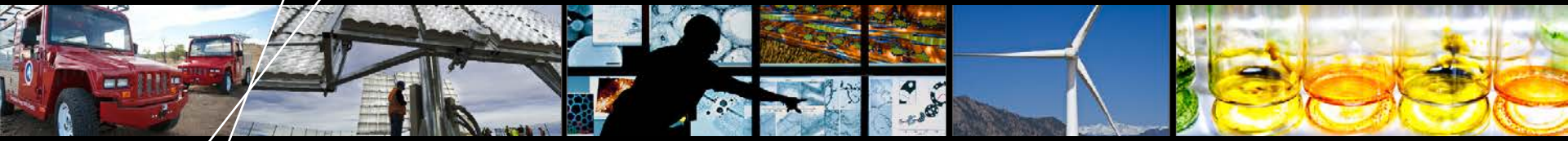
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The Impact of Distributed Wind on Bulk Power System Operations in ISO-NE



13th Wind Integration Workshop

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(NREL); and Jari Miettinen (VTT)

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Motivation and Scope

- **Wind integration is hindered in the U.S. power system**
  - The best wind resources are far from the main load centers
  - There are difficult regulatory and legal hurdles and substantial investments are required to develop new transmission
- **One possibility is to develop utility-scale wind turbines connected to existing distribution networks** (assuming no transmission investment)

- **Scope: To study the impact of a range of distributed wind penetration levels on bulk power system operations**

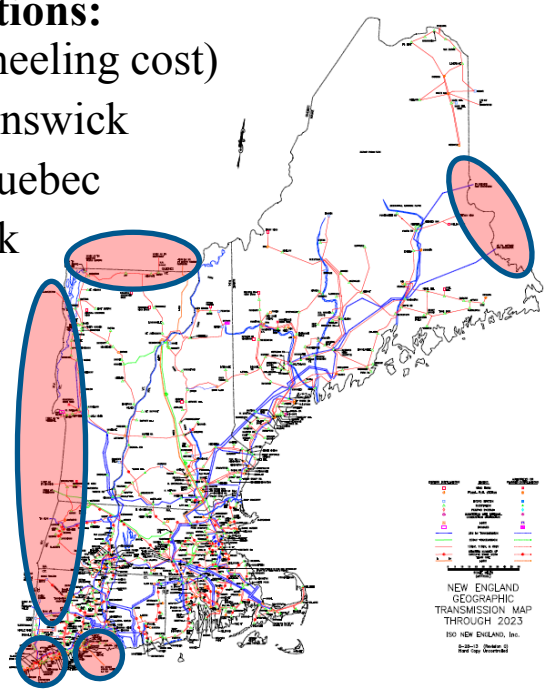
- **Case Study: Independent System Operator New England (ISO-NE)**
  - 1.37% wind penetration in 2013
  - Theoretical potential for 215 GW of onshore and offshore wind generation

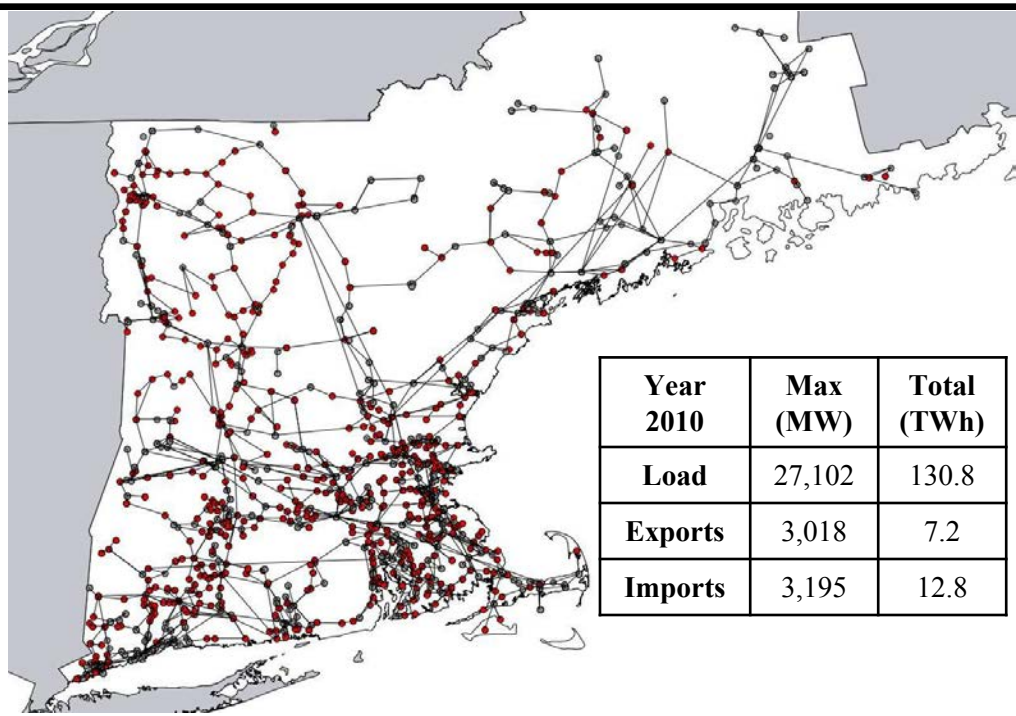
ISO-NE PLEXOS Model

- 3,314 nodes (1,862 above 69 kV)
- 2,485 lines (2,085 above 69 kV)
- 1,830 transformers
- 468 generators (excluding wind)
- DA/4HA/RT (load and wind forecasts)
- Contingency and regulation reserves

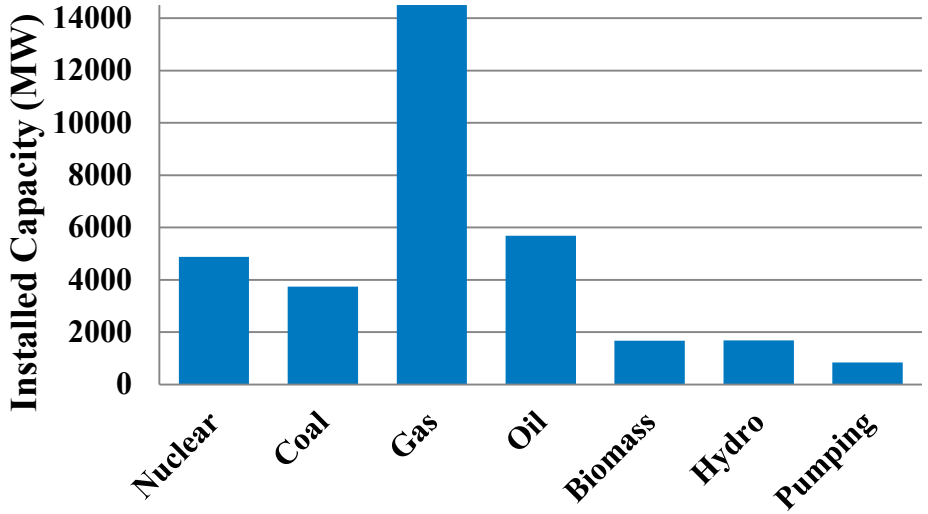
Interconnections:
($3/MWh wheeling cost)

