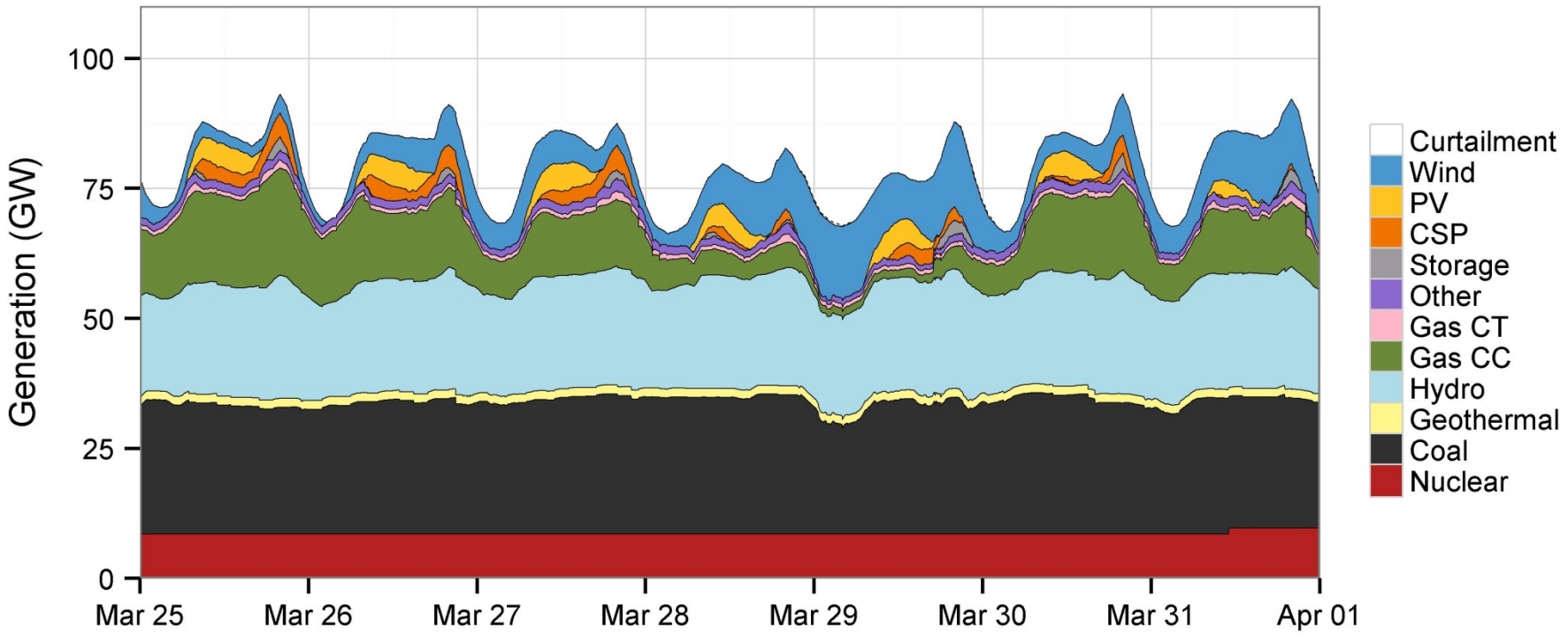
- All wind and solar is sited in US portion of Western Interconnection. 2020 peak WECC load is 171 GW, of which 147 GW is in the US. TEPPC case uses same MW as TEPPC but all sited in US, giving 13% total VG penetration
- CSP has 6 hours storage
- WECC TEPPC 2020 PC1 case

Spring Is Most Challenging for Operations

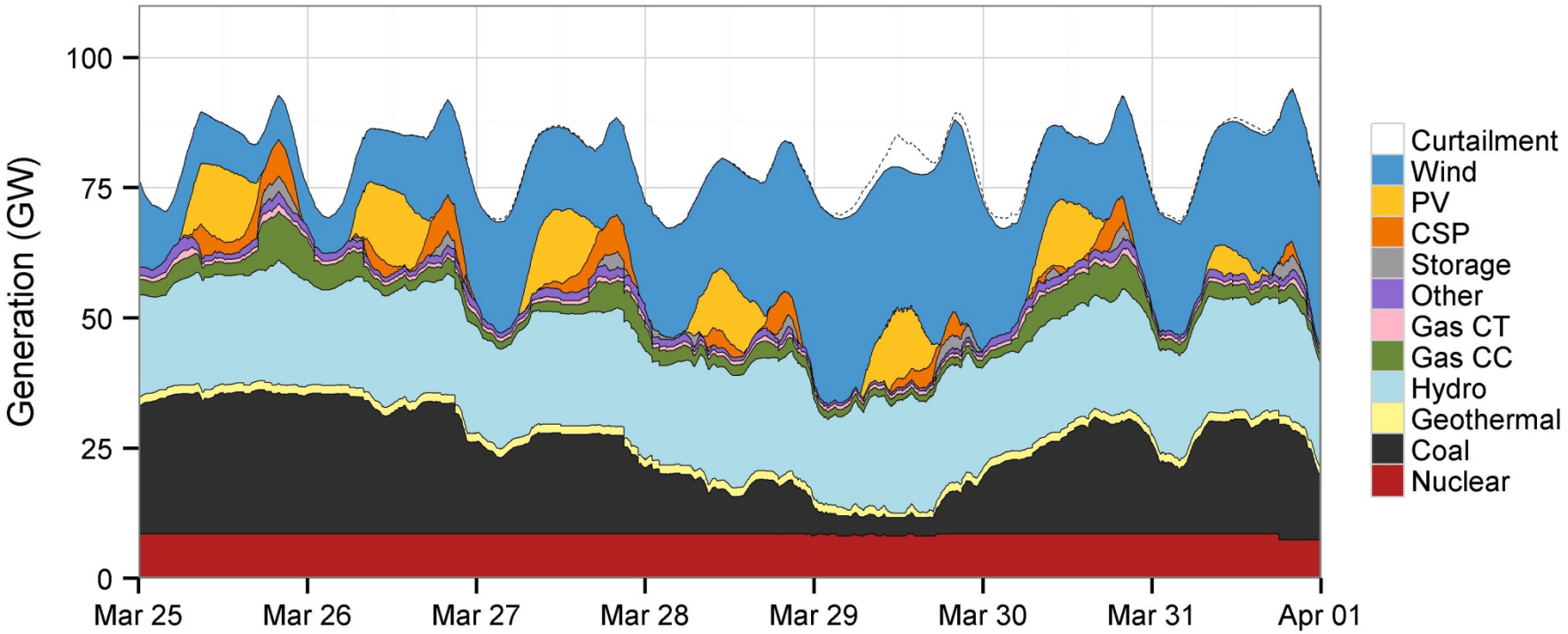
No Renewables (0% Solar, 0% Wind)



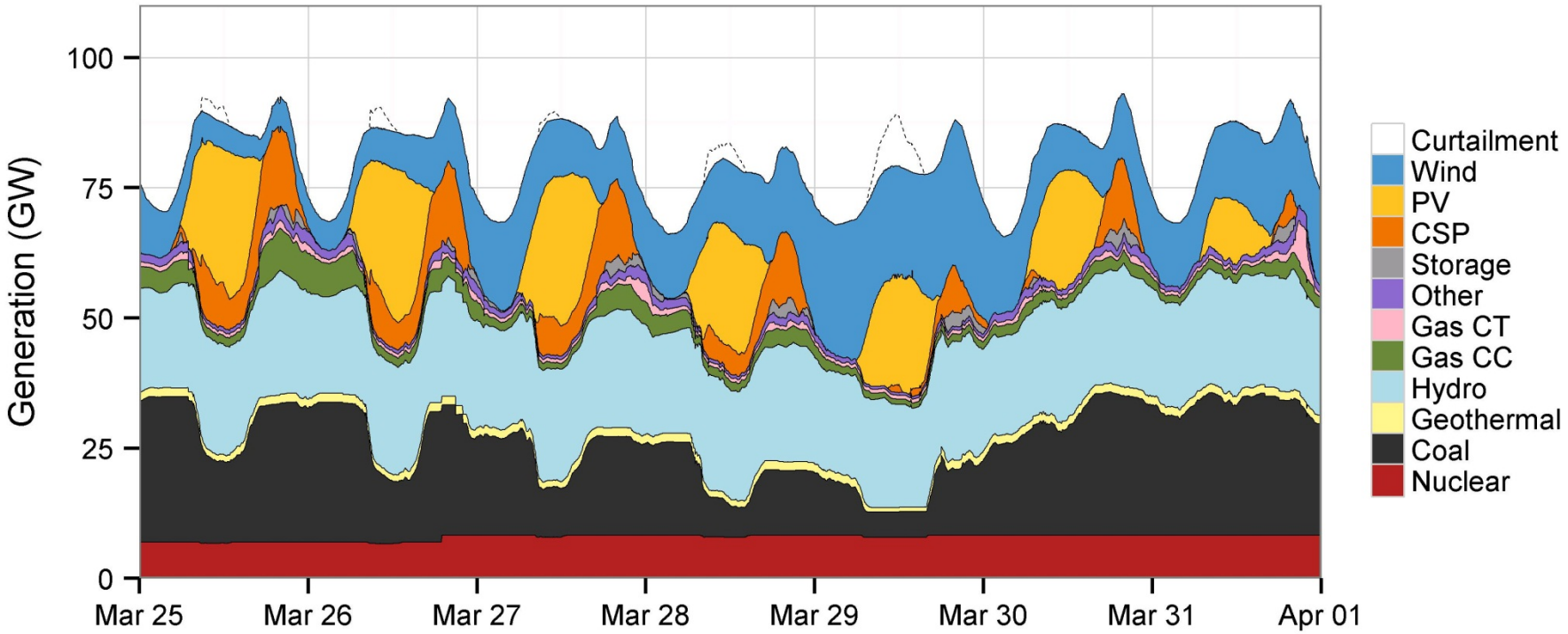
TEPPC (3.5% Solar, 9.5% Wind)



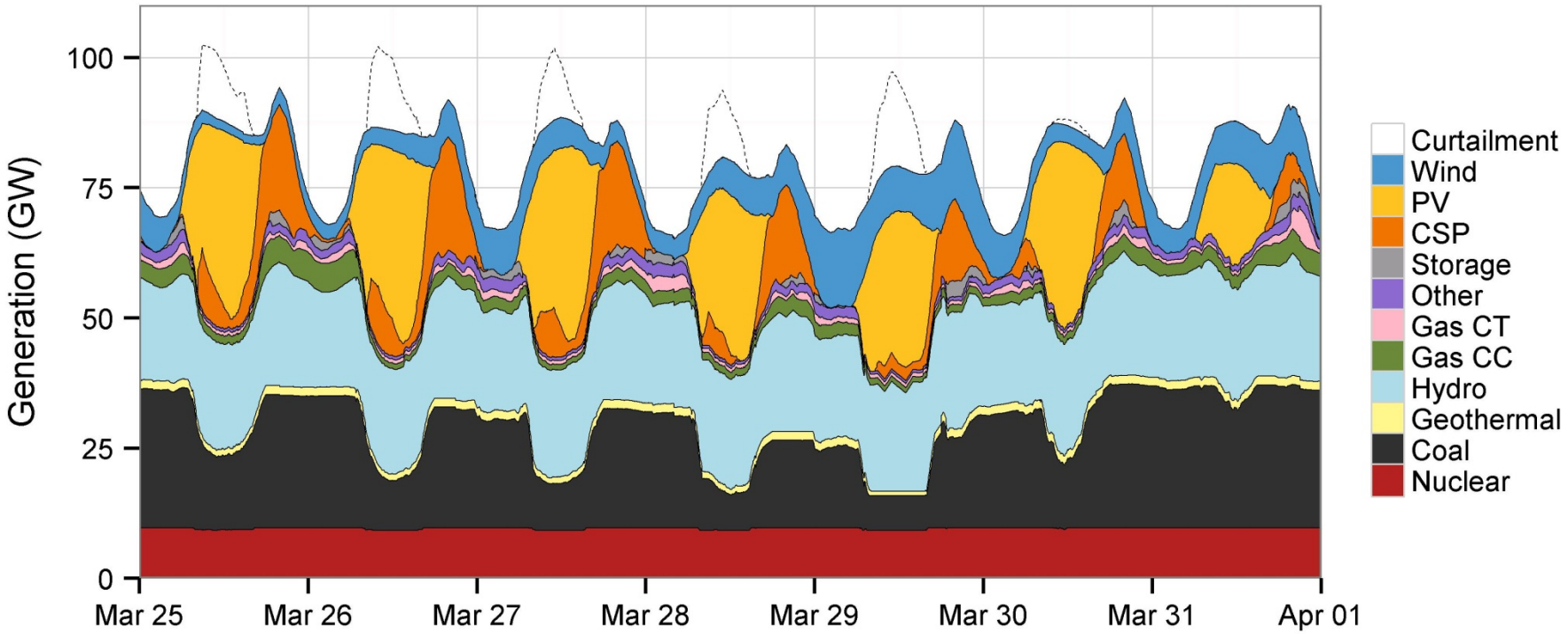
High Wind (8% Solar, 25% Wind)



