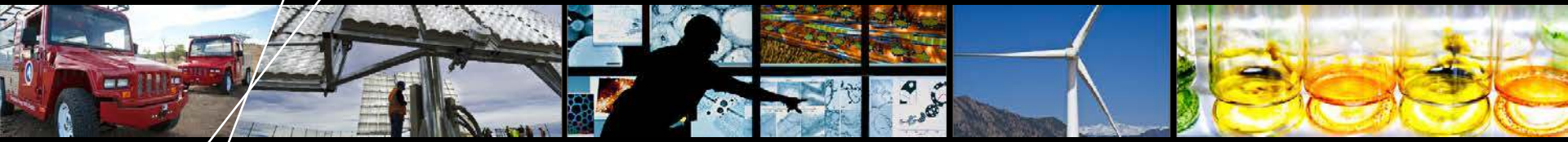
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The Western Wind and Solar Integration Study Phase 2



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The Impacts of Wind- and Solar-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

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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.

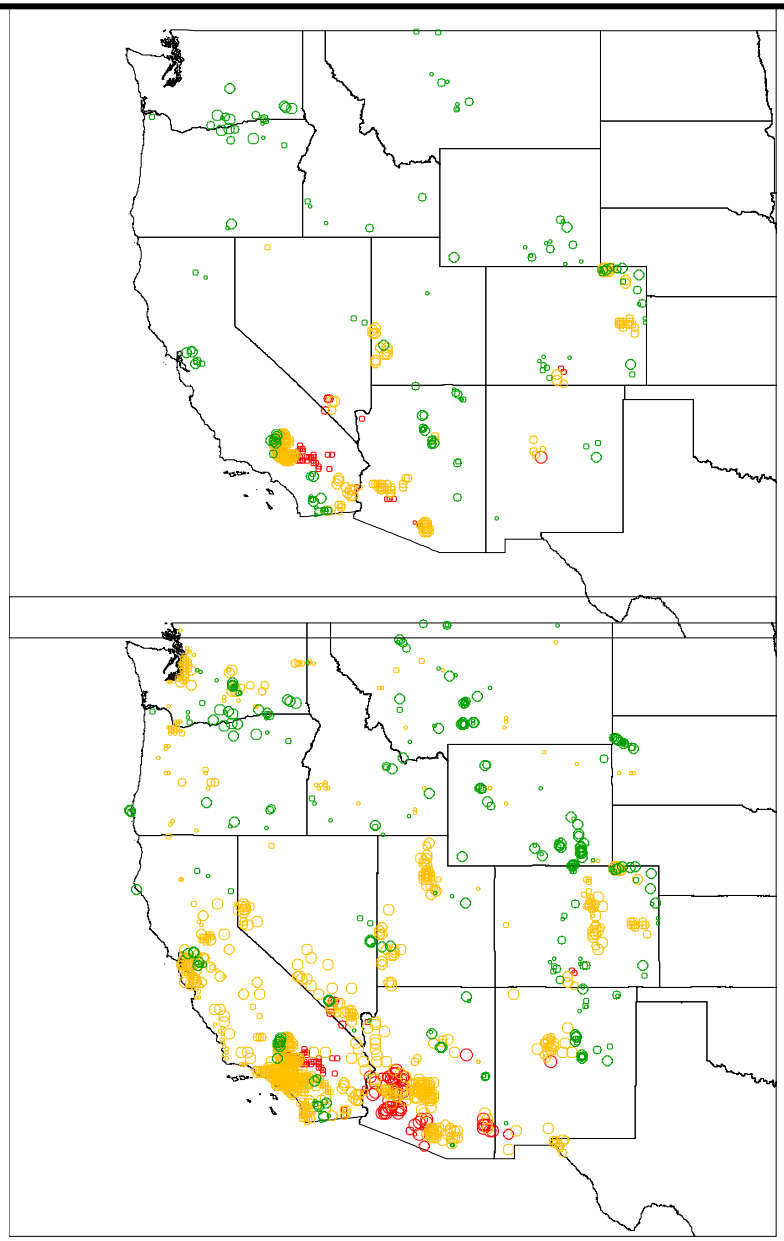
Subhourly Modeling of Grid Operations

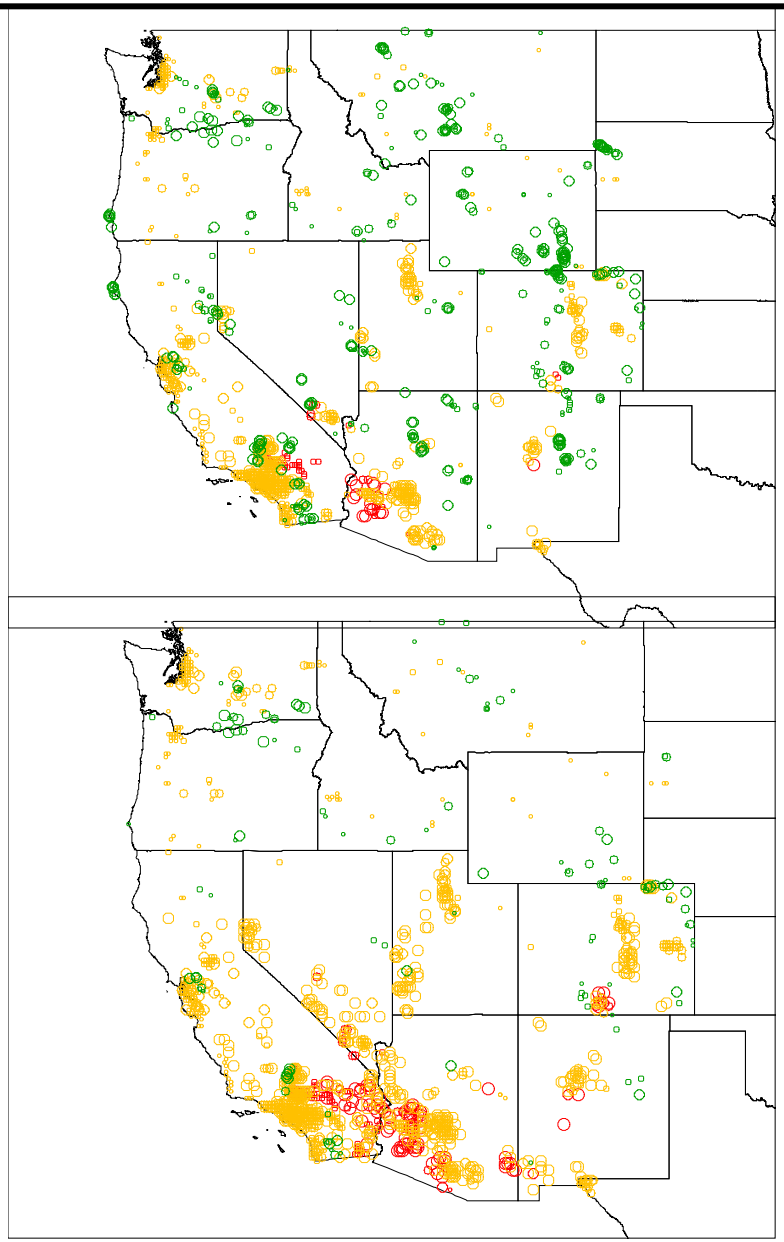
- **Needed wear-and-tear costs and emissions for start-ups and ramps for fossil-fueled plants**
  - APTECH developed a wear-and-tear cost and impact data set based on studies of 170 plants
  - NREL developed an emissions database based on measured emissions from every power plant
- **Used commercial software PLEXOS to model grid operations on a 5-minute basis for the year 2020**
- **50 utility and power plant experts on the technical review committee reviewed the data, methodology, and results**

Scope of WWSIS-2

- **We modeled 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 examined grid *operations***
  - This was not a transmission planning study
  - Reliability and stability are being examined in WWSIS-3
- **Wind and solar was sited in the United States**