- New Brunswick
- Hydro Quebec
- New York

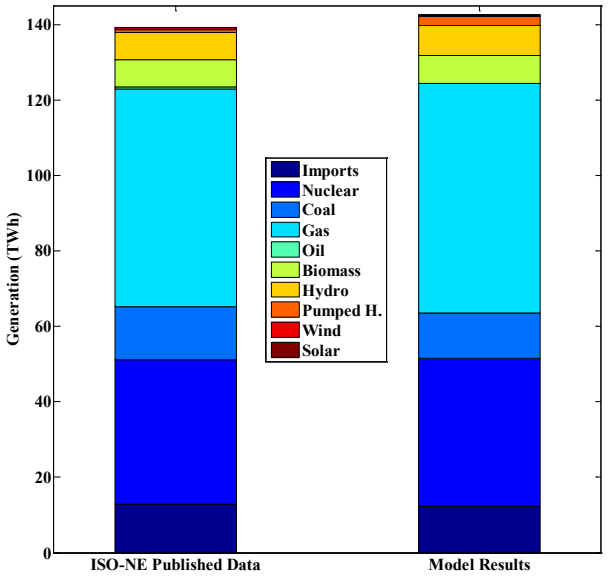


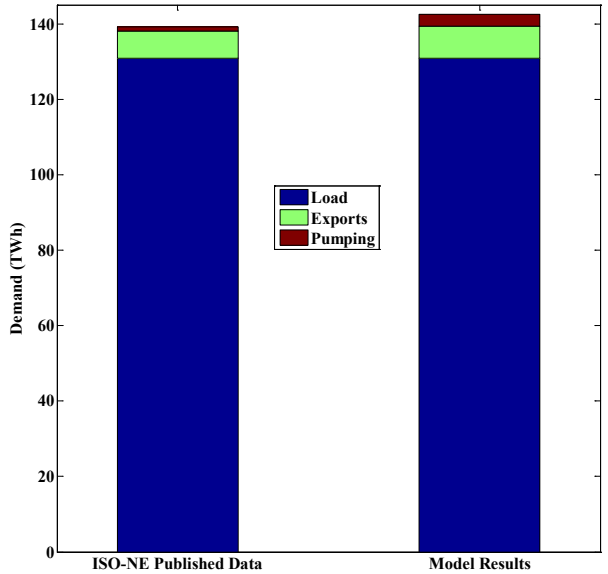


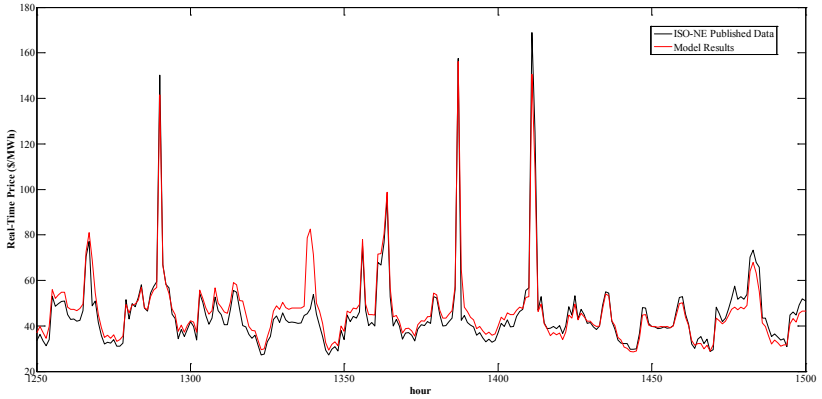
Year 2010	Max (MW)	Total (TWh)
Load	27,102	130.8
Exports	3,018	7.2
Imports	3,195	12.8