High Mix (16.5% Solar, 16.5% Wind)

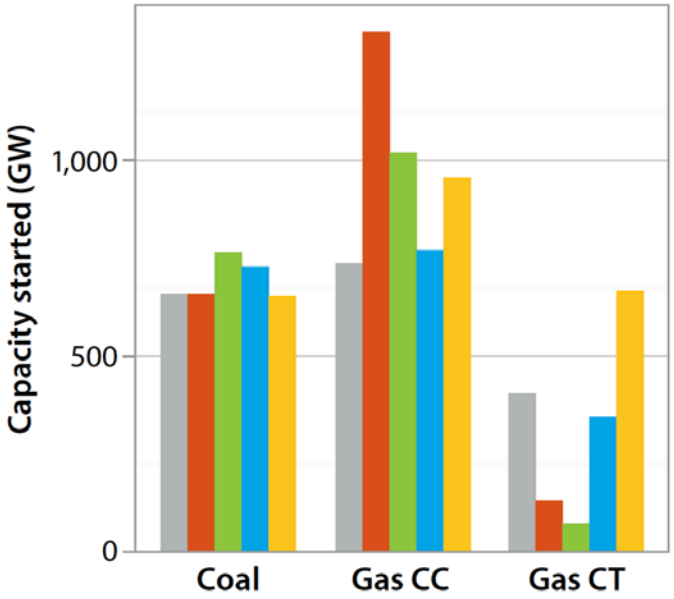


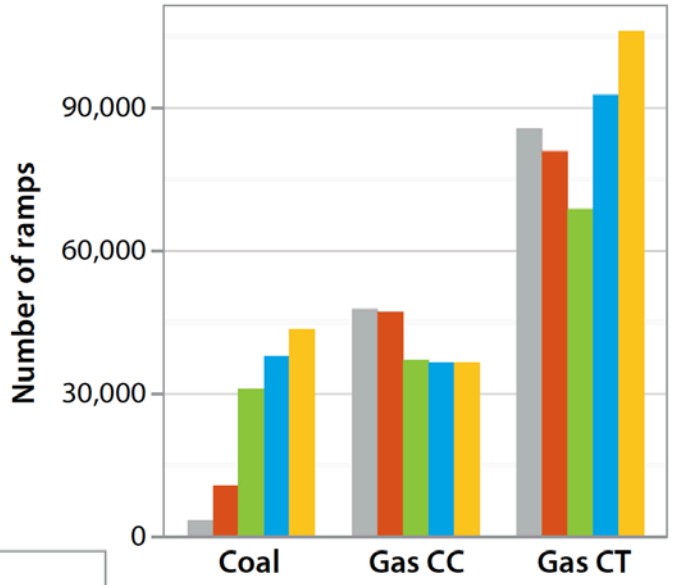
High Solar (25% Solar, 8% Wind)