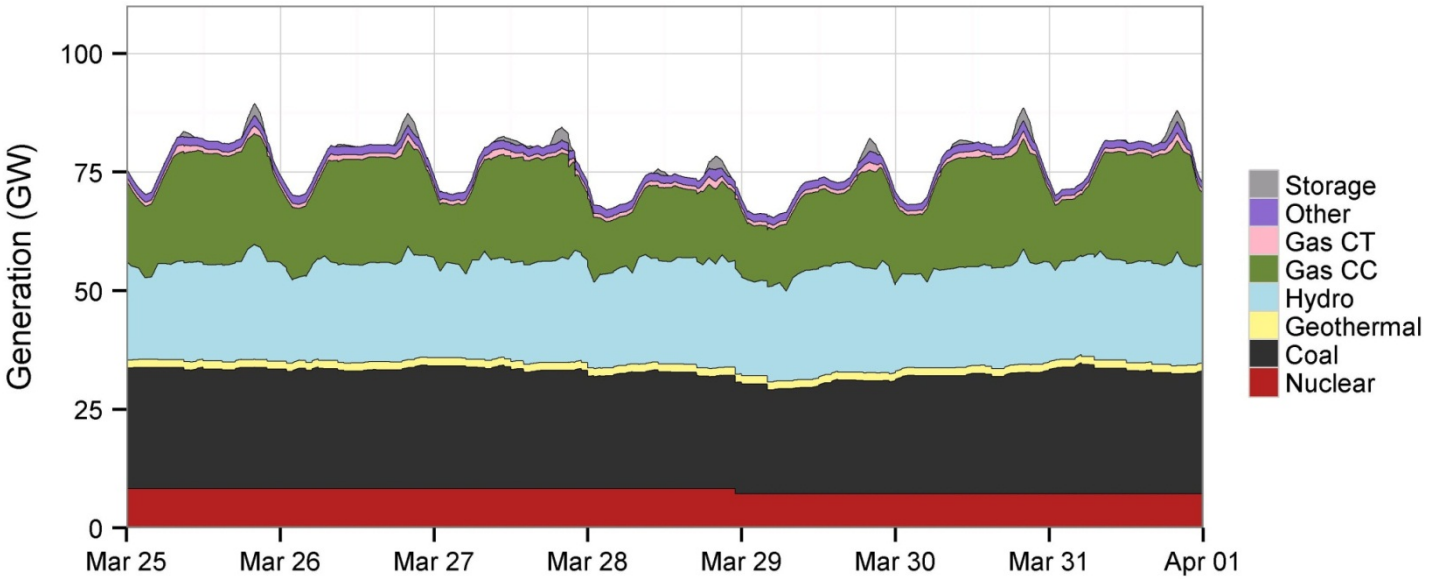
Scenarios Compared Wind and Solar



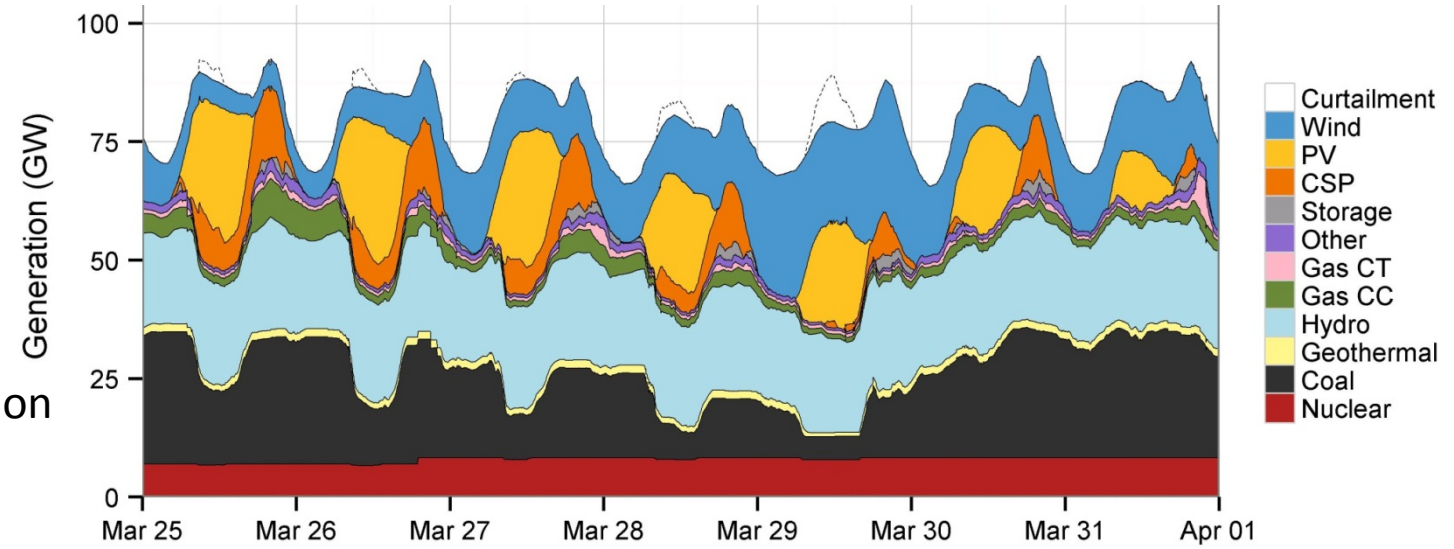


Spring Is Most Challenging for Operations

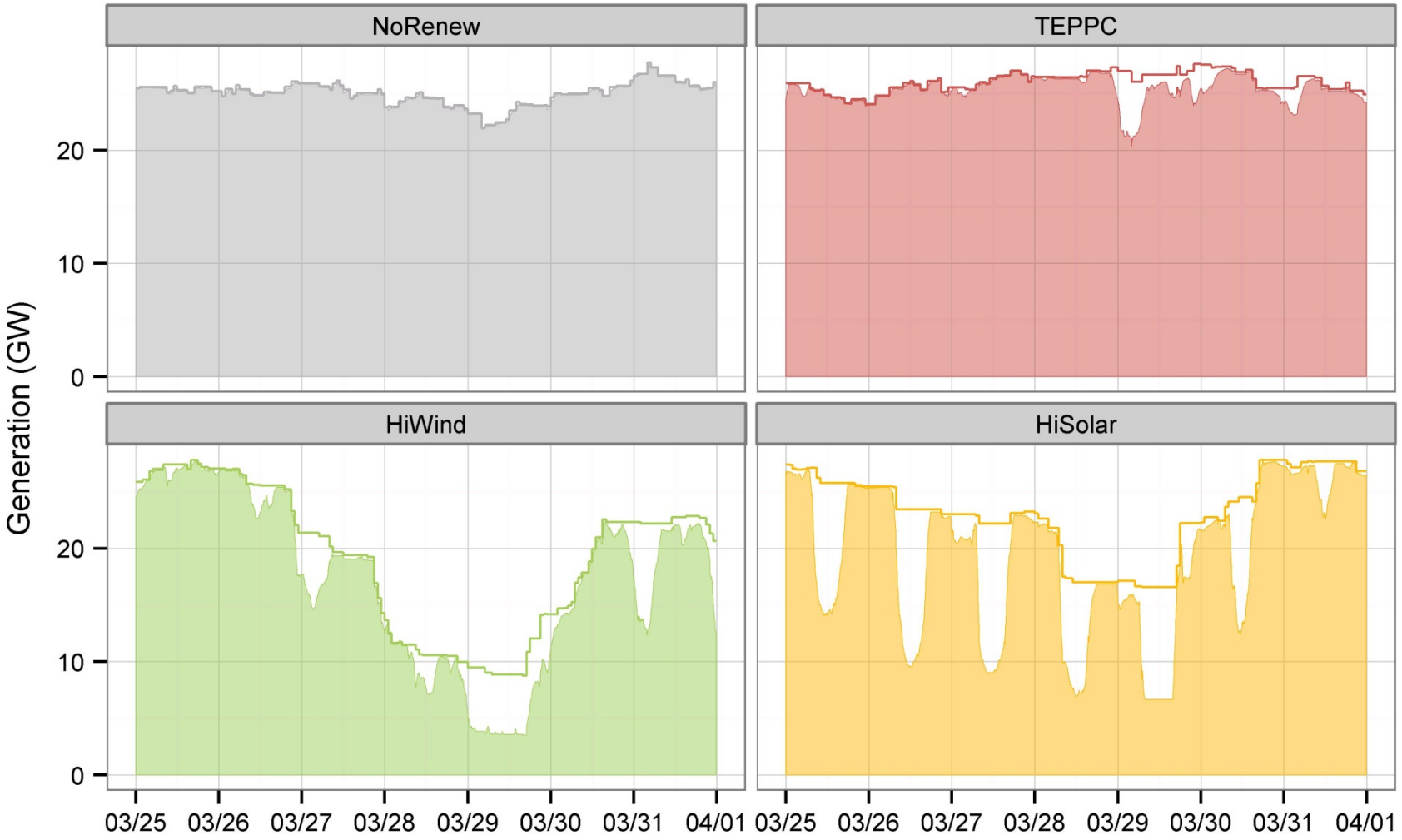
No Renewables



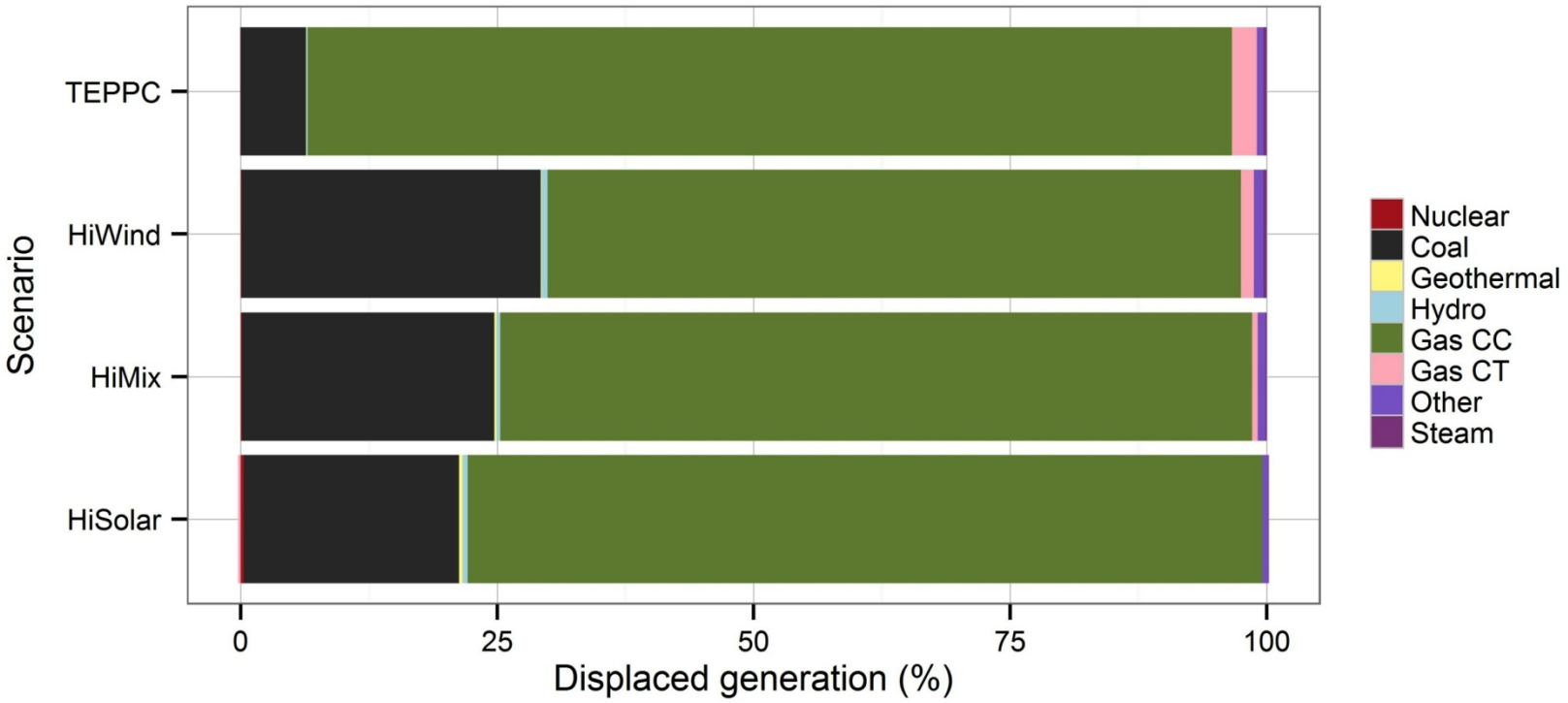
16.5% wind and
16.5% solar
energy penetration