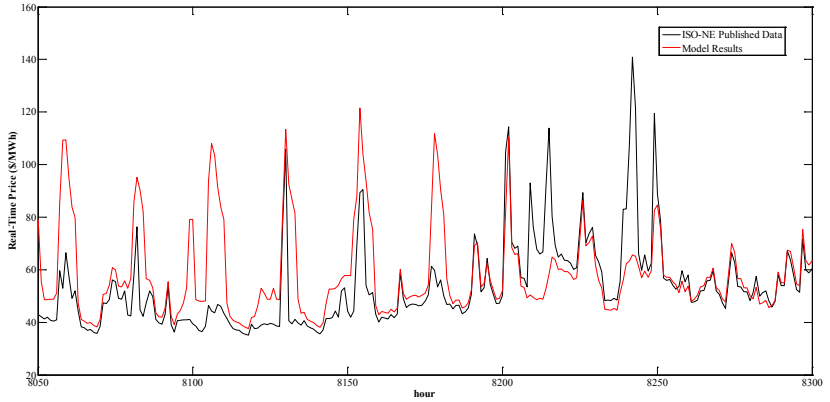


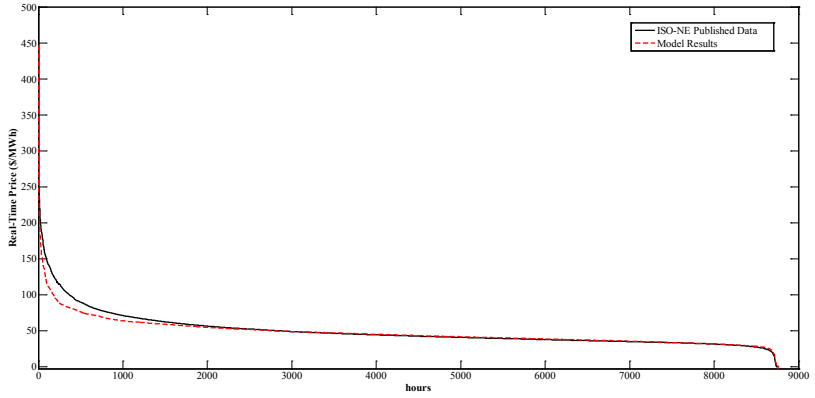
ISO-NE PLEXOS Model—Validation











Distributed Wind Scenarios

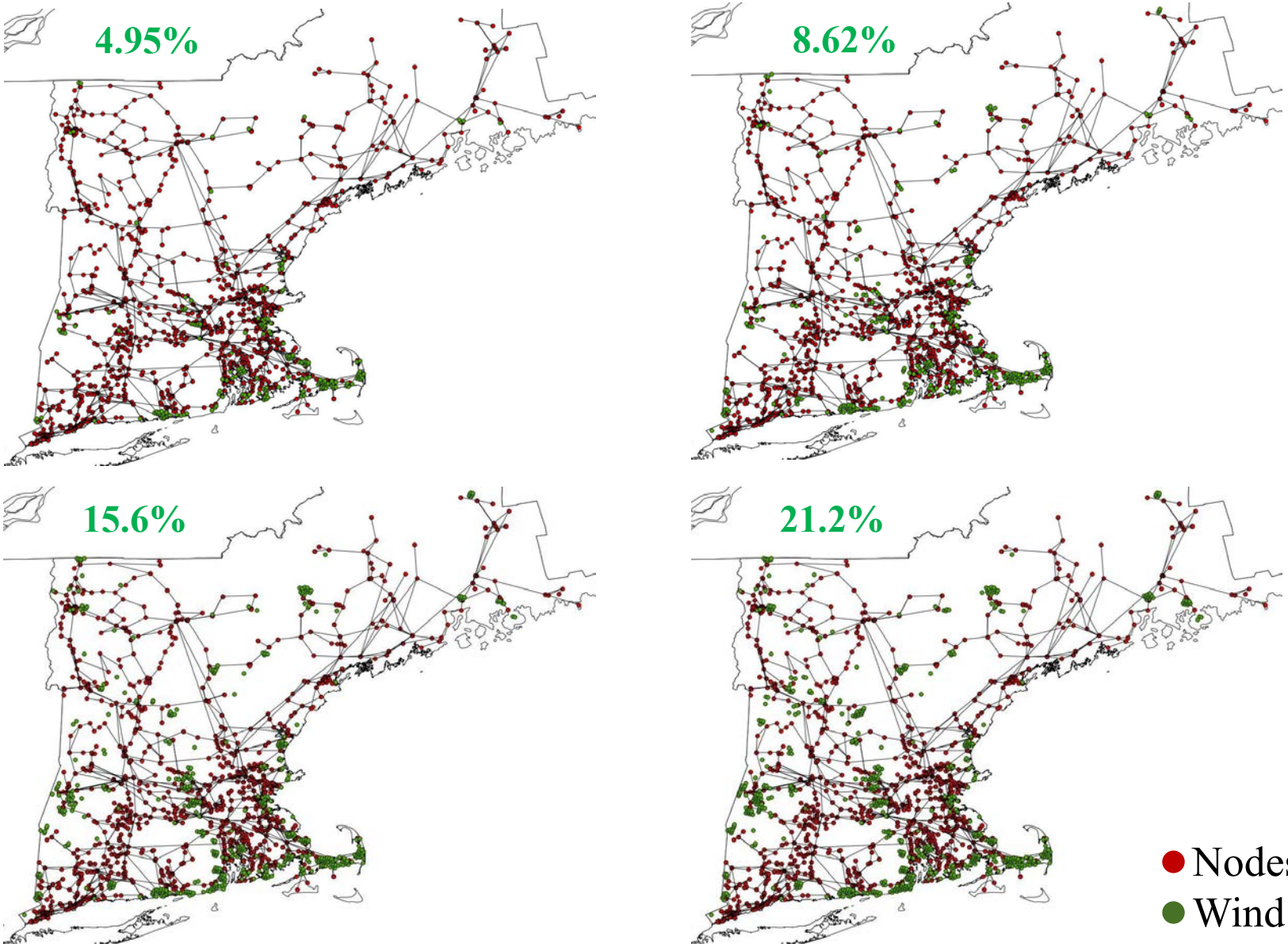
Scenario	Distance (lat-long degrees)	Ratio	Penetration Level (%)	Number of Wind Sites	Installed Wind Capacity (MW)	Mean Wind Capacity Factor
1	0.025 (approx. 2.8 km)	1	**1.95**	87	690	0.432
2	0.050 (approx. 5.6 km)	1	**4.96**	201	1,718	0.439
3	0.075 (approx. 8.3 km)	1	**6.96**	269	2,398	0.441
4	0.100 (approx. 11.1 km)	1	**8.62**	325	2,978	0.441
5	0.125 (approx. 13.9 km)	1	**10.40**	373	3,556	0.444
6	0.125 (approx. 13.9 km)	2	**15.61**	506	5,264	0.448
7	0.125 (approx. 13.9 km)	3	**18.90**	590	6,336	0.450
8	0.125 (approx. 13.9 km)	4	**21.21**	641	7,074	0.451

Distance: Maximum distance between a wind site and the transmission node to which it is connected

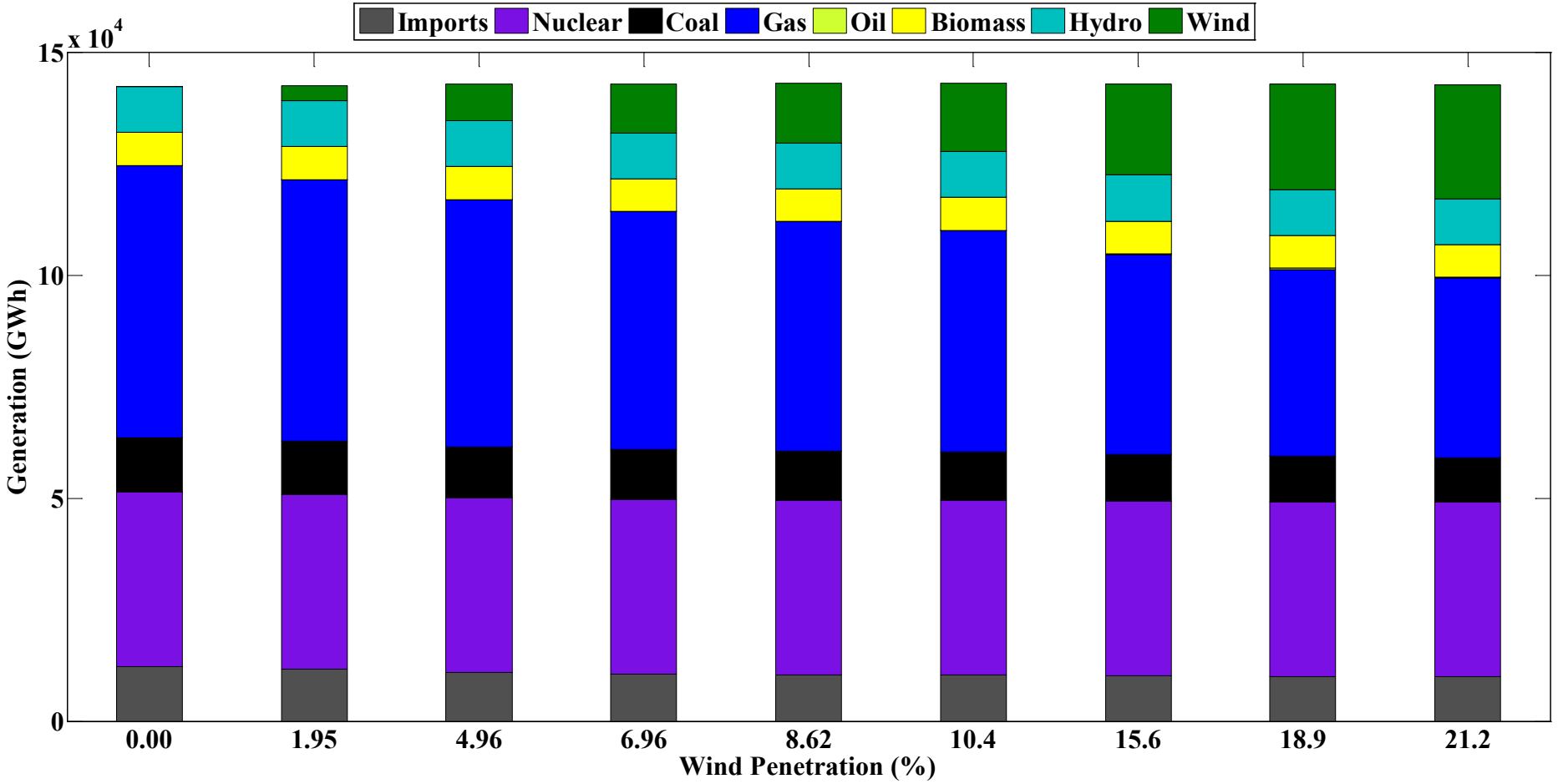
Ratio: Maximum ratio between the sum of the capacities of the wind sites connected to a node and the peak load at the node