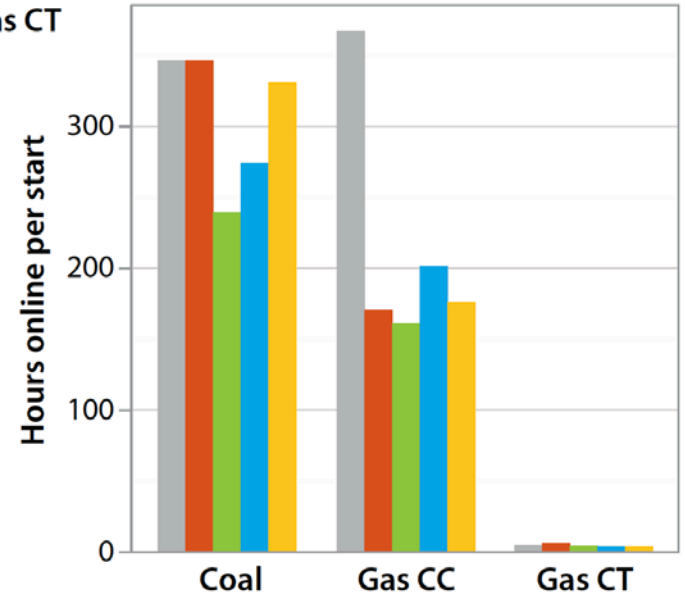


Solar is 60% PV and 40% Concentrating Solar Power with 6 hours thermal storage

Coal Ramping Increases with Wind/Solar

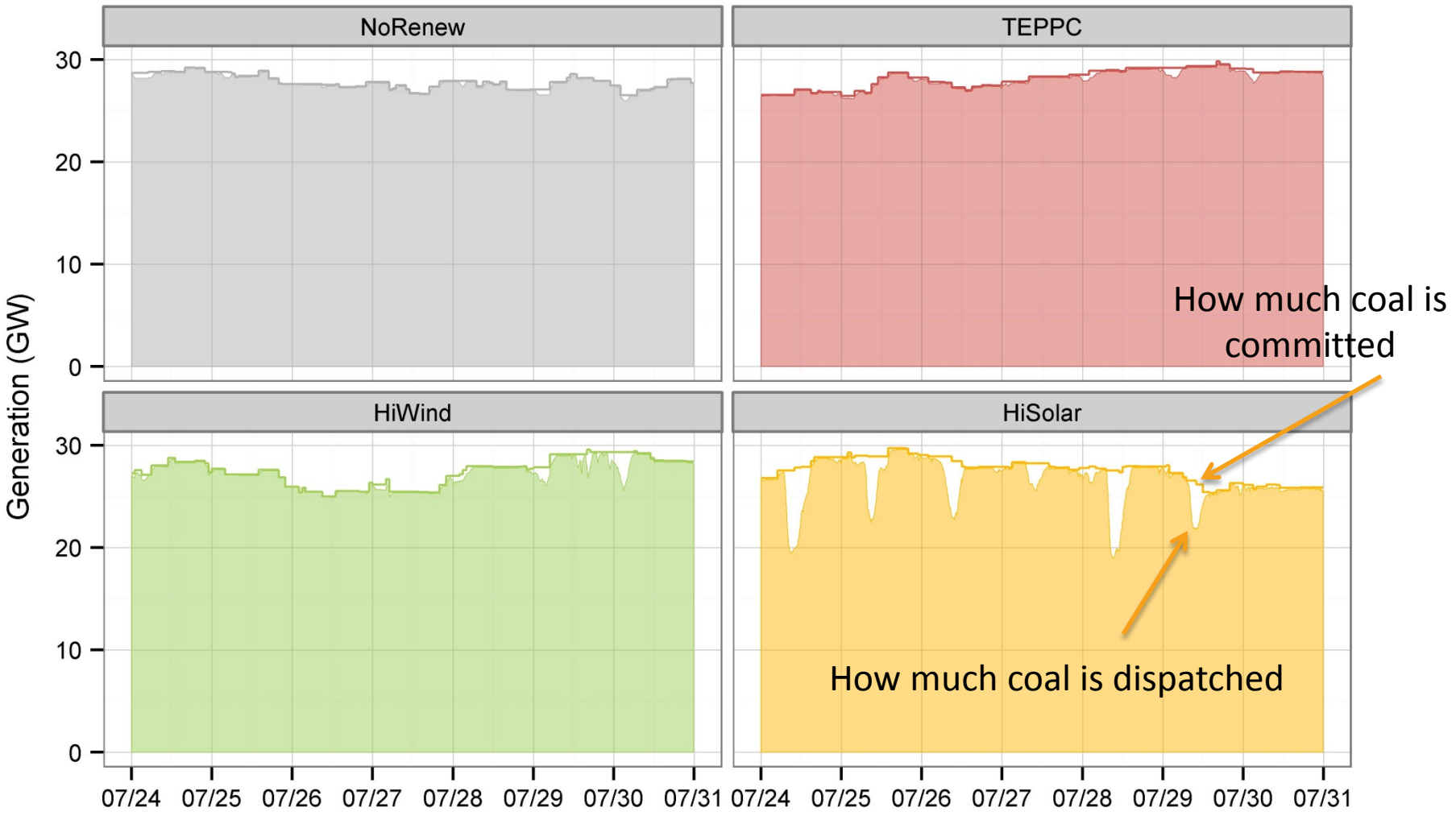




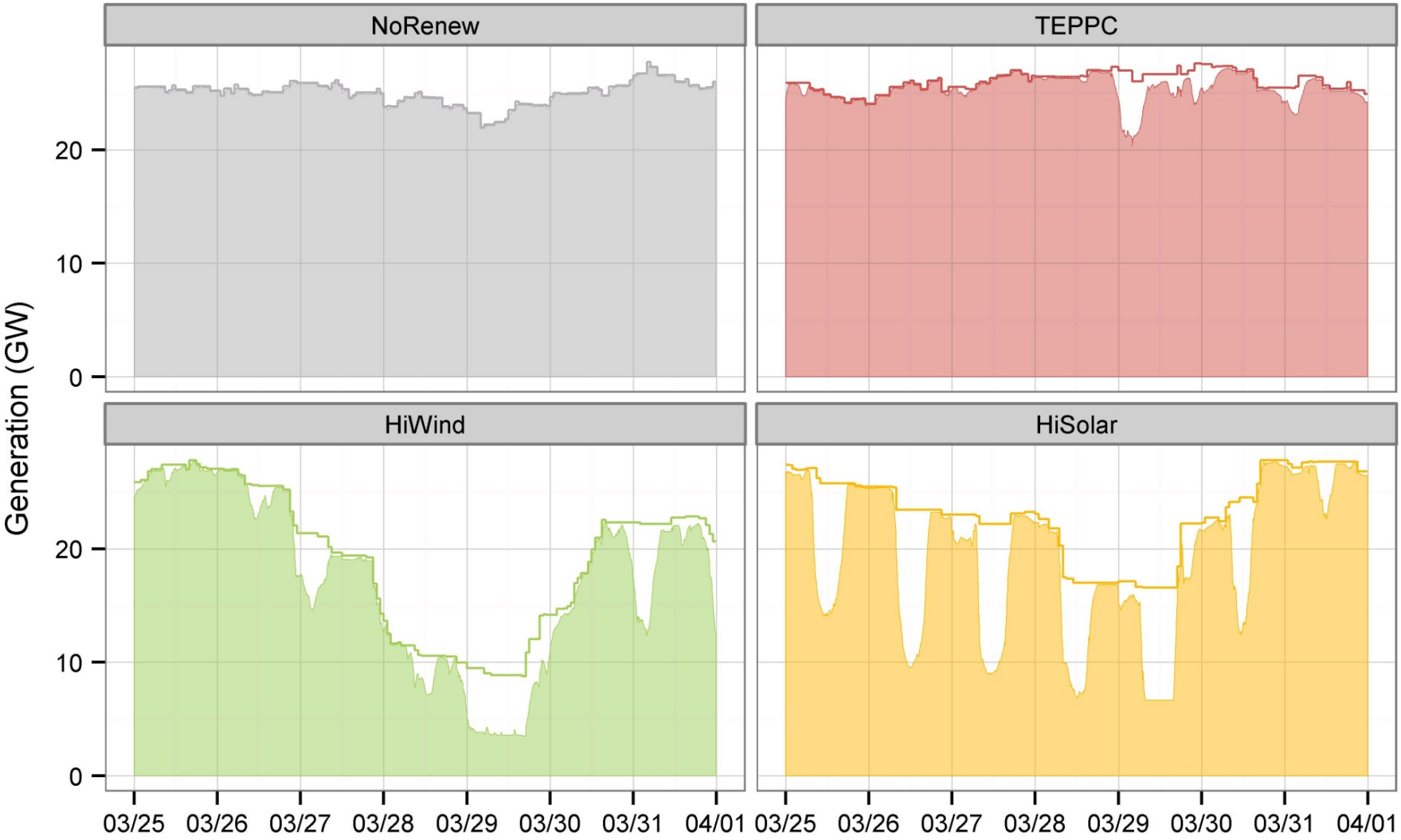


Excludes must-run gas combustion turbines which would distort statistics

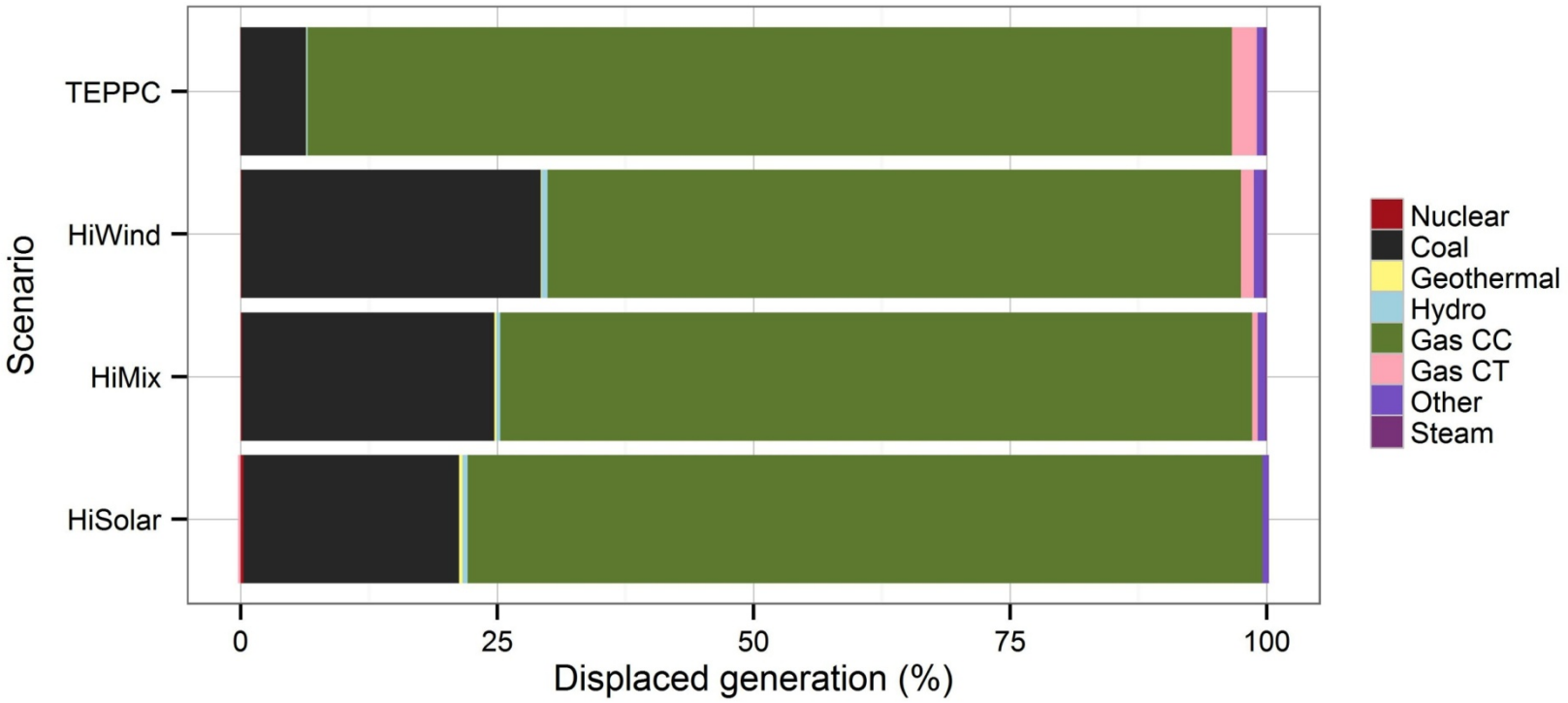
Little Impact on Coal Operation in Summer



Spring: Wind Leads to Coal Shutdowns
Solar Leads to Coal Rampdowns



Renewables Displace Gas and Some Coal



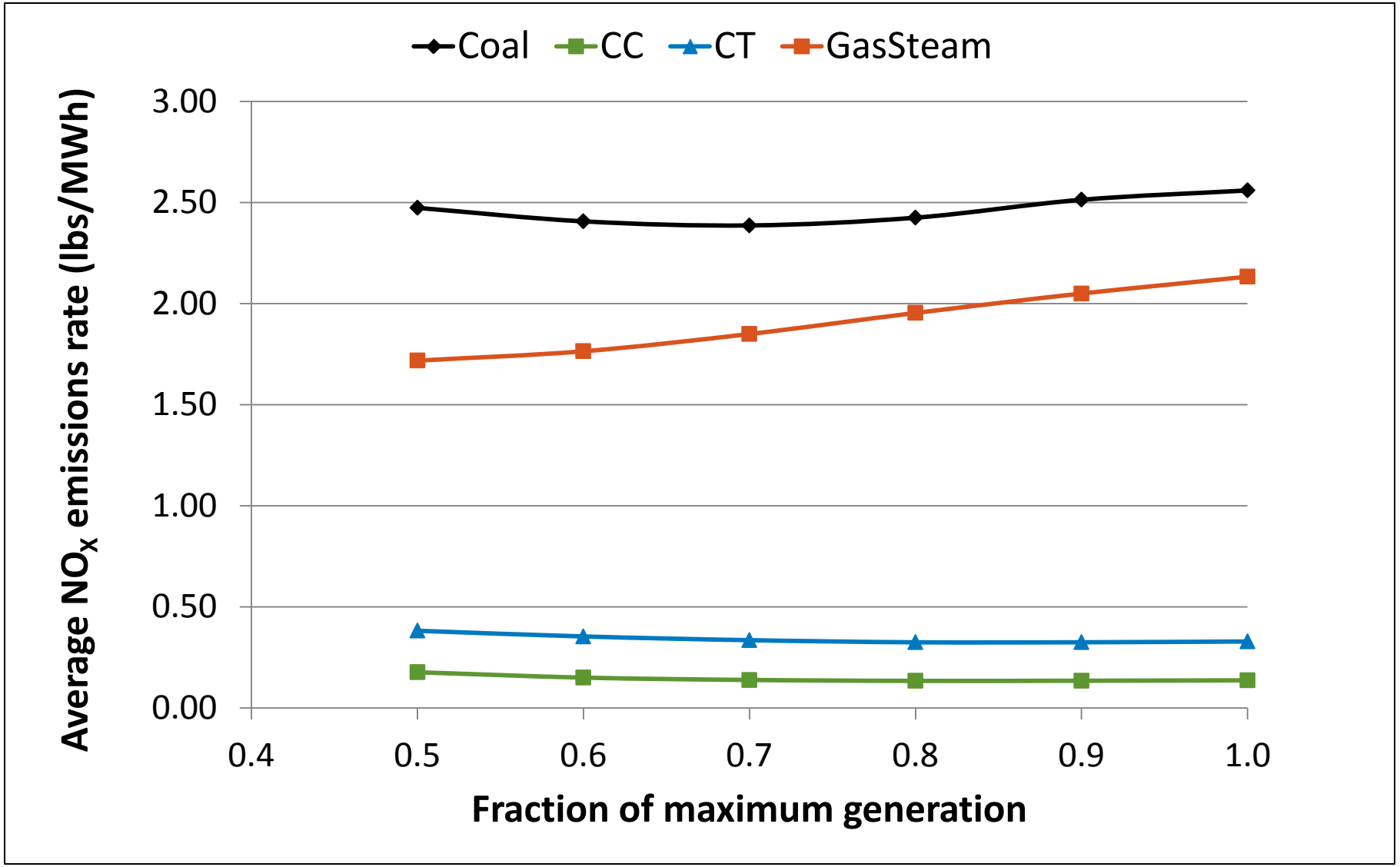
Gas prices average $4.60/mmbtu

How are emissions impacted by cycling?

Emission Impacts of Cycling Are Relatively Small

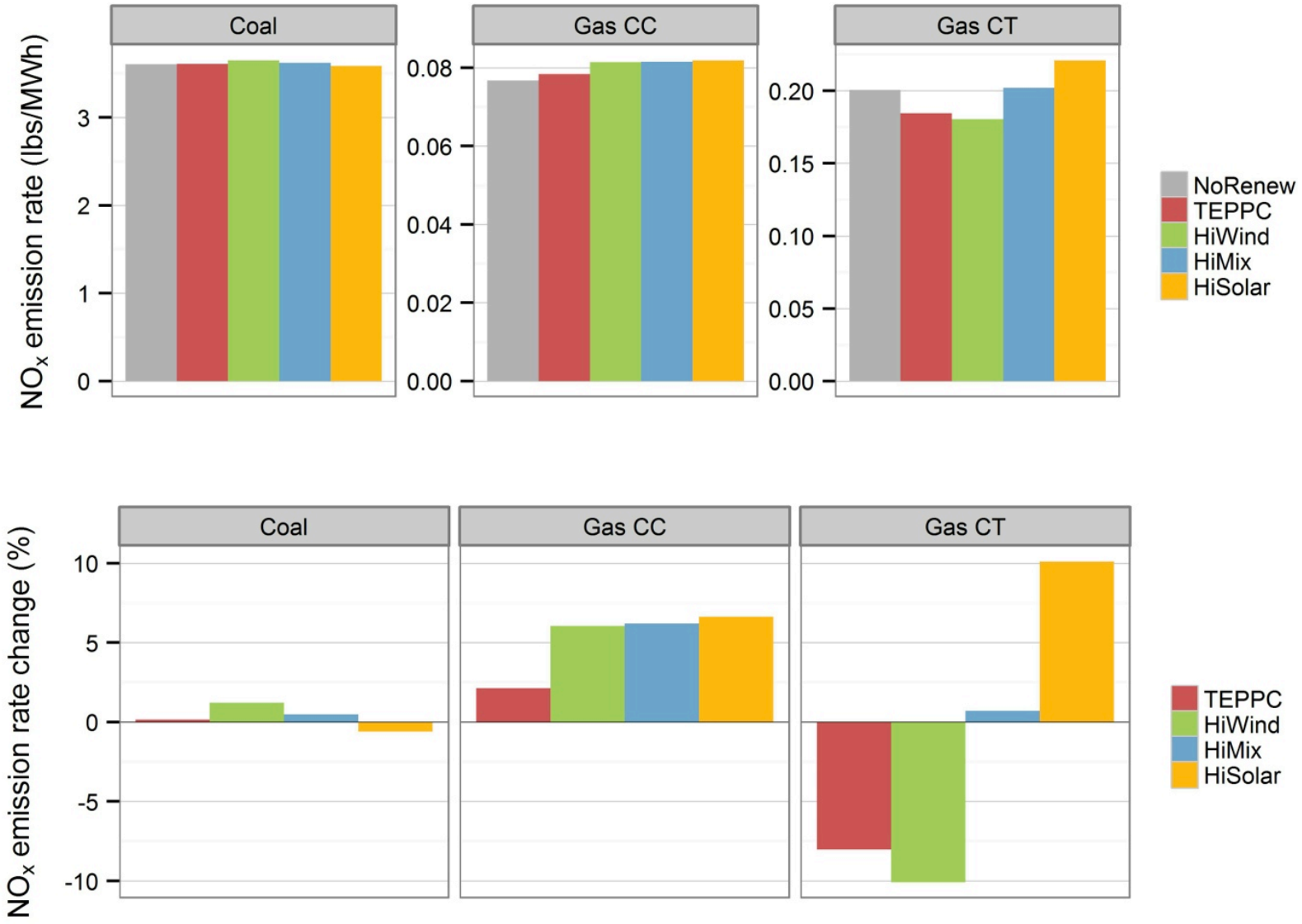
	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260–300 billion lbs 29%–34%	Negligible Impact
NO_x	170–230 million lbs 16%–22%	3–4 million lbs
SO_2	80–140 million lbs 14%–24%	3–4 million lbs

Wind- and Solar-Induced Cycling Can Have a Positive or Negative Impact on Emissions