Spring: Wind Leads to Coal Shutdowns; Solar Leads to Coal Ramp-downs



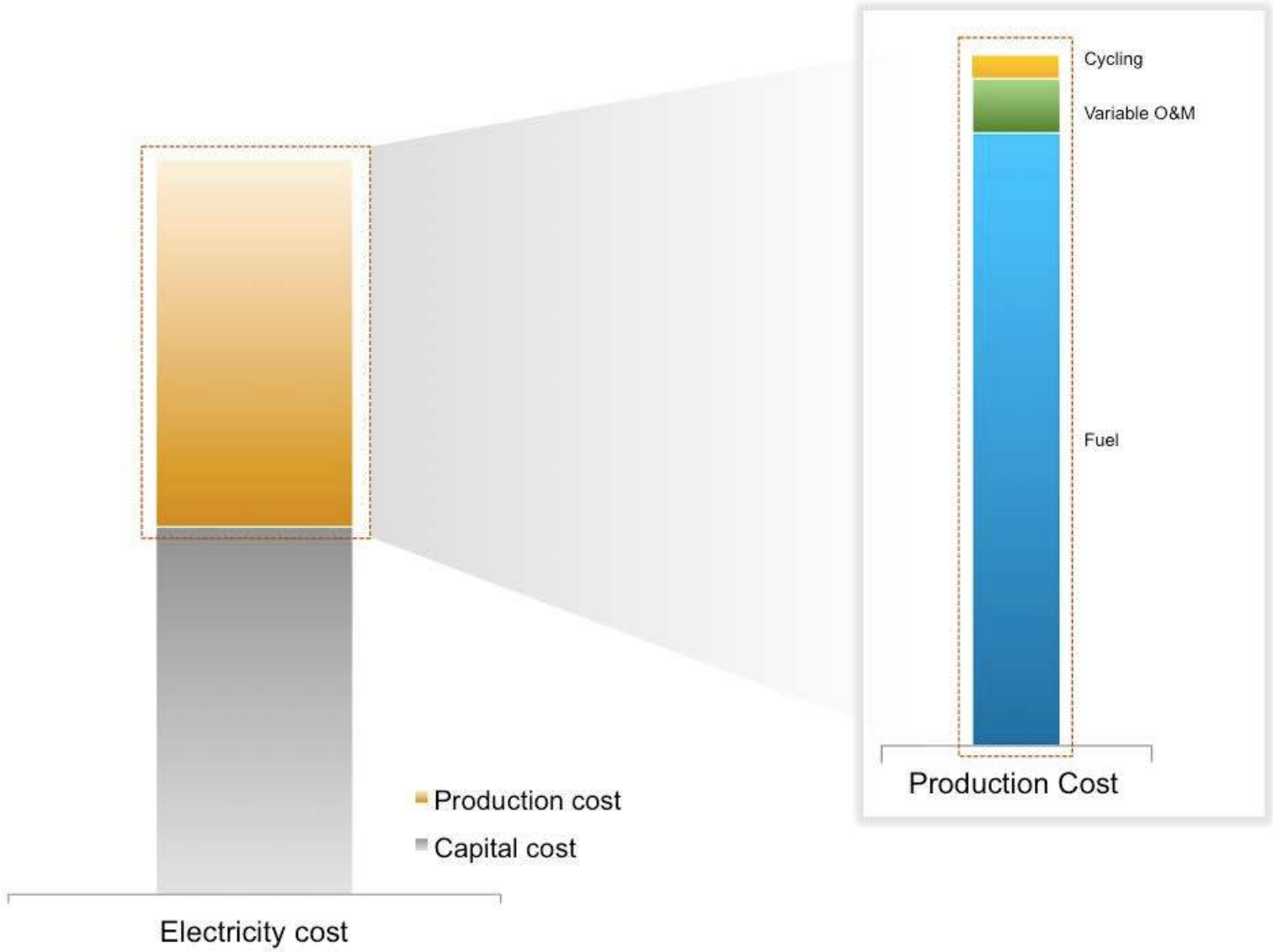
Renewables Displace Gas and Some Coal



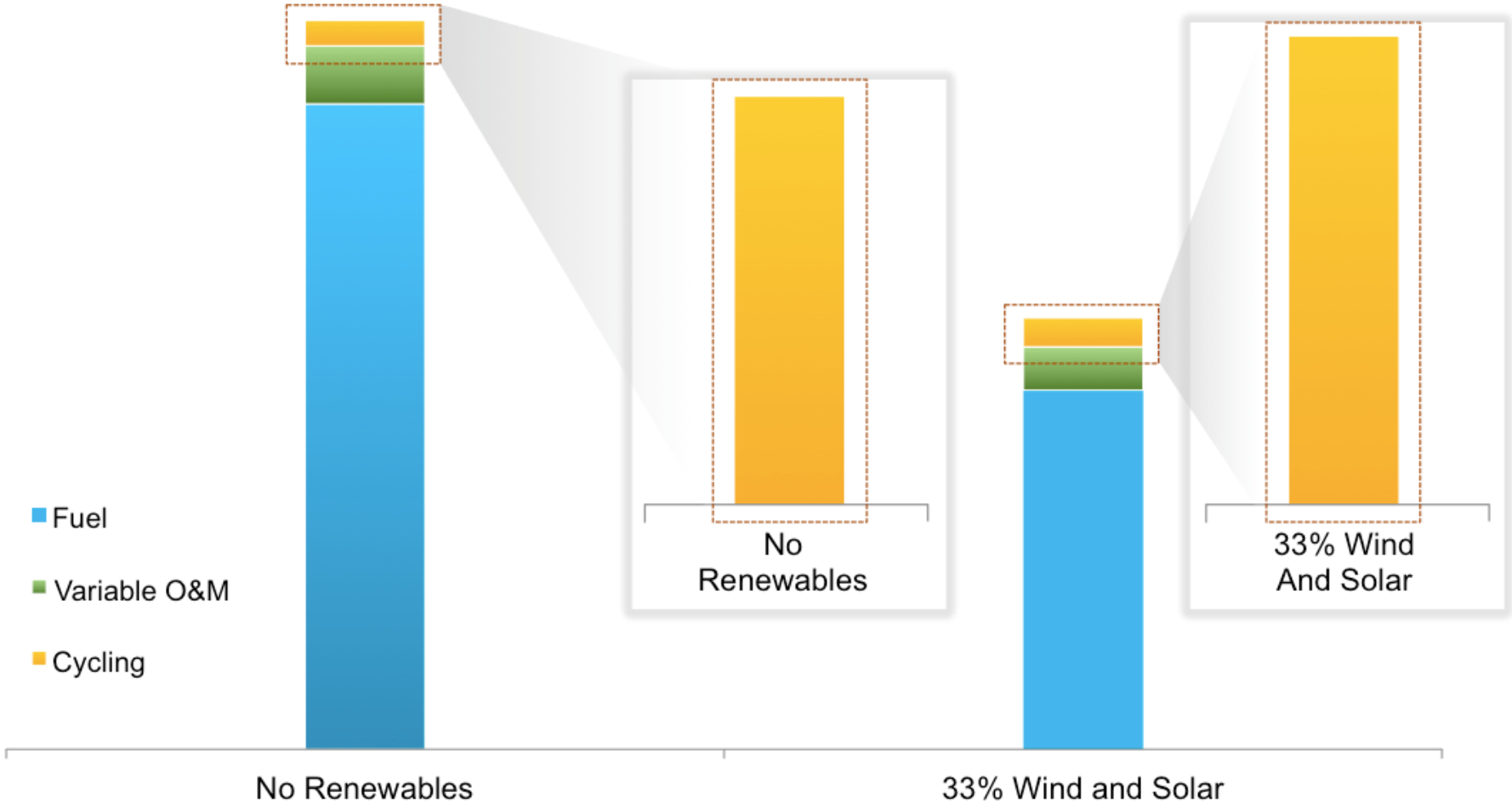
Gas prices average $4.60/mmbtu

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

Electricity Costs Include Capital and Production Costs



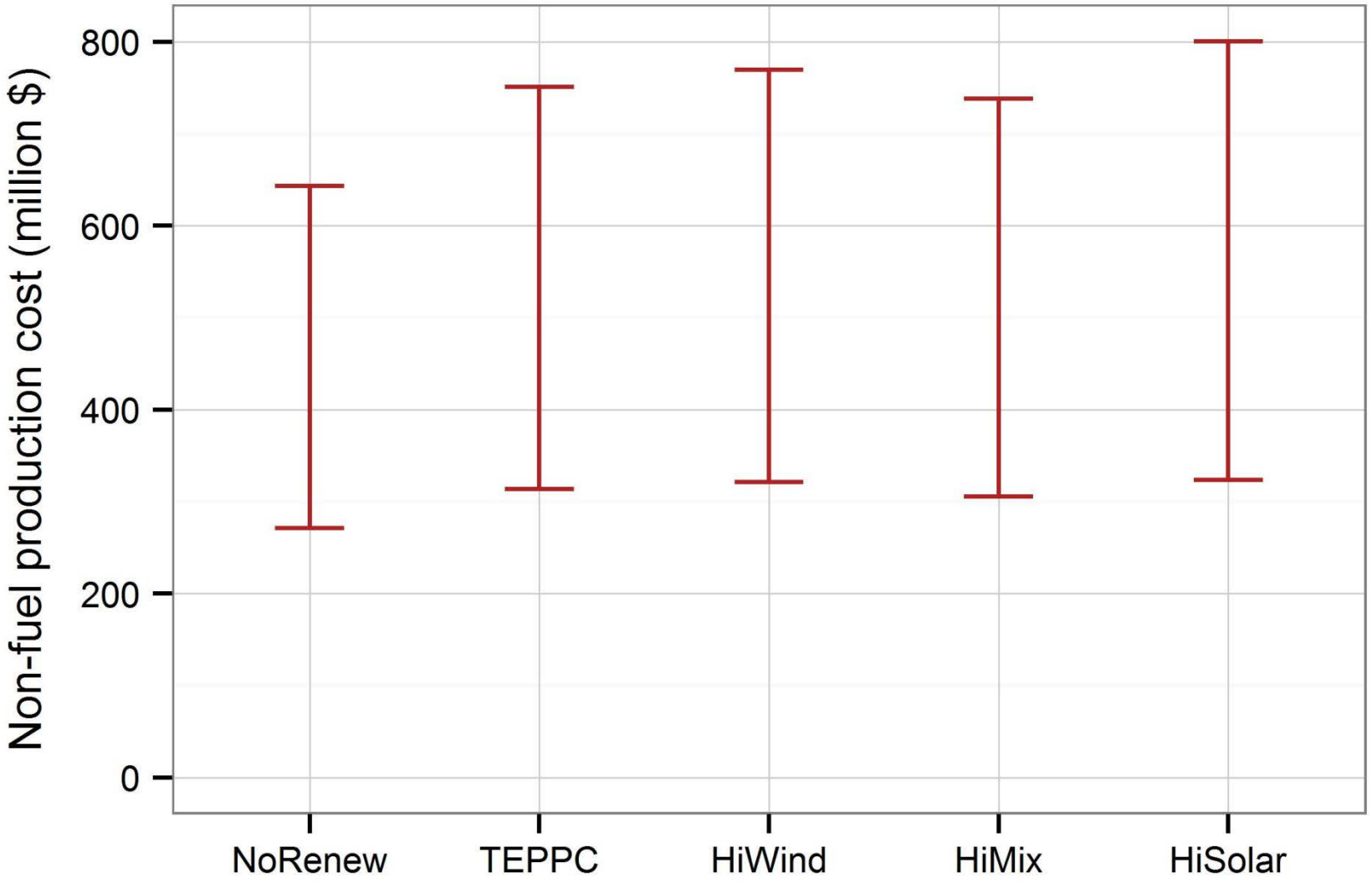
Production Costs Include Cycling Costs



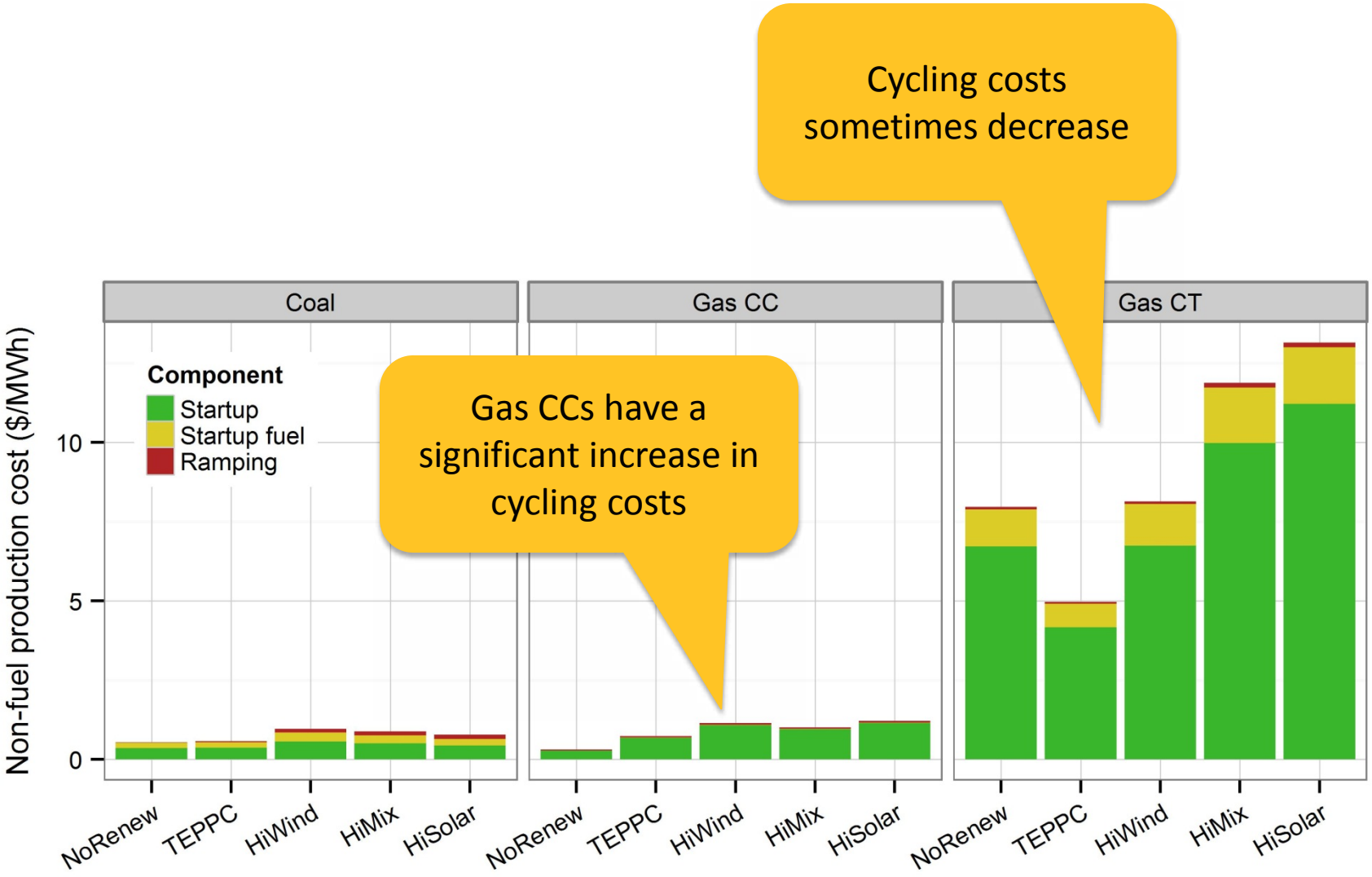
33% Wind and Solar Induce $35–157 M of Cycling Costs

- **Fossil-fueled plant perspective**
  - No Renewables had $300–650M of cycling costs
  - Cycling costs increased by 13%–24%
  - This represents an increase of $0.5–1.3/MWh of O&M
- **System perspective**
  - Wind/solar avoided $7–8B in production costs
  - Cycling costs reduced that production cost savings by 0.5%–2.2%