Wind Data: WIND Toolkit

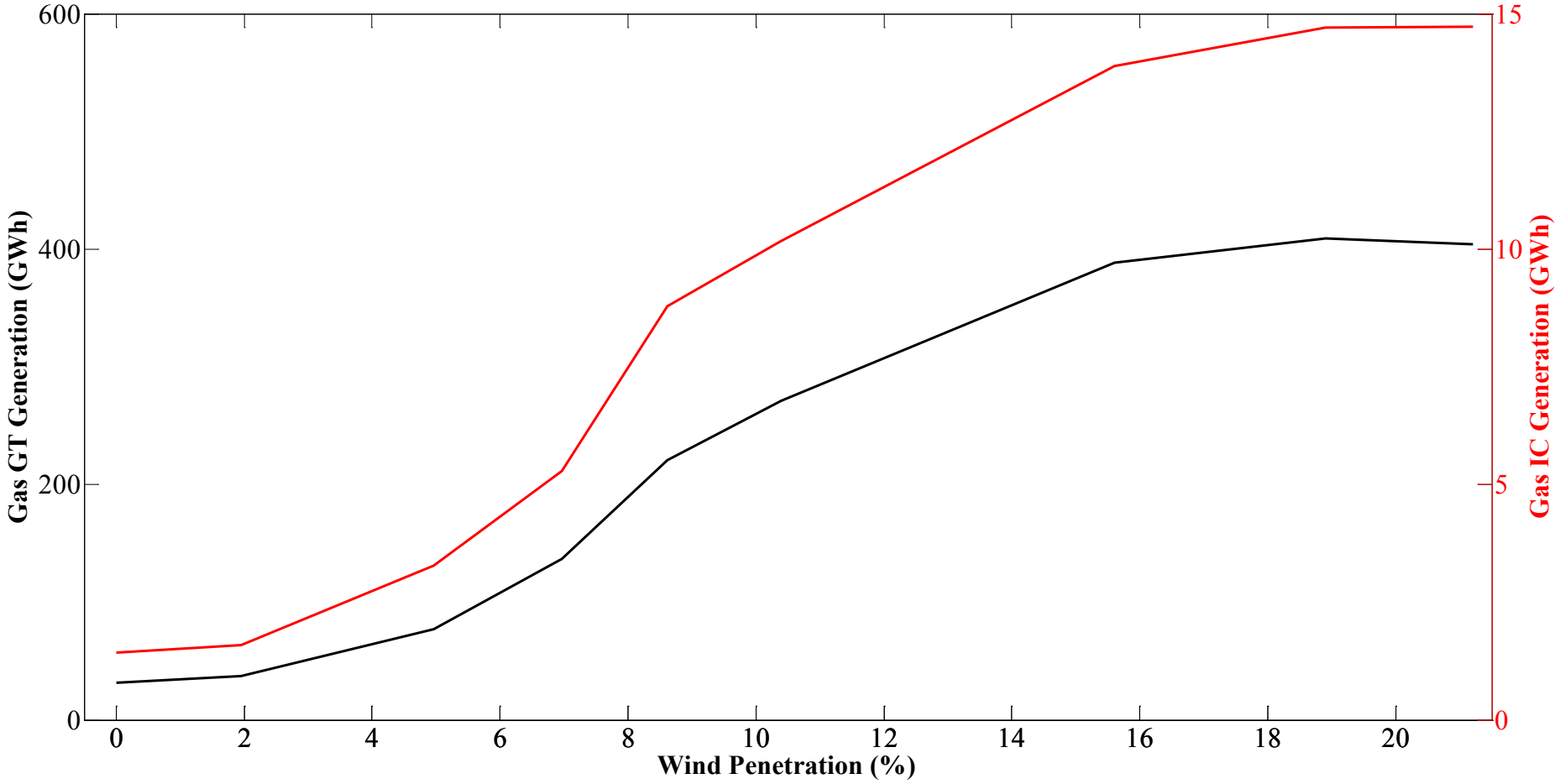
Distributed Wind Scenarios



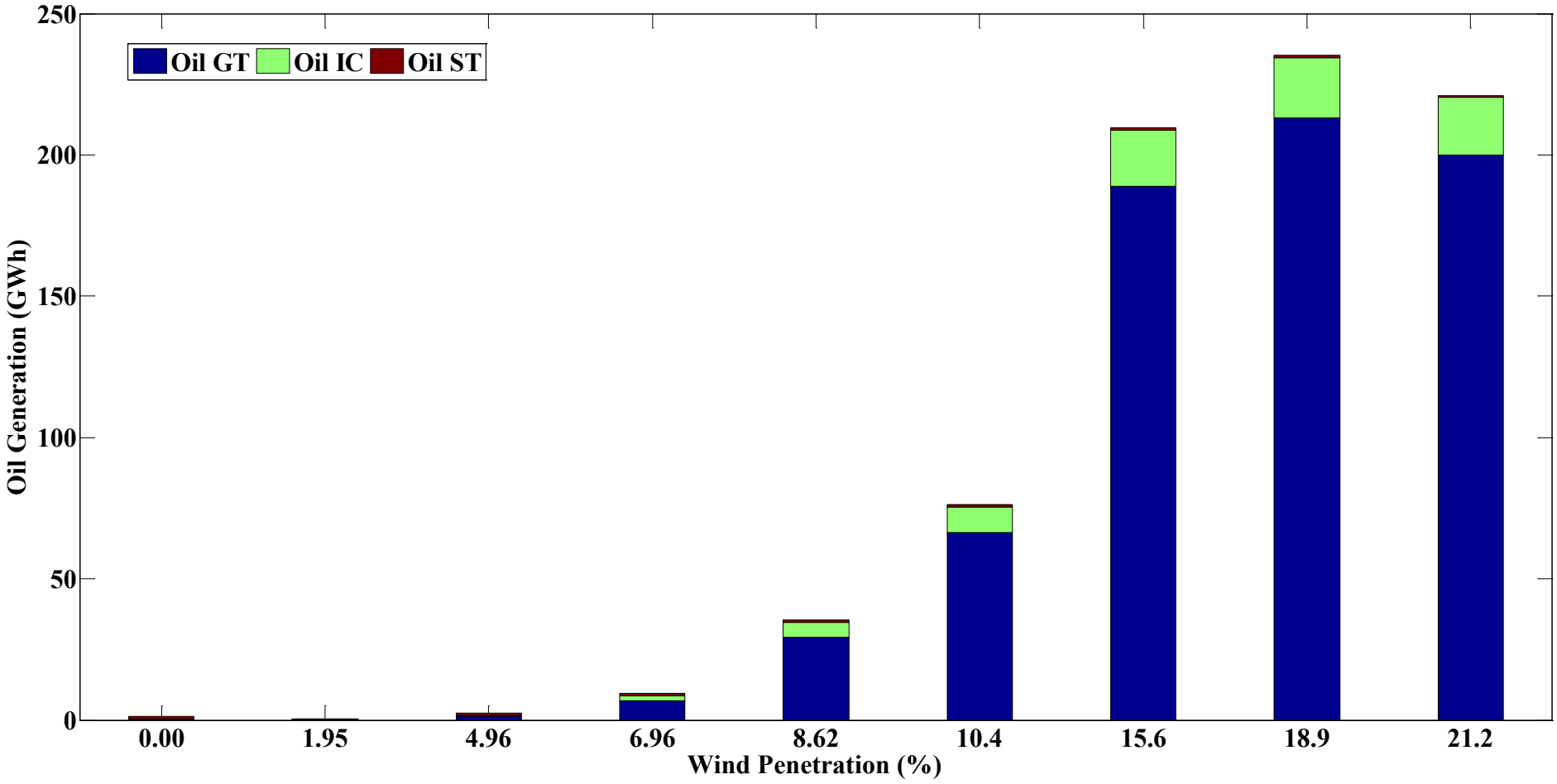
Electricity Generation Mix



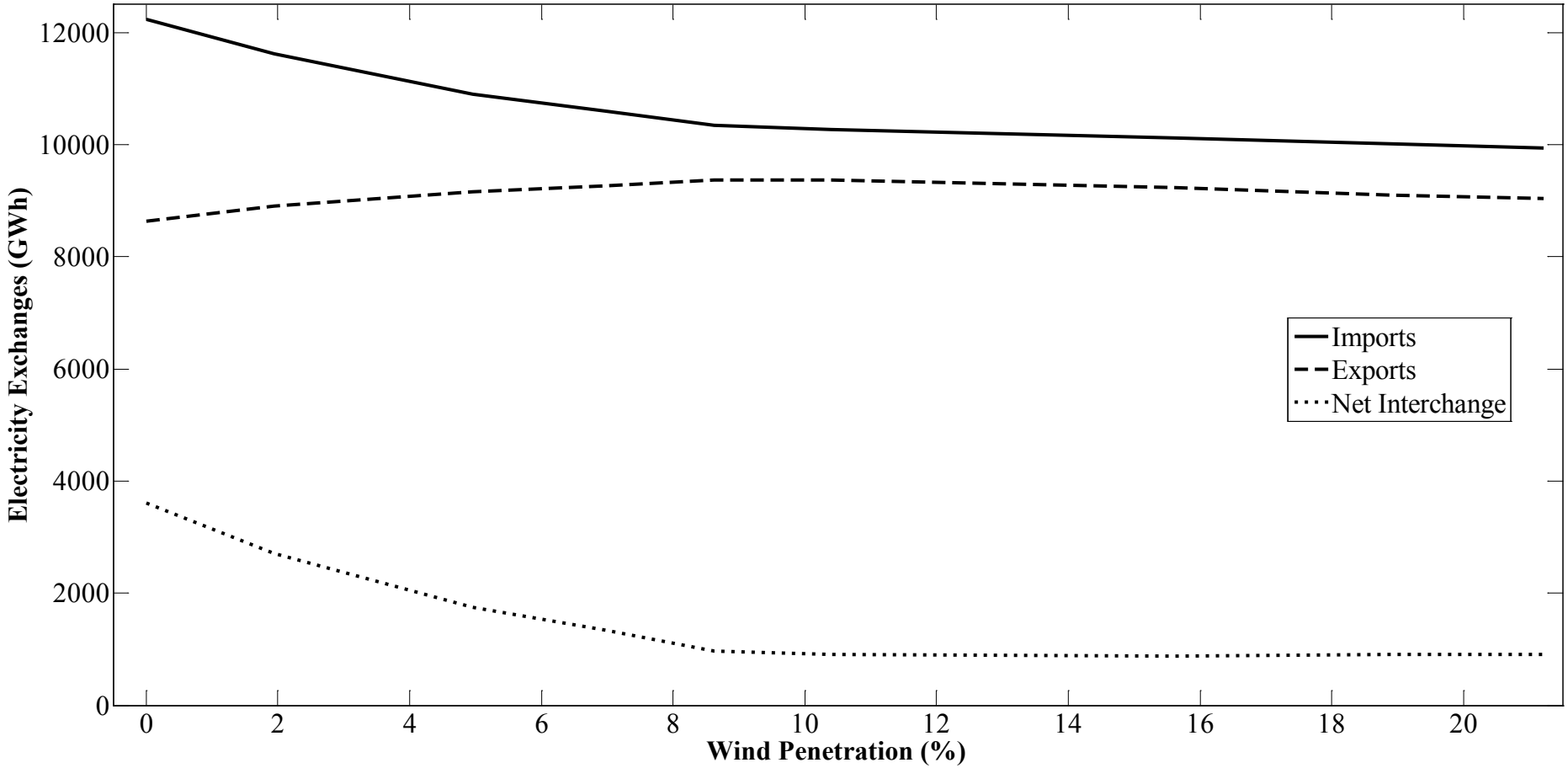