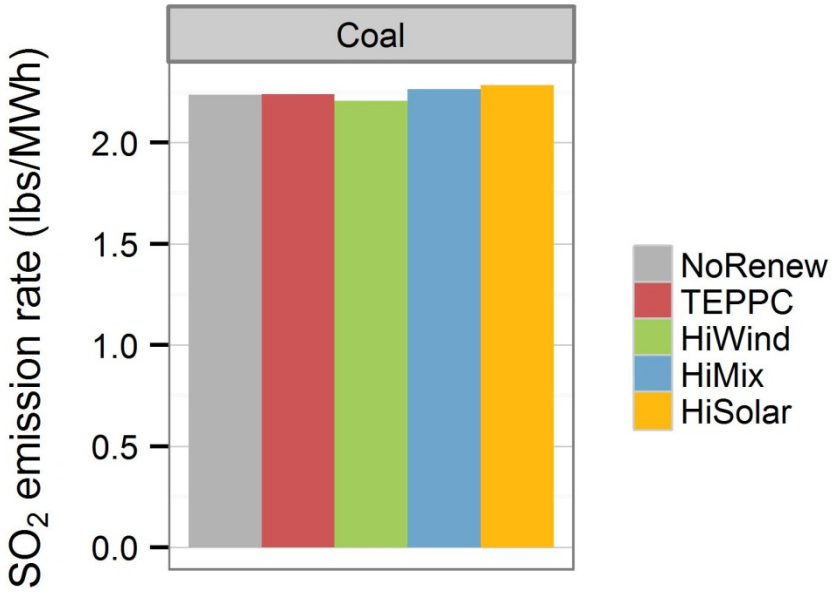


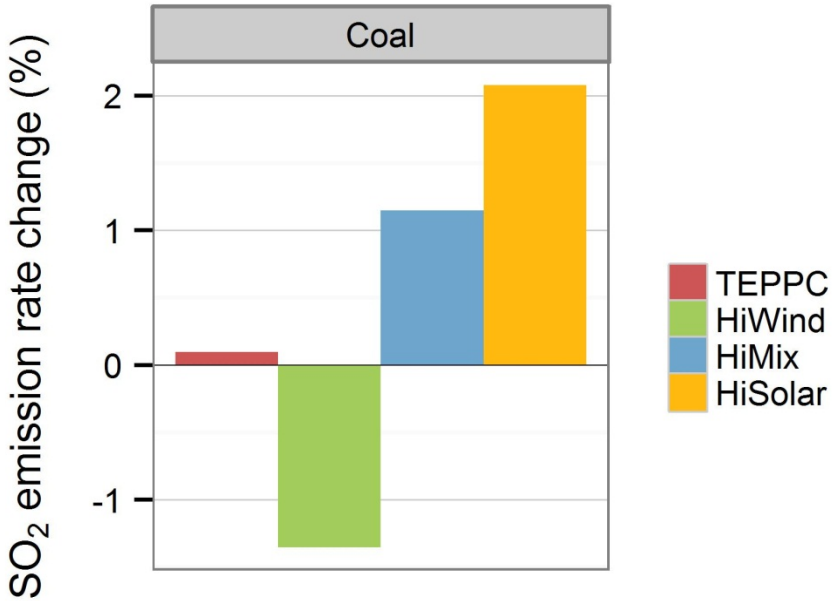
Average CO_2 Emission Rates From Coal Don't Change

Changes in NO_X Emission Rates Depend on Wind/Solar Mix



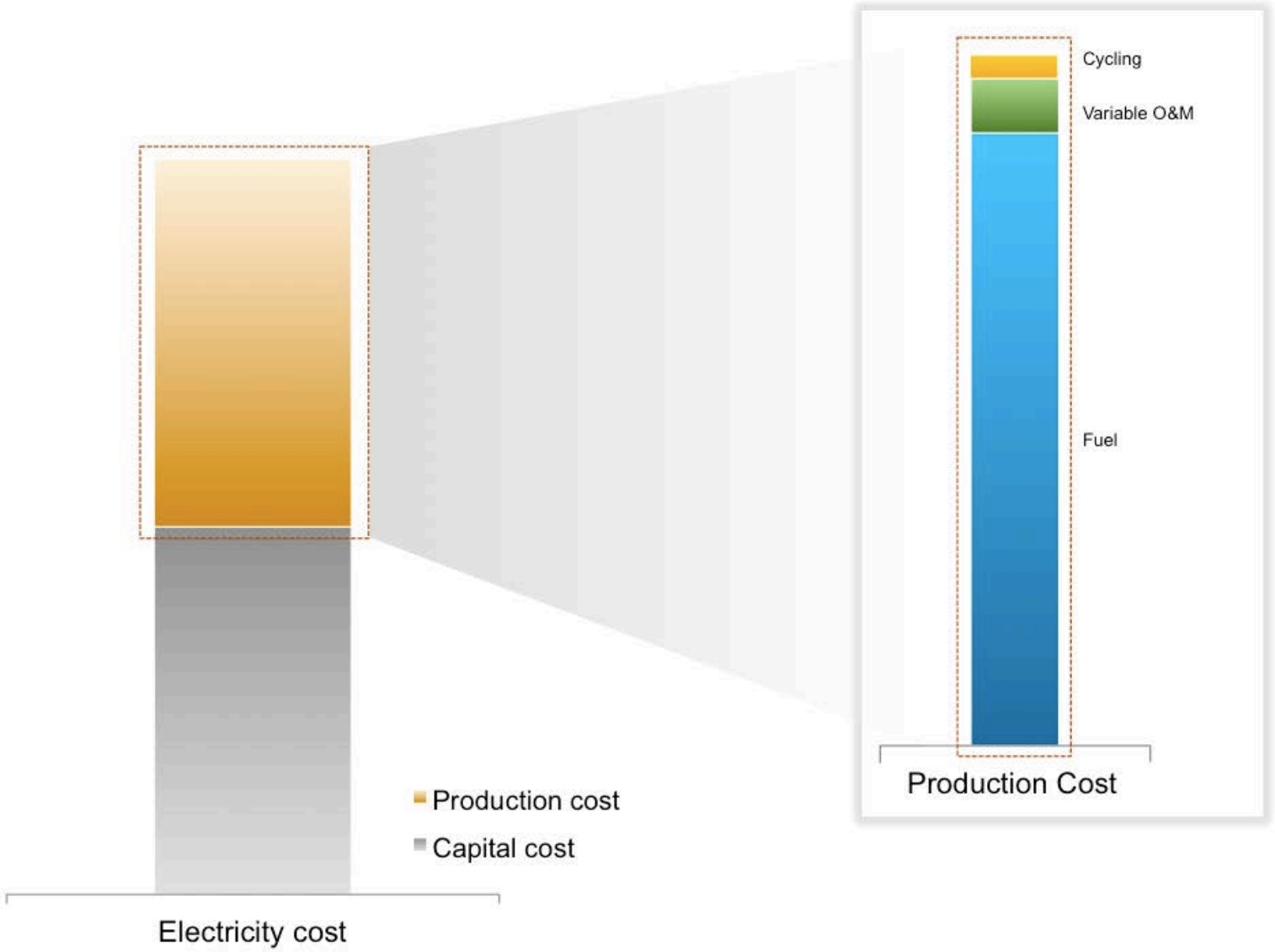
Changes in SO_2 Rates Depend on Wind/Solar Mix



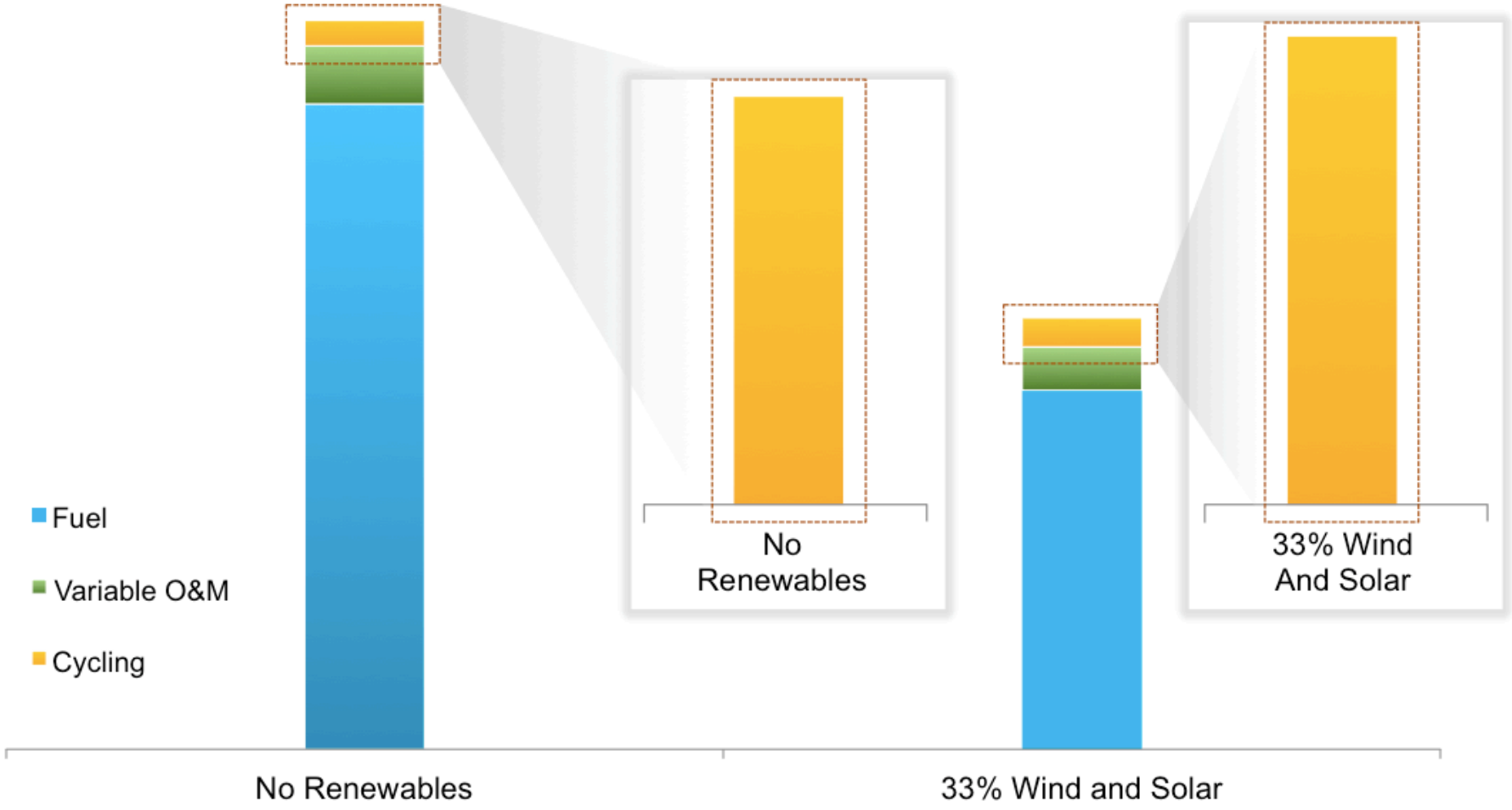


How are wear-and-tear costs impacted by cycling?

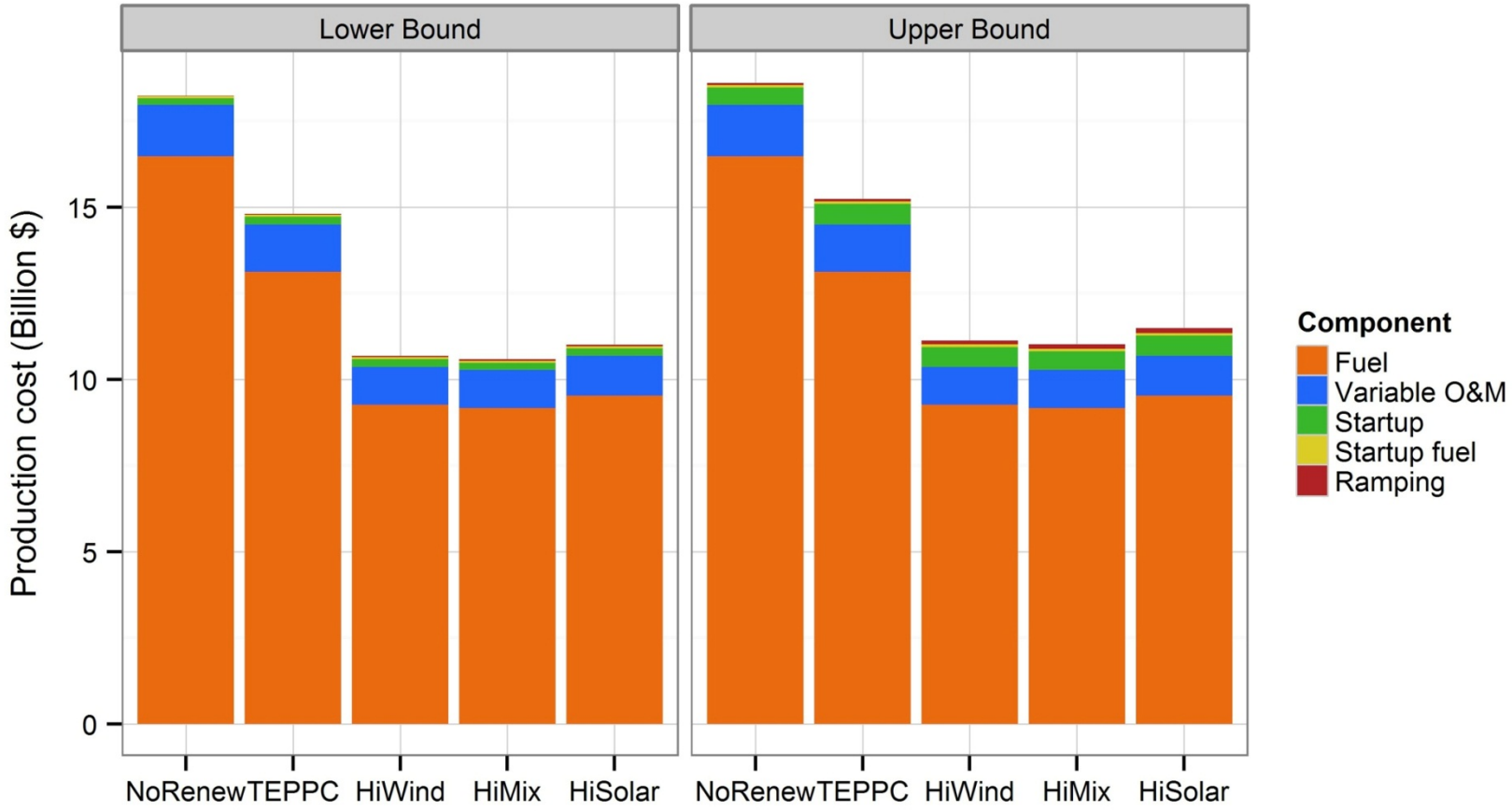
Electricity Costs Include Capital and Production Costs