  - This represents a reduction in production cost savings of $0.14–0.67/MWh

33% High Mix Had Lower Cycling Costs Than 13% TEPCC Scenario



Gas Combustion Turbines Bear Brunt of Cycling Costs



Note: These are the lower bound cycling costs

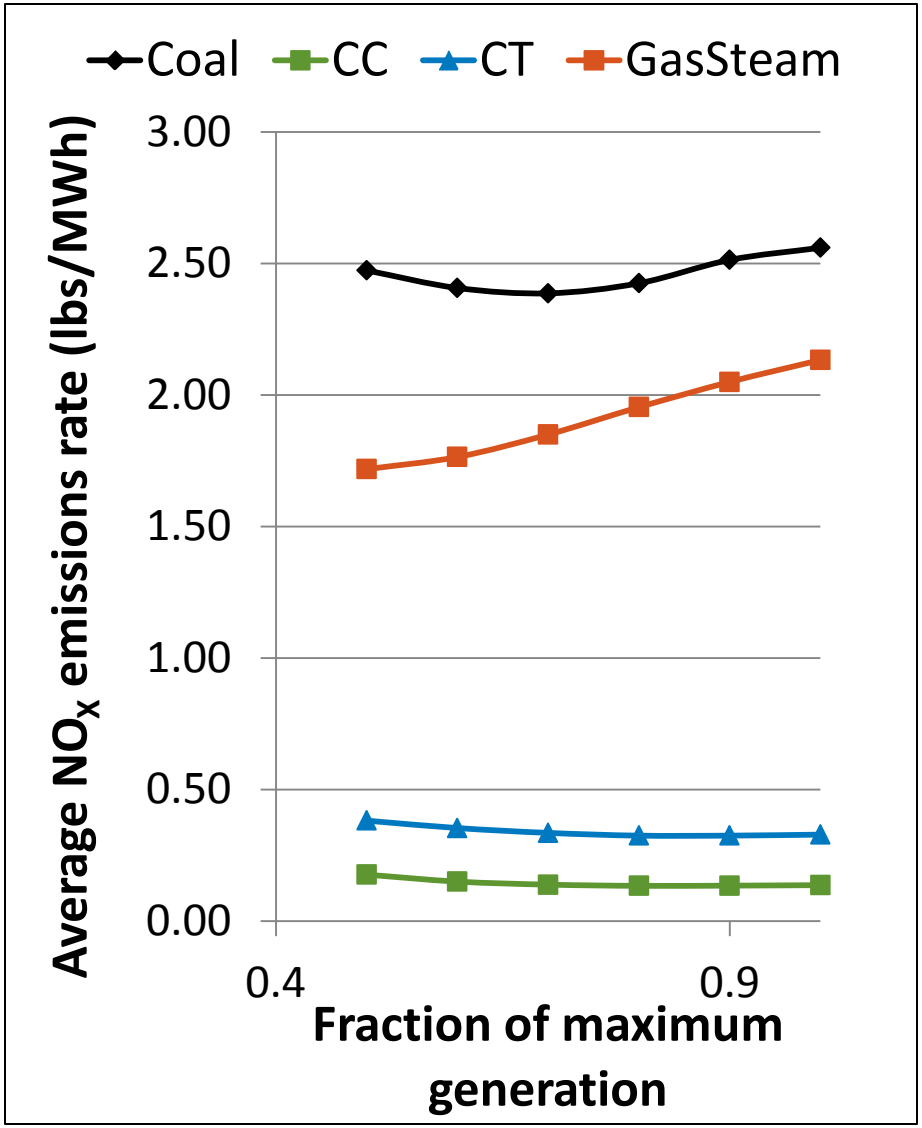
Increase in Cycling and Ramping Costs

	Increase in Cycling and Ramping Costs:		
Scenario	As a fraction of production cost savings from renewable generation	Per MWh renewable generation	Per MWh of fossil-fueled generation
TEPPC	1.2% – 3.2%	$0.41 – 1.05 / MWh	$0.18 – 0.44 / MWh
High Wind	0.7% – 1.7%	$0.20 – 0.50 / MWh	$0.52 – 1.24 / MWh
High Mix	0.5% – 1.3%	$0.14 – 0.38 / MWh	$0.47 – 1.14 / MWh
High Solar	0.7% – 2.2%	$0.22 – 0.67 / MWh	$0.50 – 1.28 / MWh

How are emissions impacted by cycling?