Gas GT and IC Electricity Generation



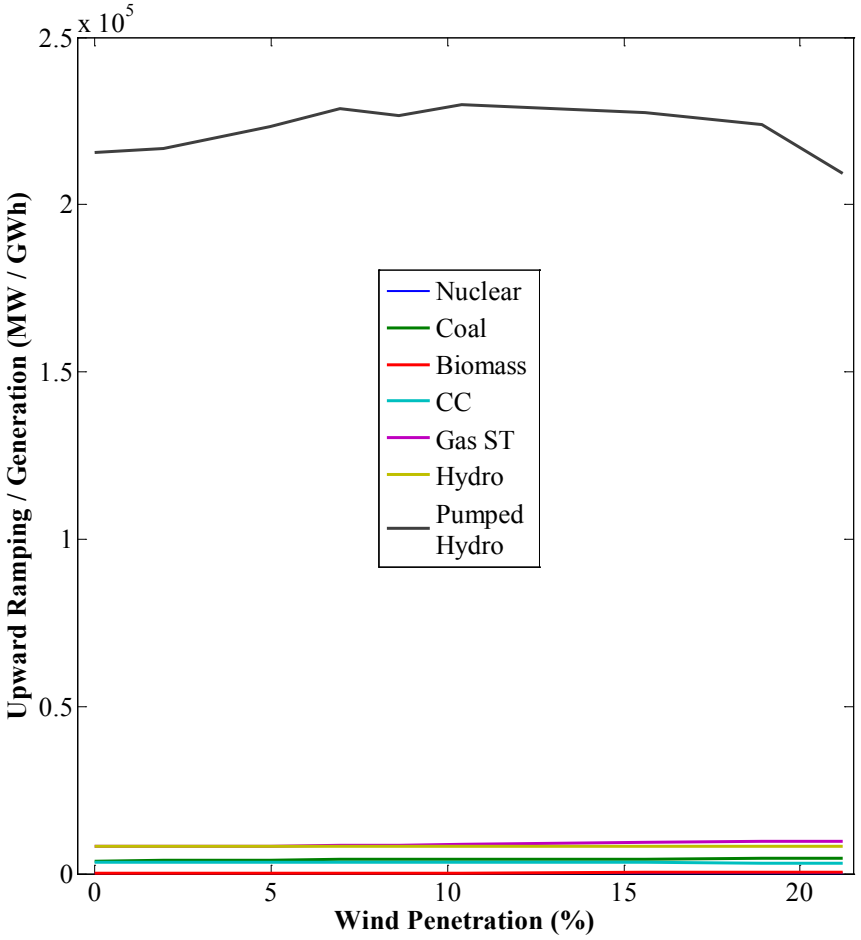
Oil-Fired Electricity Generation

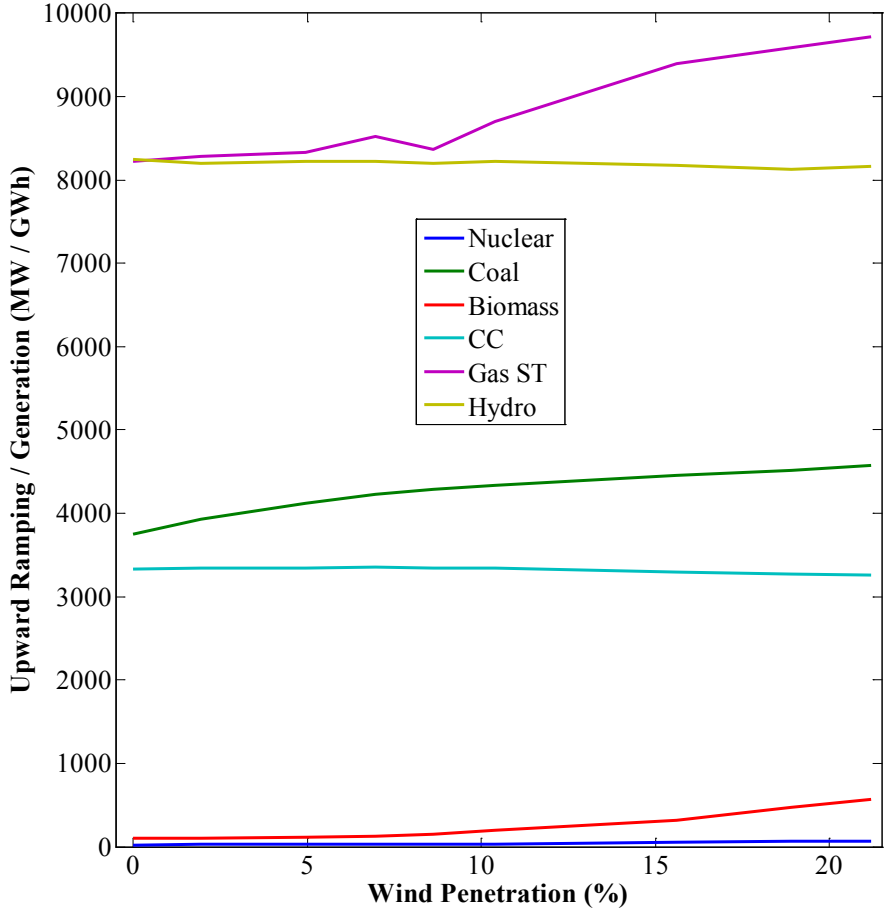


Electricity Exchanges

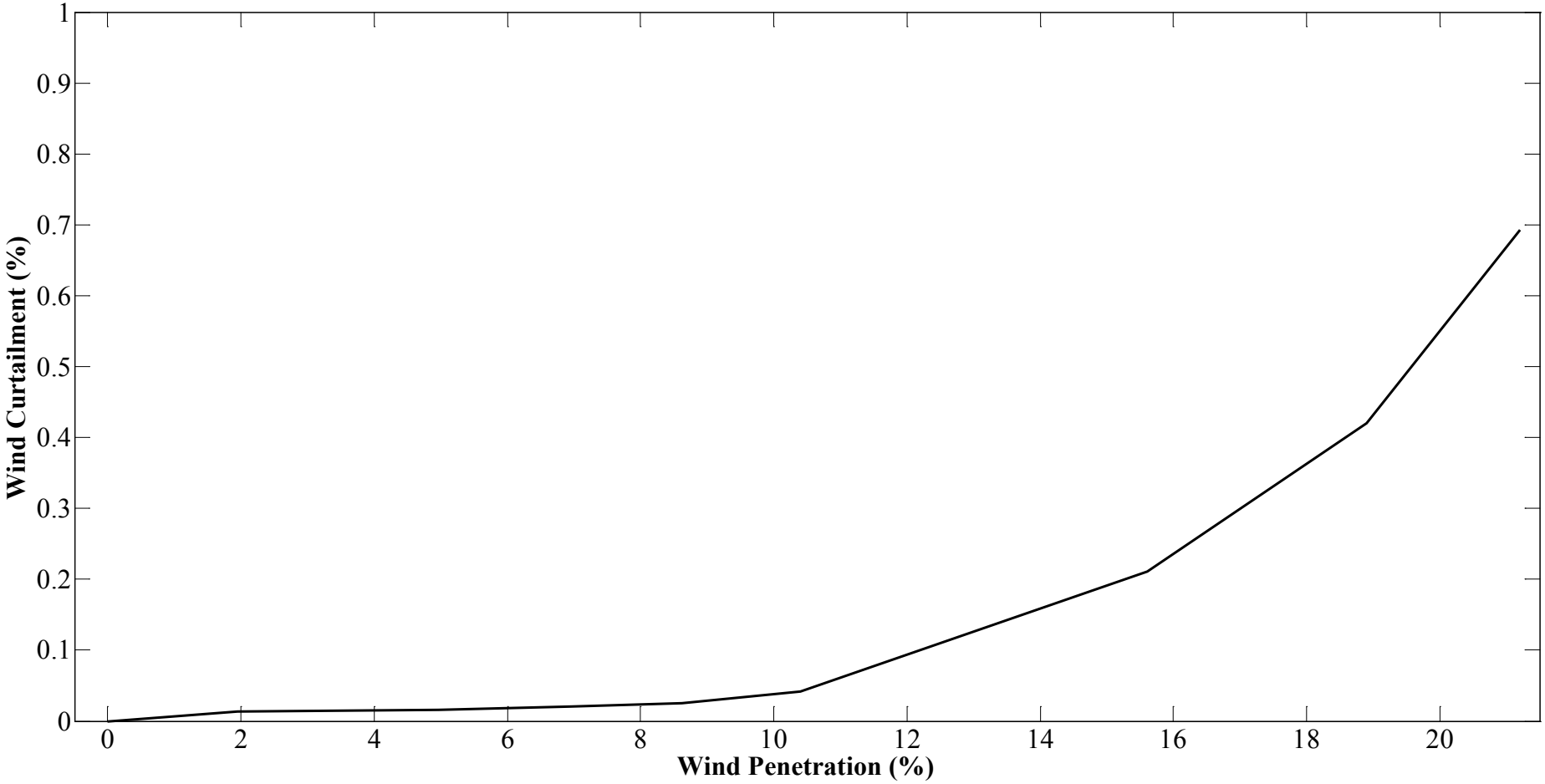