Production Costs Include Cycling Costs

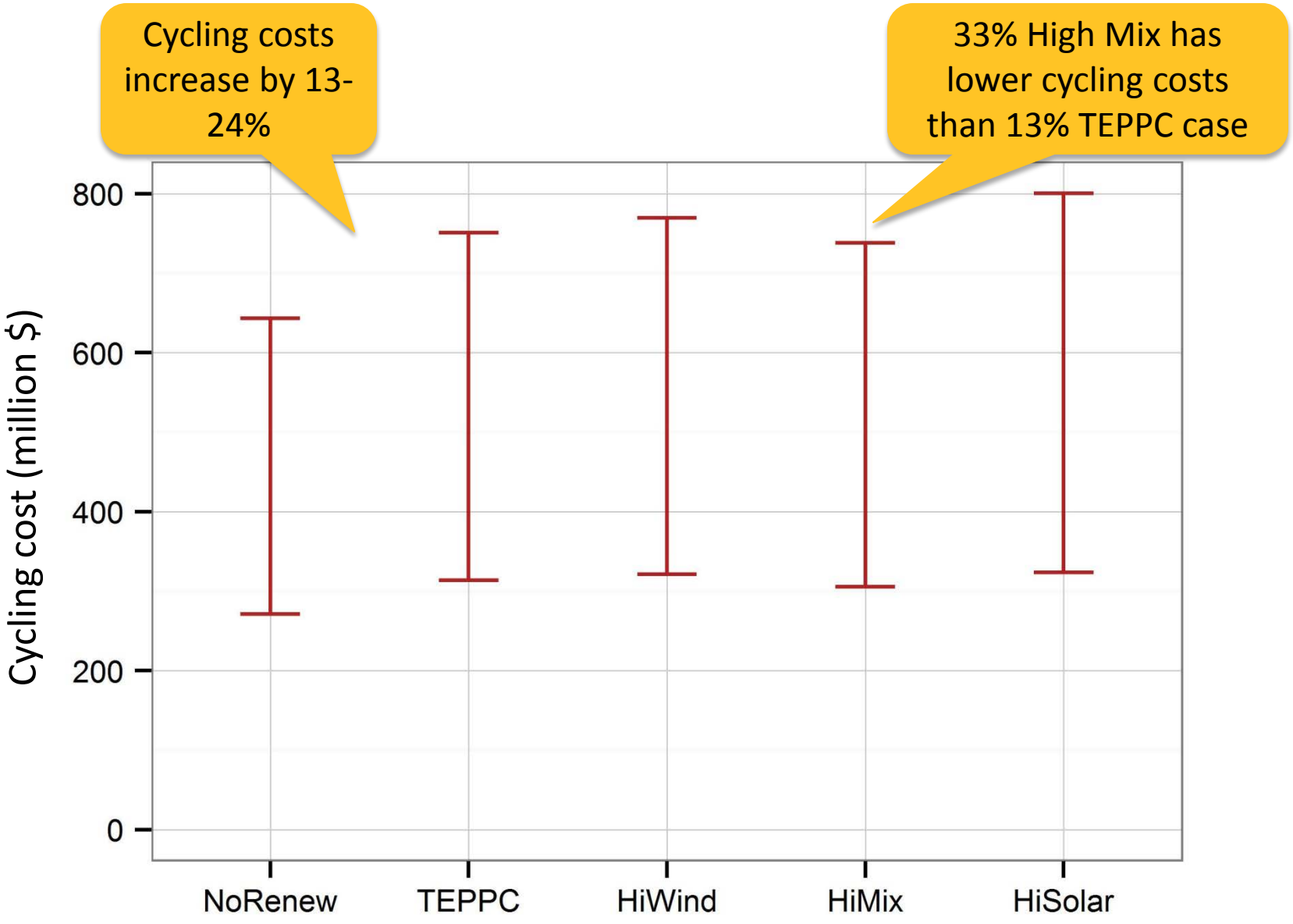


Cycling Costs are 1% to 7% of Overall Production Cost



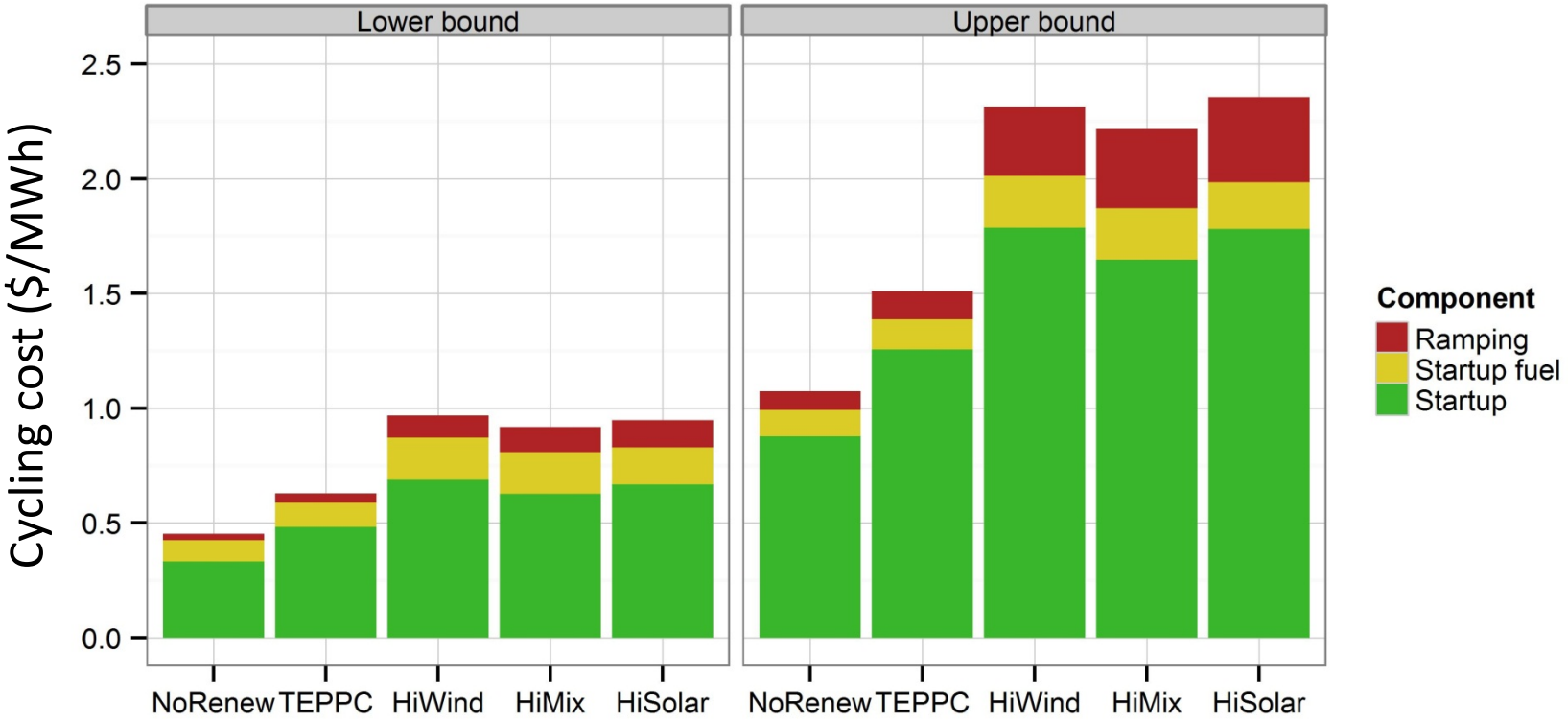
Cycling costs in these scenarios range from $271-800 million

33% Wind/Solar Induces $35 to $157 M/yr of Cycling Costs



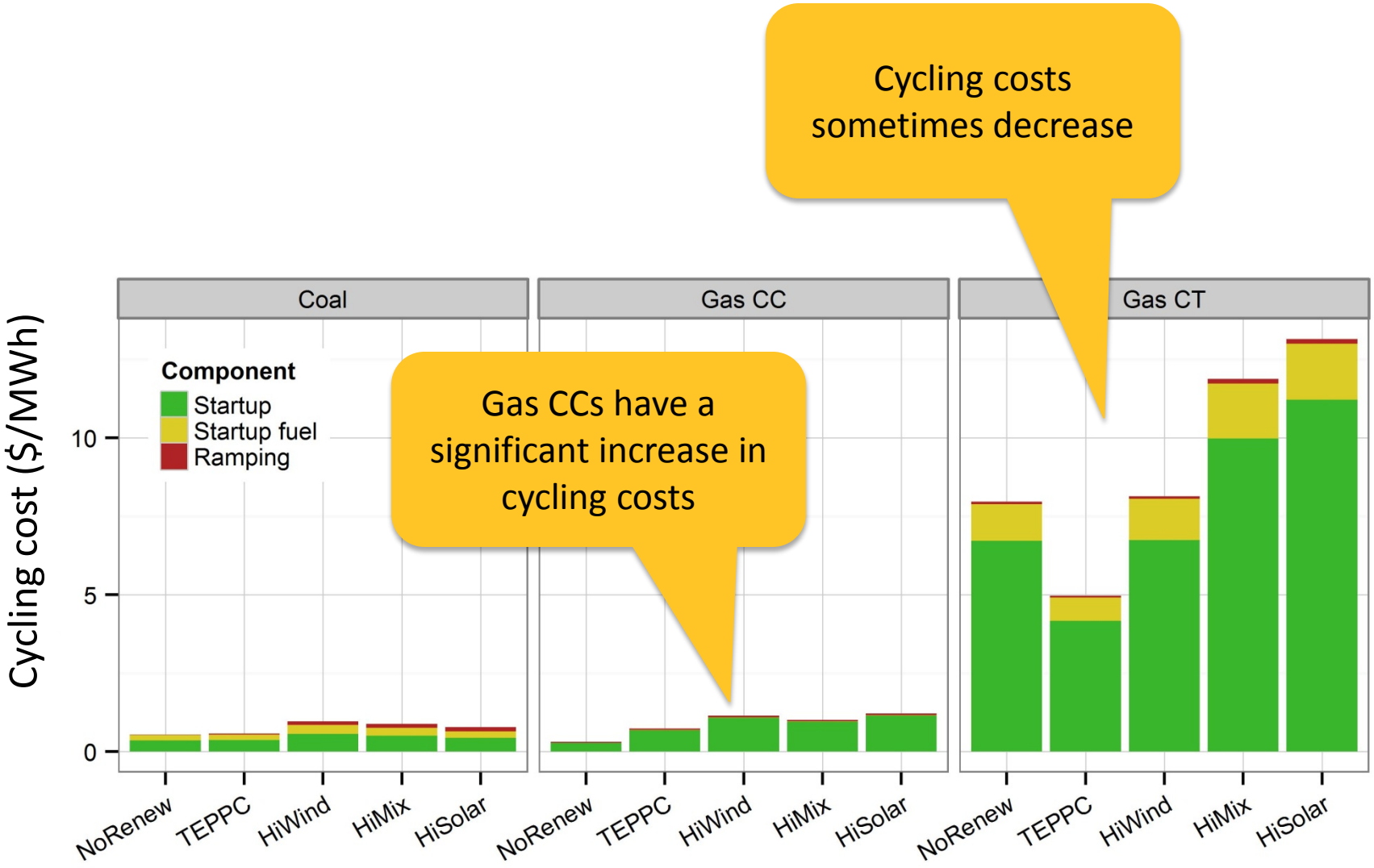
The Generator Perspective

The average fossil-fueled plant sees an increase in O&M of $0.47-1.28 per MWH generation