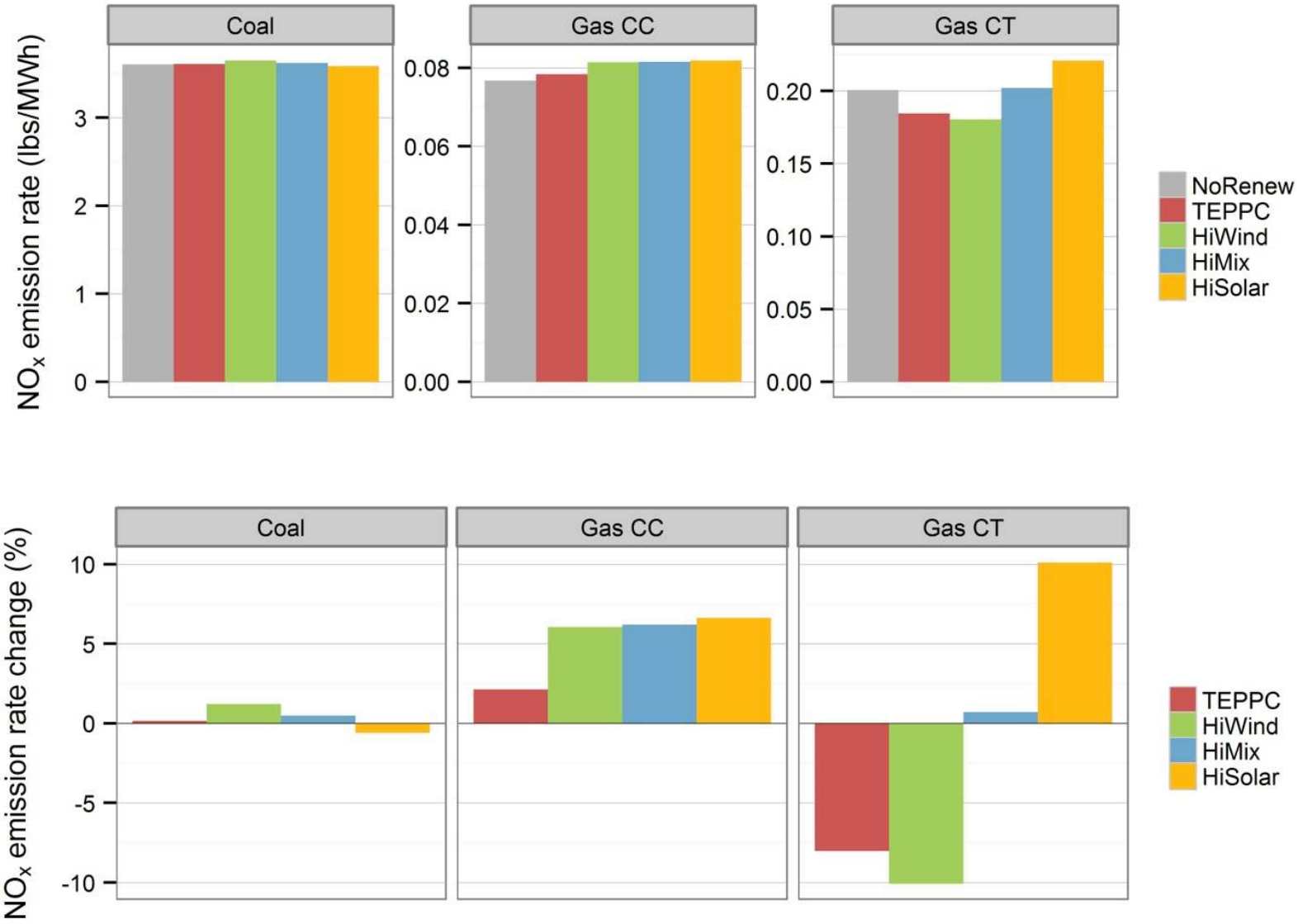
Wind- and Solar-Induced Cycling Can Have a Positive or Negative Impact on Emissions

- **24%–26% wind and solar energy across the western grid reduces:**
  - CO_2 by 29%–34%
  - NO_X by 16%–22%
  - SO_2 by 14%–24%
- **System-wide impacts of cycling:**
  - Negligible impact (<0.2%) on CO_2 benefit
  - Improves NO_X benefit by 1%–2%
  - Lessens SO_2 benefit by 2%–5%

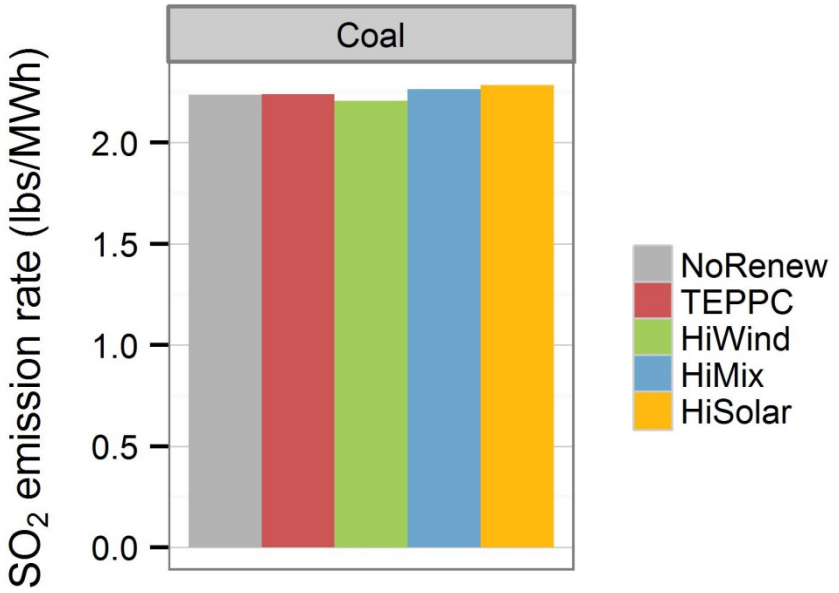


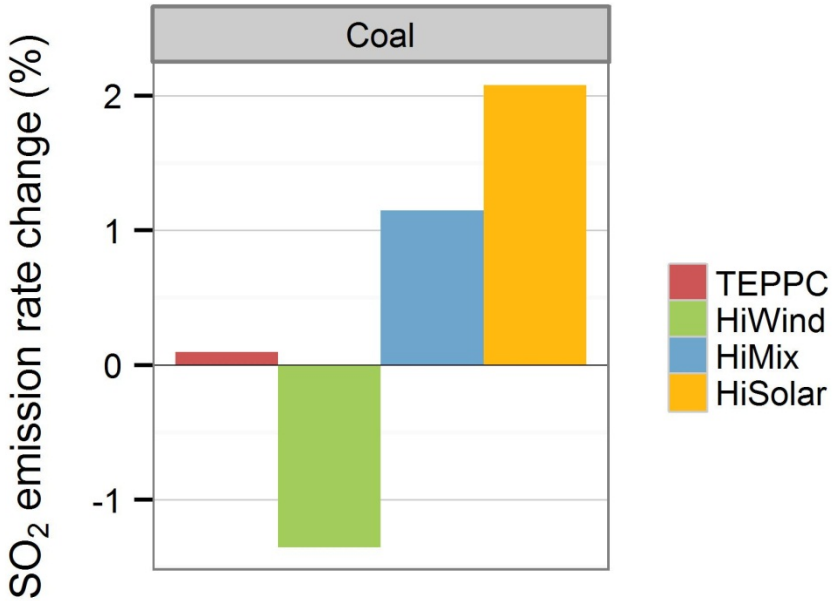
Average CO_2 Emissions Rates From Coal Do Not Change