Ramping of Electricity Generators

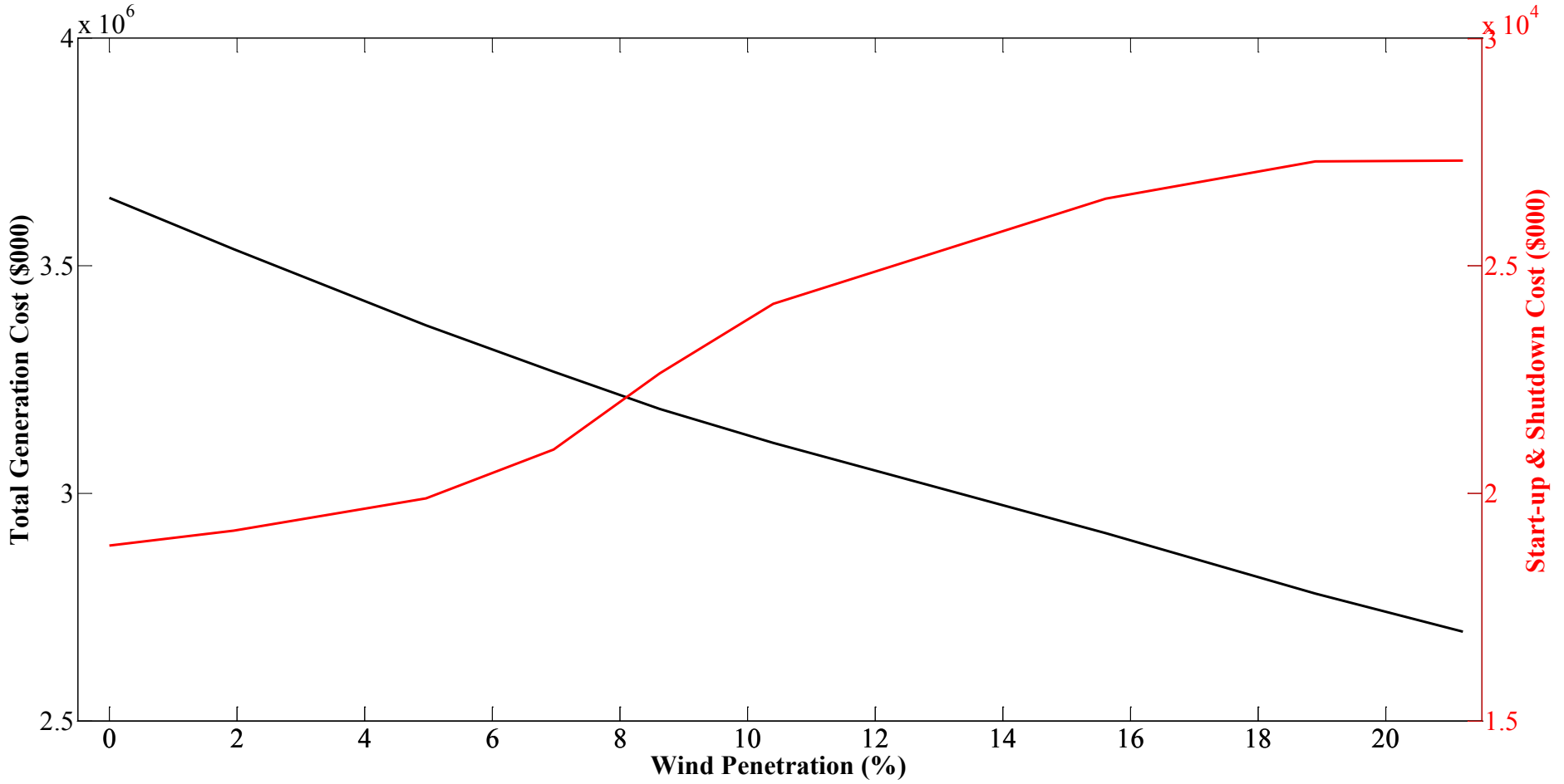




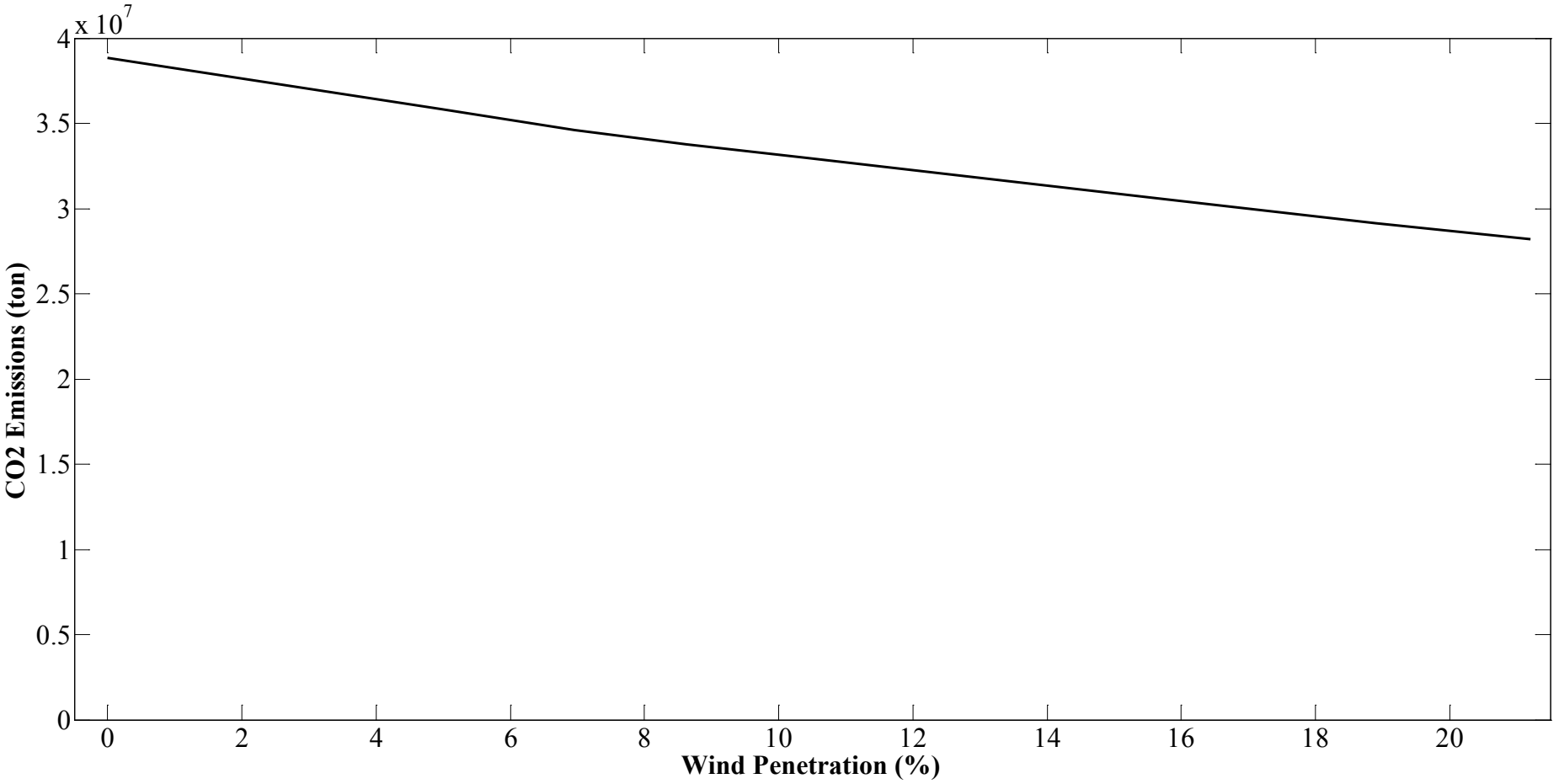
Wind Power Curtailment



Electricity Generation Costs

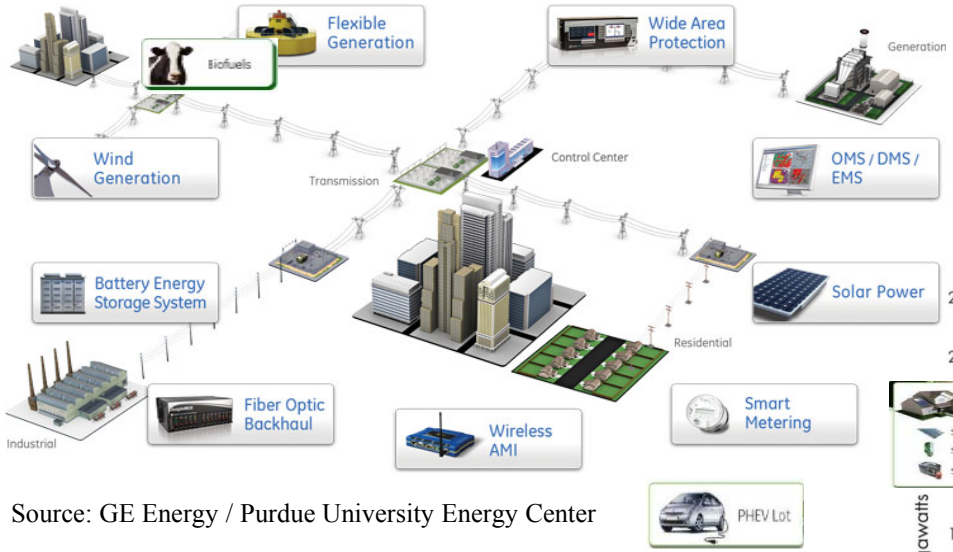