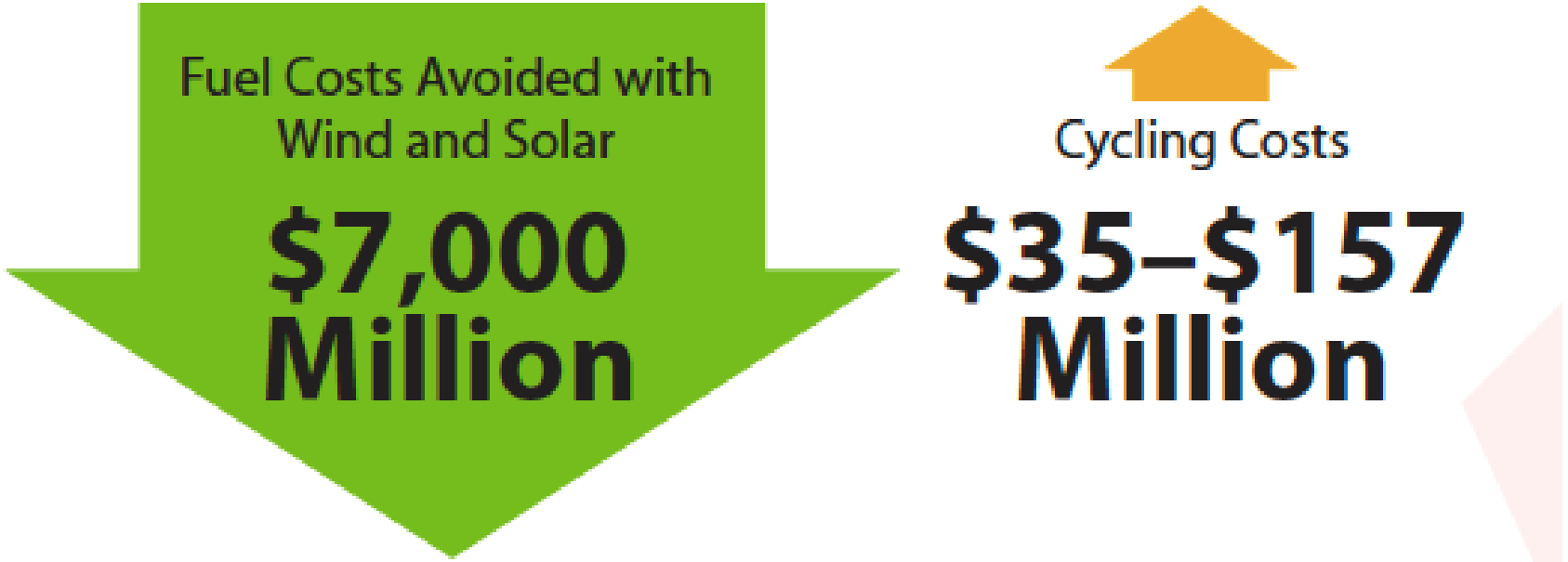
Starts, not ramps, drive wear and tear costs

Gas Combustion Turbines Bear Brunt of Cycling Costs



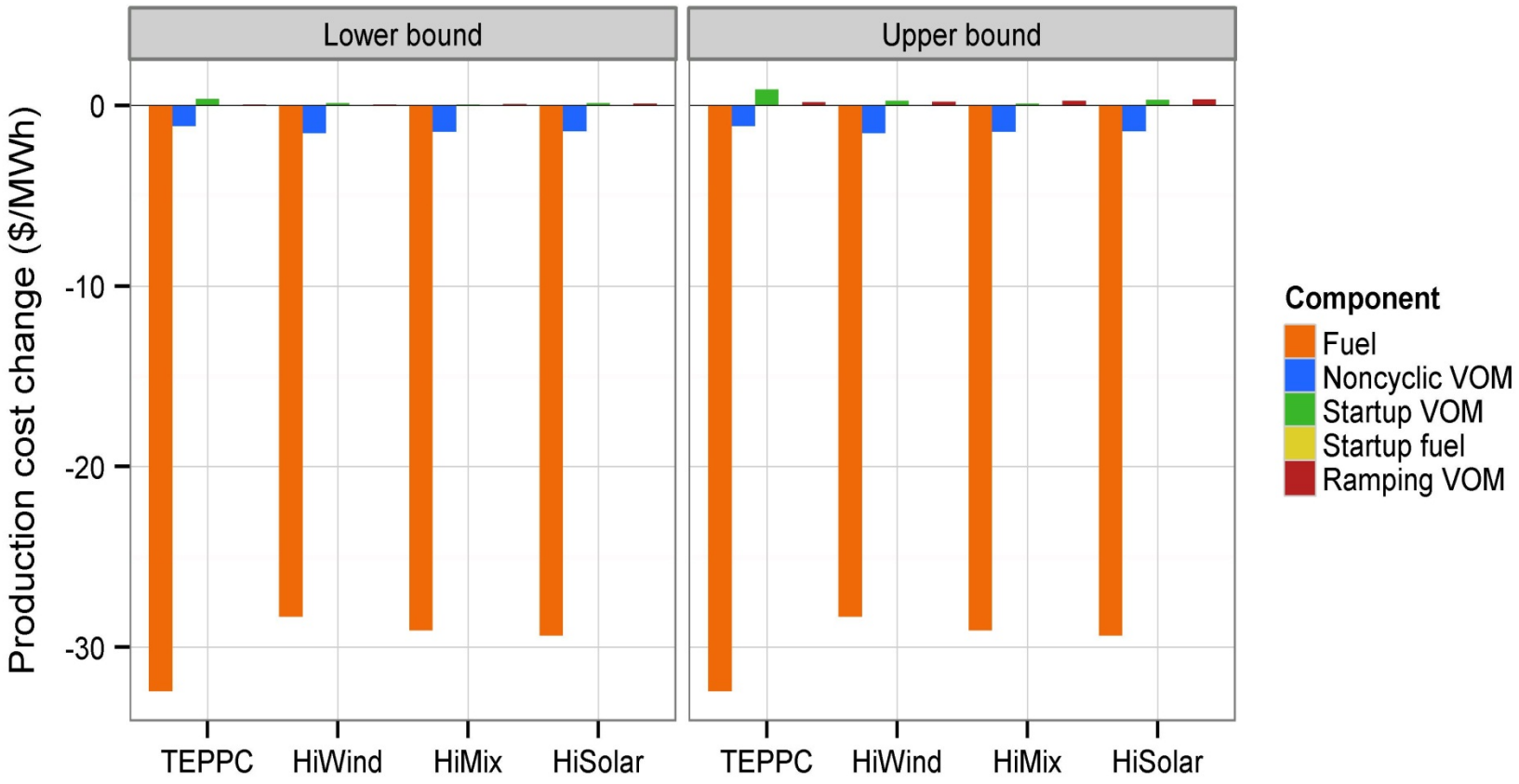
Note: These are the lower bound cycling costs

From a System Perspective, Cycling Costs Are Relatively Small



Note: Capital costs for wind and solar are not reflected.

The System Perspective

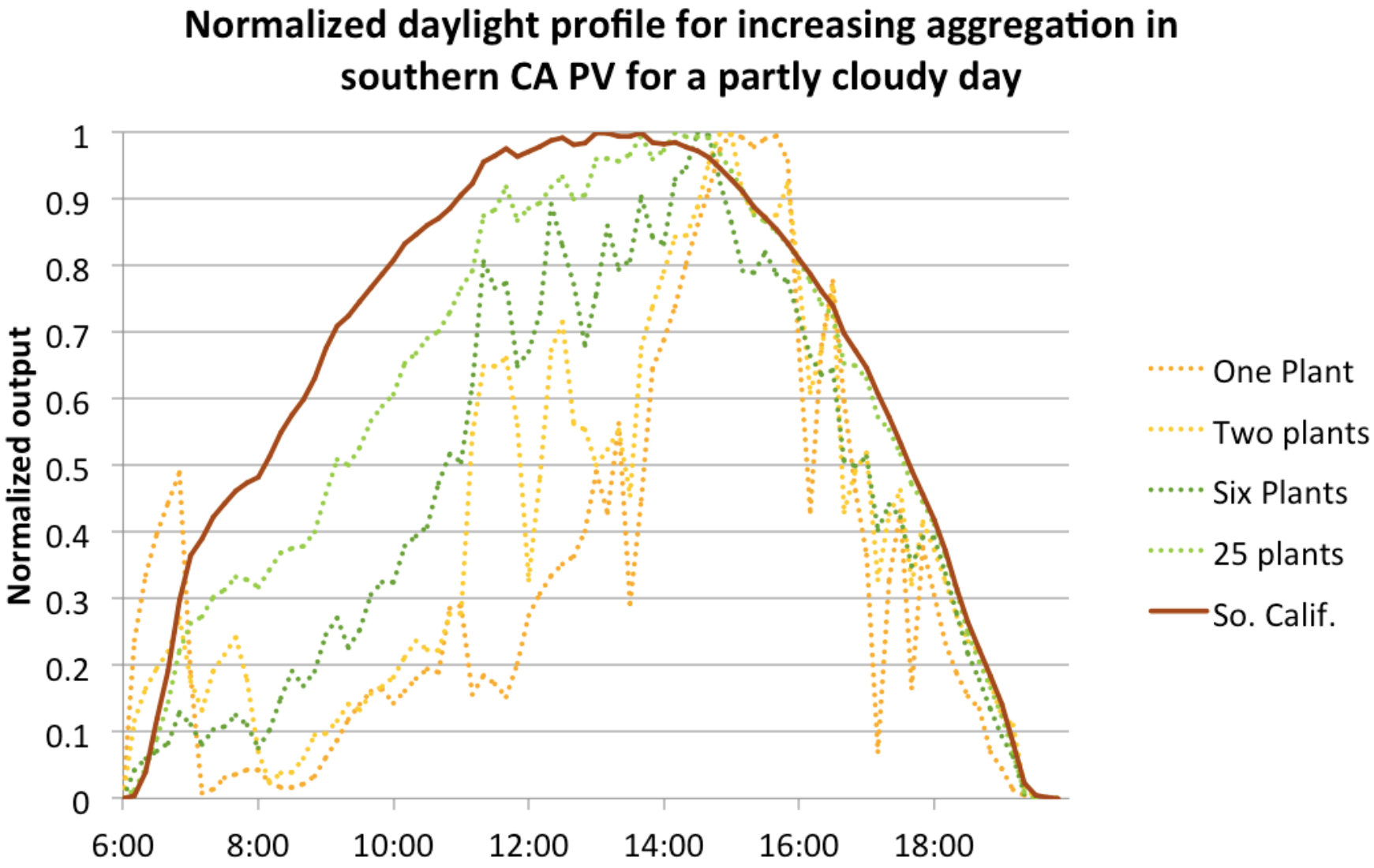


Production cost change of wind/solar ranges from $29.4-$30.6 per MWh in the high penetration scenarios.
Cycling costs reduce this by $0.14-$0.67 per MWh of wind/solar

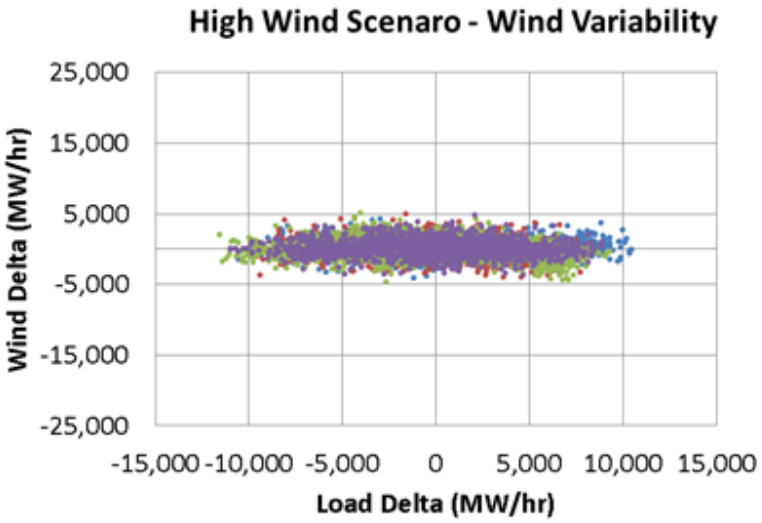
Note: These do not include capital costs of construction of generation or transmission

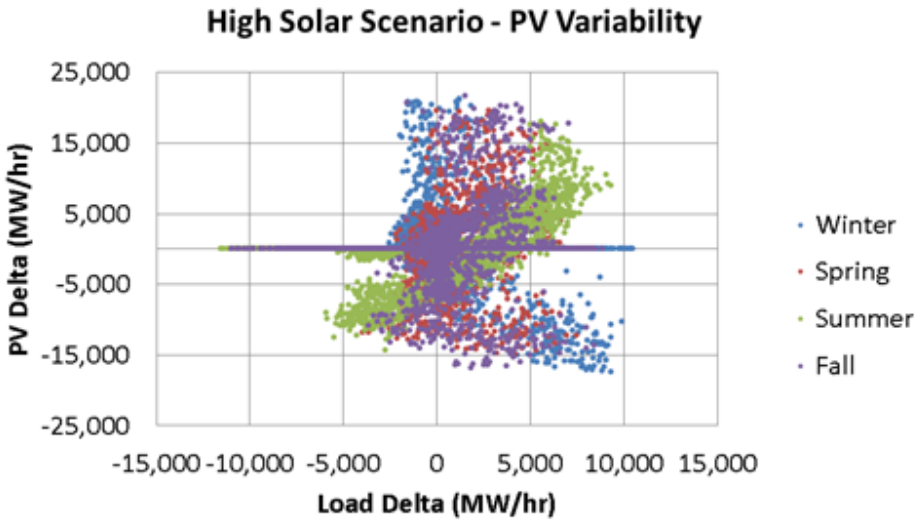
How do wind and solar impacts compare?