Changes in NO_X Emissions Rates Depend on Wind/Solar Mix

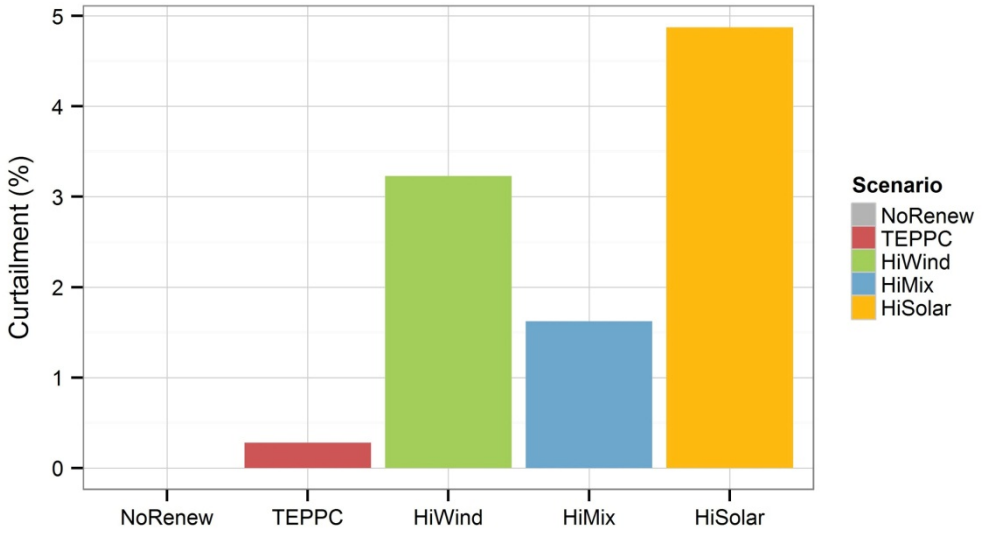


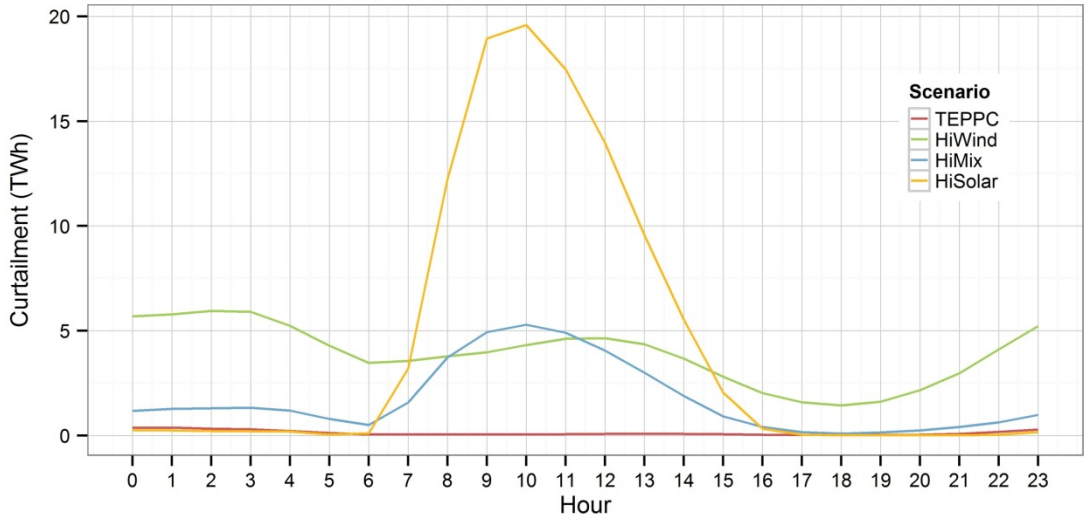
Changes in SO_2 Rates Depend on Wind/Solar Mix