CO_2 Emissions

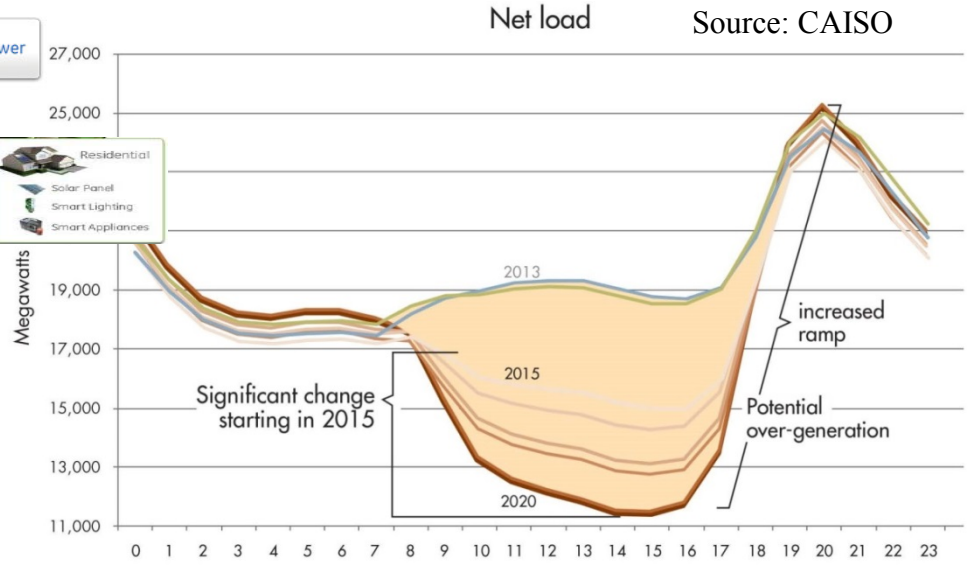


Different Wind Integration Approaches

How would the presented results vary if no or perfect wind power forecasts would be assumed and if wind power curtailment would not be allowed?