Aggregation Reduces Variability

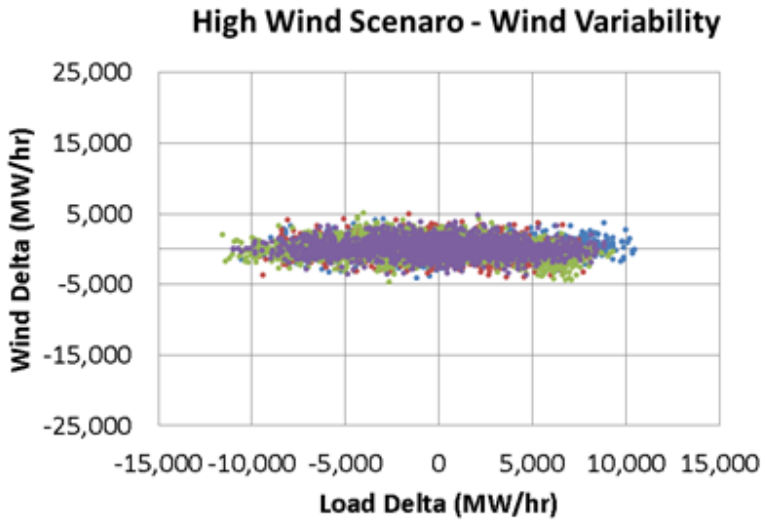


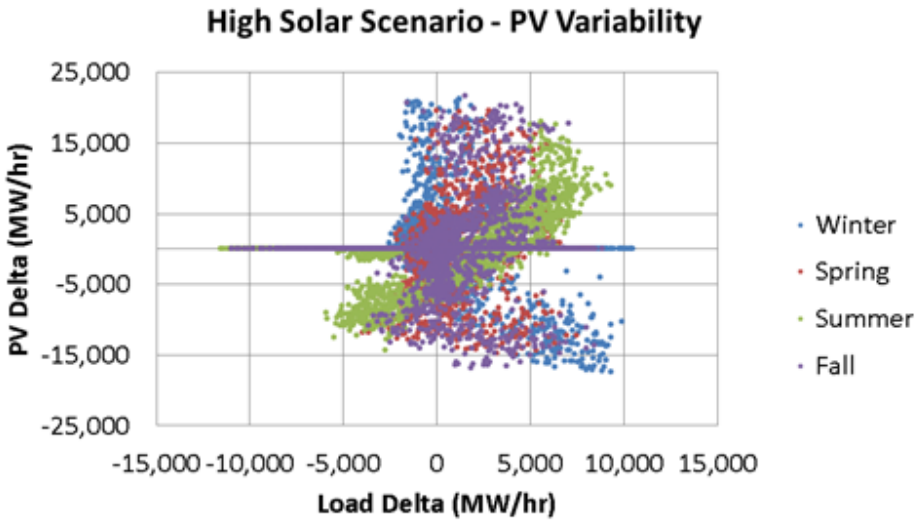
PV Dominates Variability Extremes



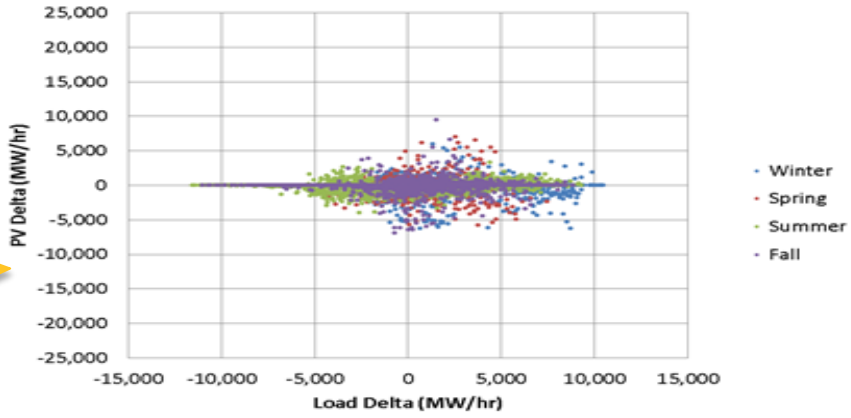


PV Variability Is Dominated by Sun Movement

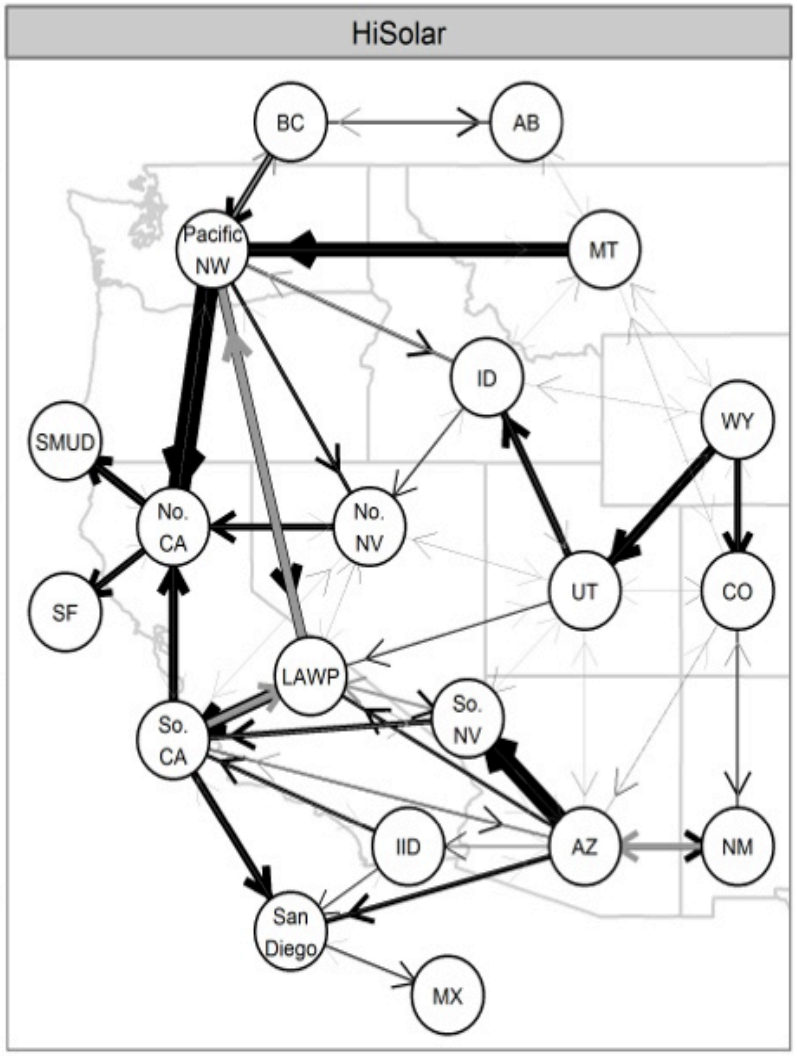


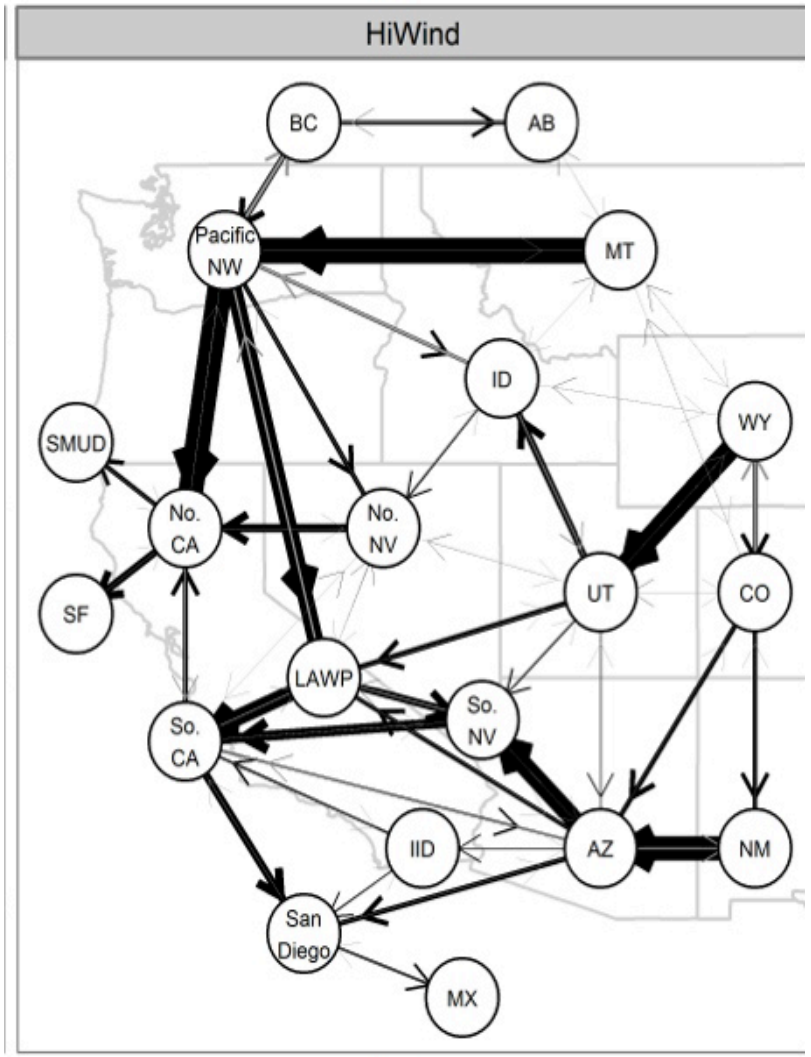


Removing the known path of the sun through the sky leaves us with weather/cloud variability which is significantly less