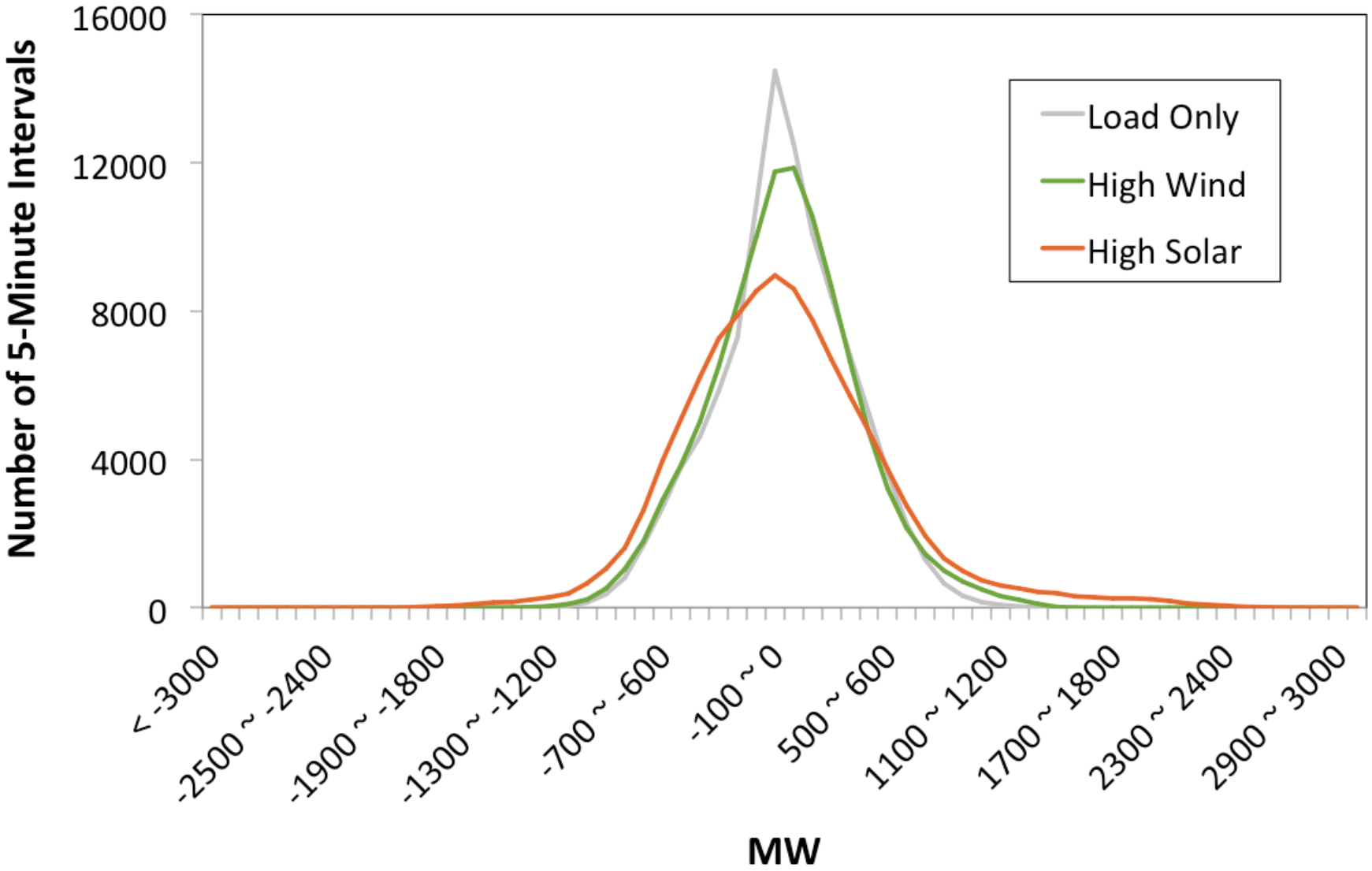


Balanced Mix of Wind and Solar Reduces Curtailment

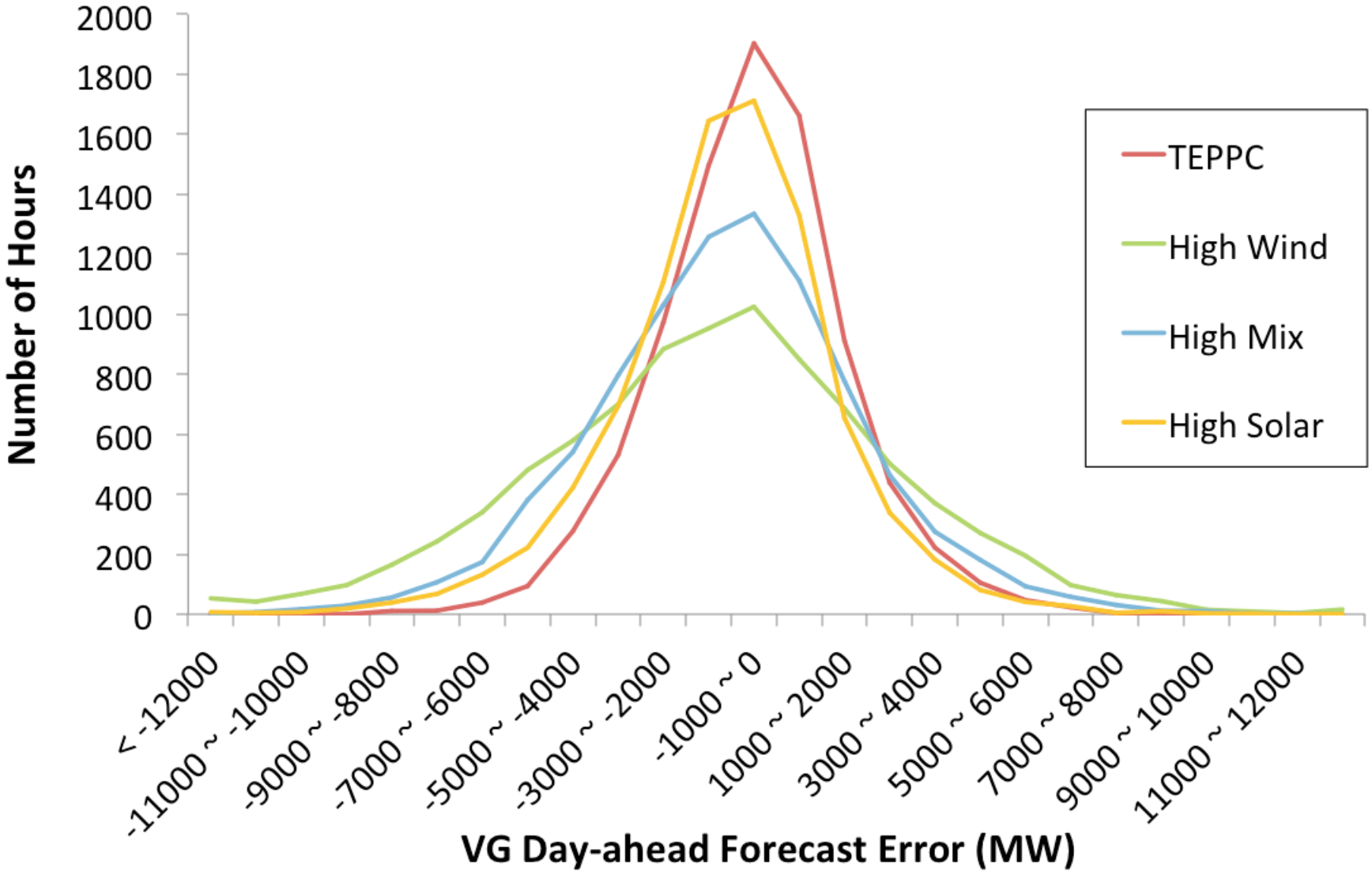




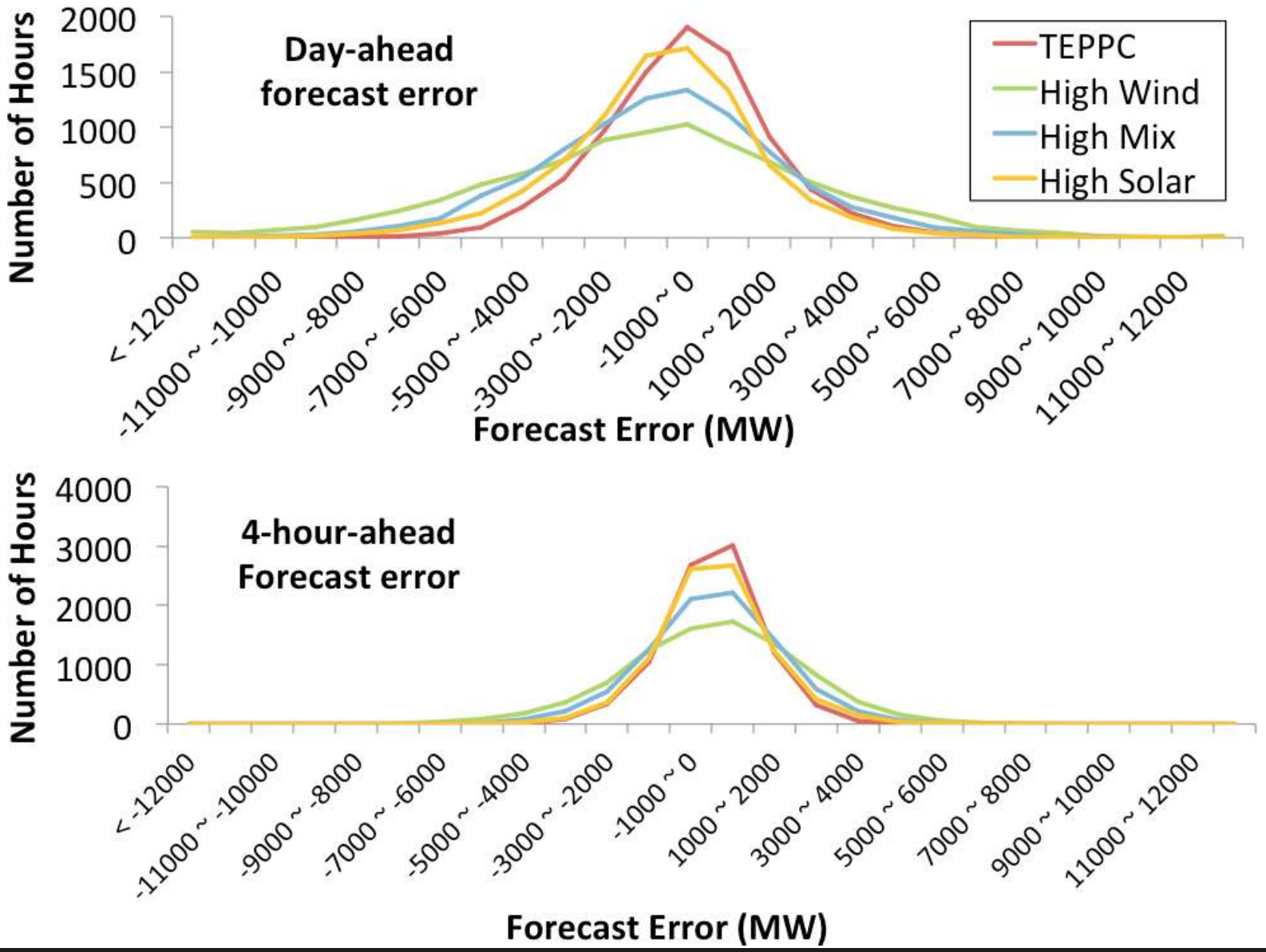
Solar Dominates Variability Extremes



Wind Dominates Uncertainty Extremes



4-Hour-Ahead Unit Commitment Can Mitigate Wind Forecast Error



Conclusions

- **Wind and solar increase cycling costs**
  - From the fossil-fueled perspective, cycling O&M increases by $0.5–1.3/MWh
  - From the system perspective, cycling reduces production cost savings by $0.14–0.67/MWh
- **Emissions induced by cycling are much smaller than benefits**
  - Wind- and solar-induced cycling can help or hurt emissions from a fossil-fueled plant, depending on plant type, wind/solar mix, and penetration
- **Wind and solar impact fossil-fueled plants differently, but production cost savings are similar**
- **As with any analysis, conclusions are specific to only grid footprint studied**

Next Steps

- **U.S. DOE is reviewing final report with anticipated publication in February**
- **Examining cost-benefit analysis of retrofitting coal/gas plants for increased flexibility**
- **Starting reliability and stability study in Western Interconnection**
  - How do wind and solar provide grid-friendly support for frequency response and transient stability?

For More Details

- Preliminary results:
  www.nrel.gov/docs/fy12osti/56171.pdf
  www.nrel.gov/docs/fy12osti/56217.pdf
- Emissions and wear-and-tear summary:
  www.nrel.gov/docs/fy12osti/53504.pdf
- Wear-and-tear costs and impacts:
  www.nrel.gov/docs/fy12osti/55433.pdf
- Cycling cost analysis:
  www.nrel.gov/docs/fy12osti/54864.pdf
- Forecasts: www.nrel.gov/docs/fy12osti/54384.pdf
- Reserves: www.nrel.gov/docs/fy12osti/56169.pdf
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