High Solar Results in Less Transmission Use





Solar Requires Less Reserves Than Wind

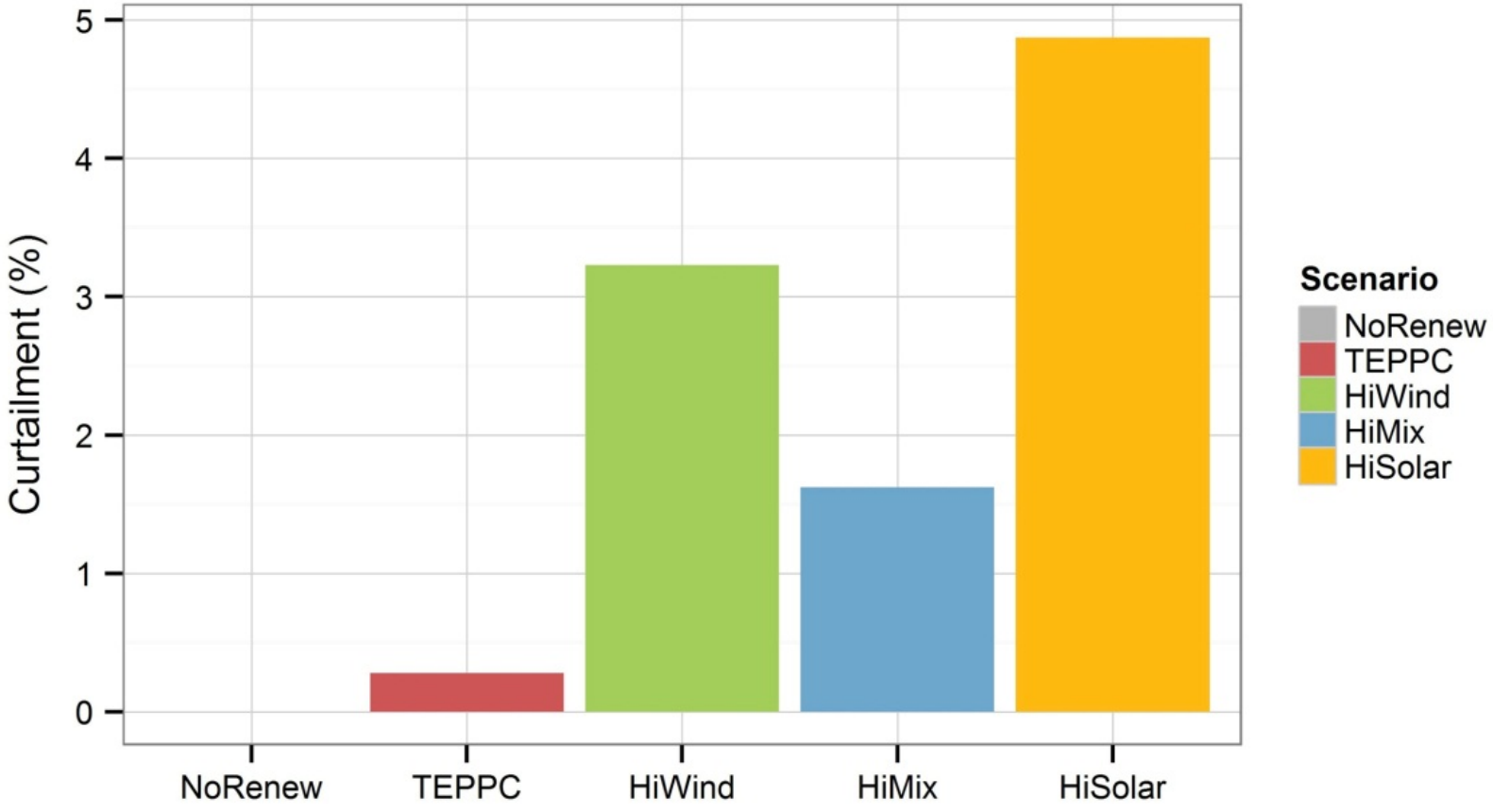
Scenario	Contingency (MW)	Regulation (MW)	Flexibility (MW)
No Renewables	3,361	1,120	0
TEPPC	3,361	1,158	1,193
High Wind	3,361	1,236	2,599
High Mix	3,361	1,211	2,035
High Solar	3,361	1,207	1,545

Contingency reserves are unchanged with wind/solar.

High Wind/Solar requires up to 10% more regulating reserves than the No Renewables Scenario.

High Wind Scenario requires Flexibility reserves of 3% of installed Wind/Solar capacity. This is reduced to 1% for the High Solar Scenario.

Balanced Mix of Wind and Solar Reduces Curtailment



Conclusions

- **CO_2, SO_2, and NO_x emissions induced by cycling are a fraction of the overall reductions in emissions**
  - Wind- and solar-induced cycling can help or hurt emissions from a fossil plant, depending on plant type, wind/solar mix and penetration
- **Wind and solar increase cycling costs by $35-157M/yr**
  - From fossil perspective, cycling O&M increases by $0.47-1.28 per MWh of fossil generation
  - From system perspective, cycling reduces production cost savings by $0.14-0.67 per MWh of wind/solar
- **Wind and solar impact fossil plants differently but production cost savings is similar**
- **As with any analysis, conclusions specific to only to grid footprint studied**

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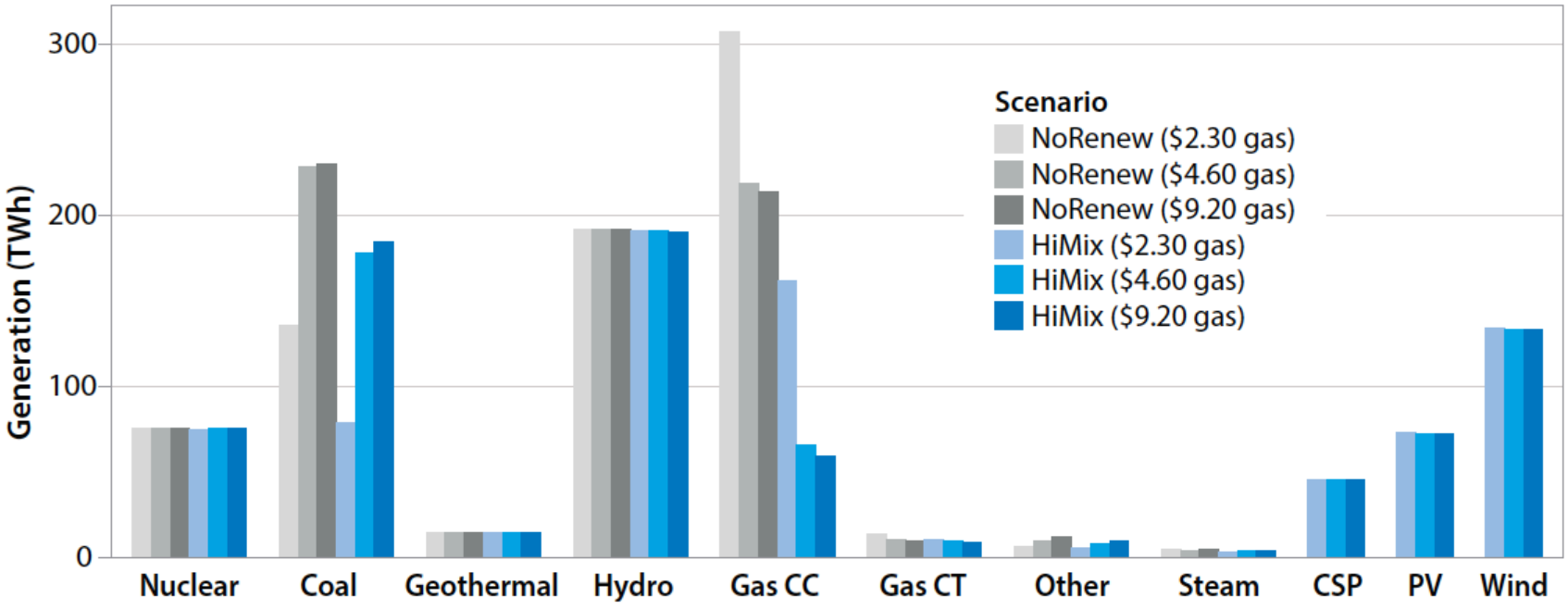
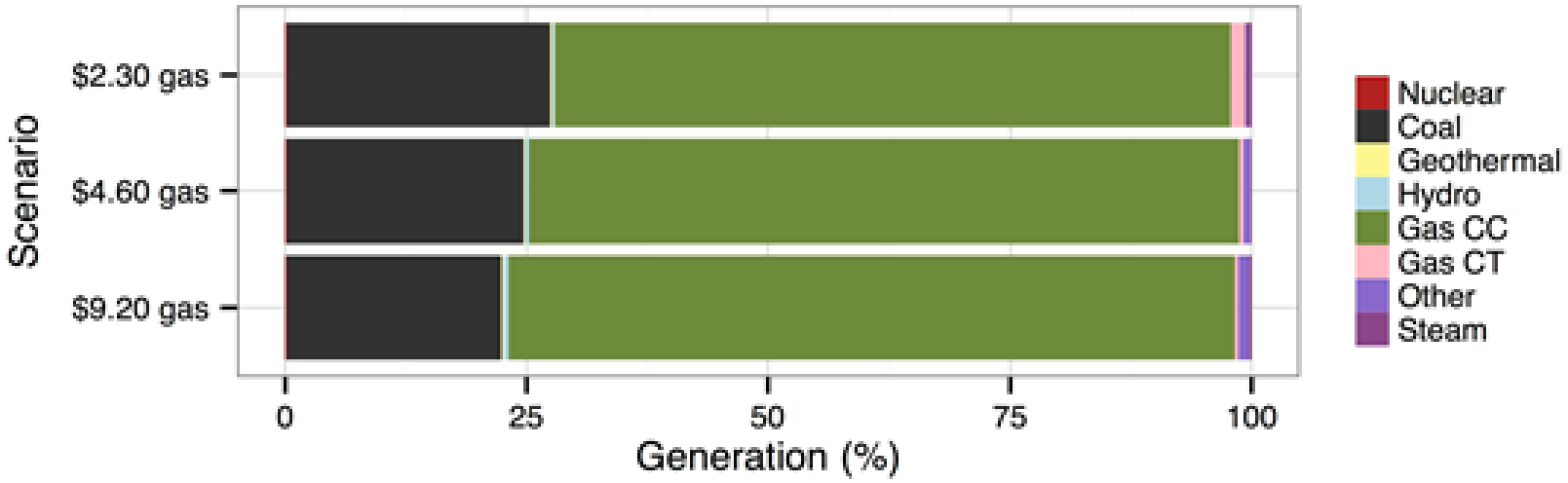
Extra Slides

What if gas prices change?

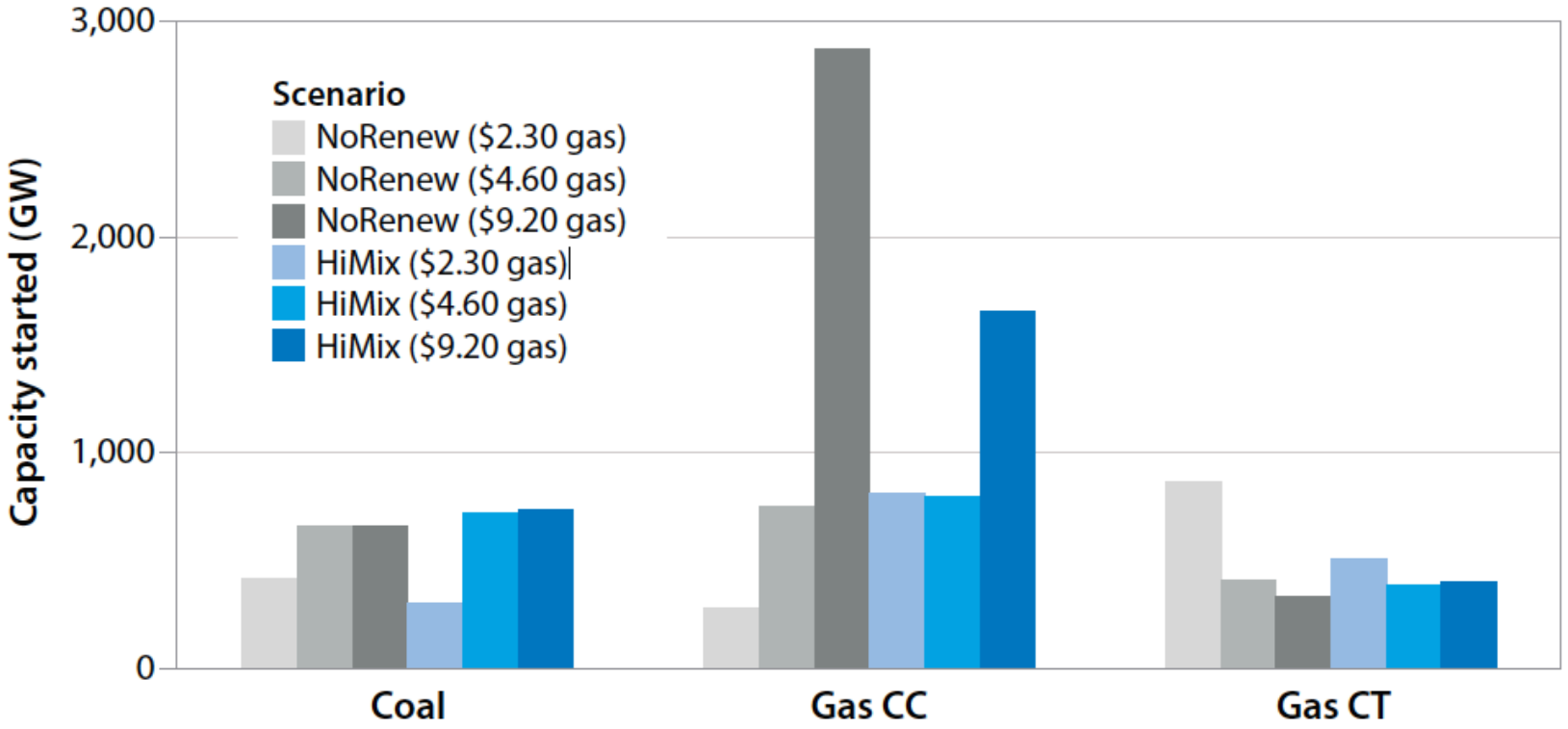
Gas Price Has Greater Impact on Cycling Costs Than Wind and Solar Do



With Low Gas Prices, Wind/Solar Still Displace Mostly Gas



Adding Wind/Soar to $2.30 and $9.60 Gas Scenarios Results in Less Systemwide Cycling



Adding Wind/Solar to $2.30 and $9.60 Gas Scenarios Results in Less Systemwide Cycling