Source: GE Energy / Purdue University Energy Center



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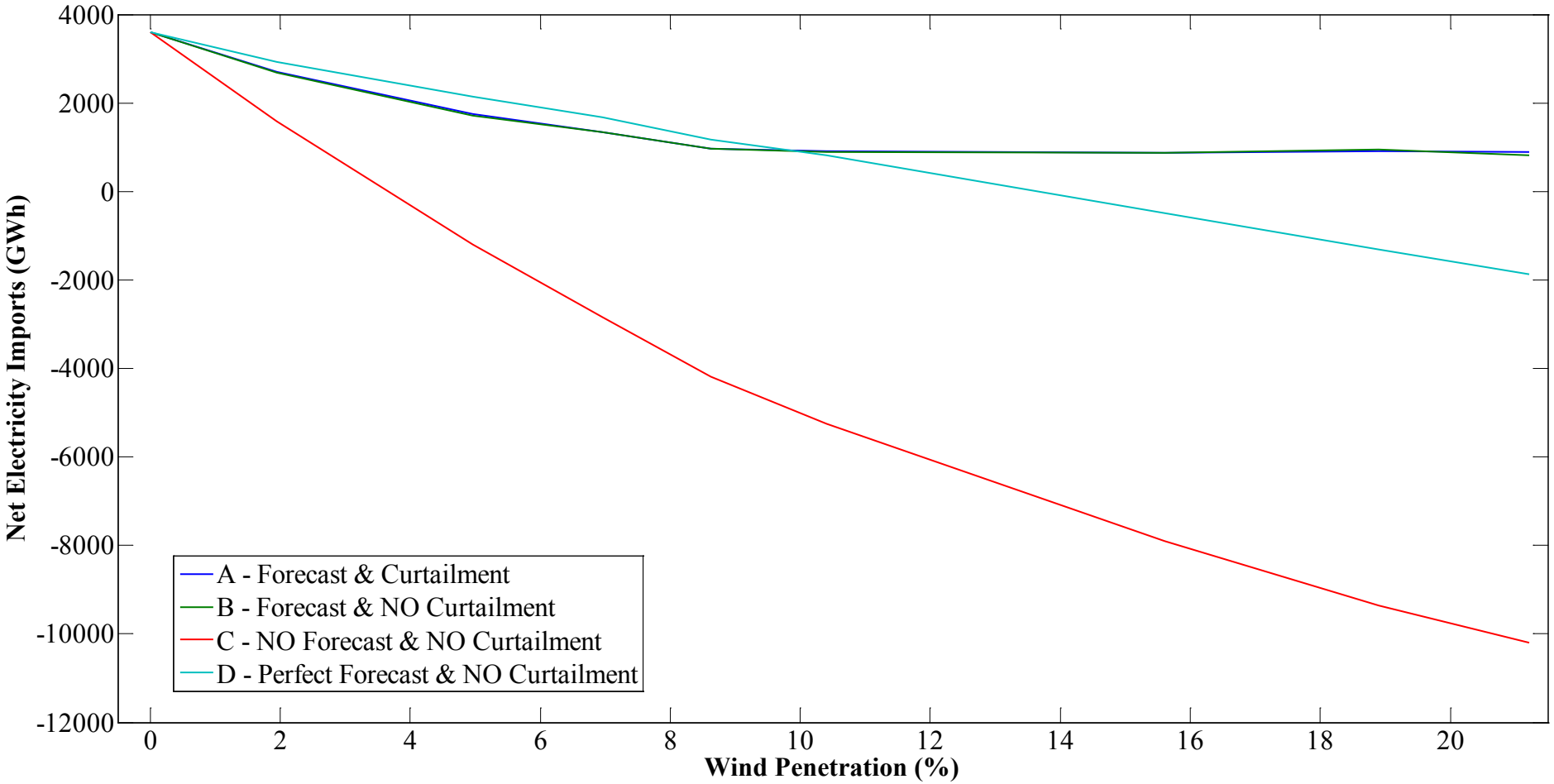

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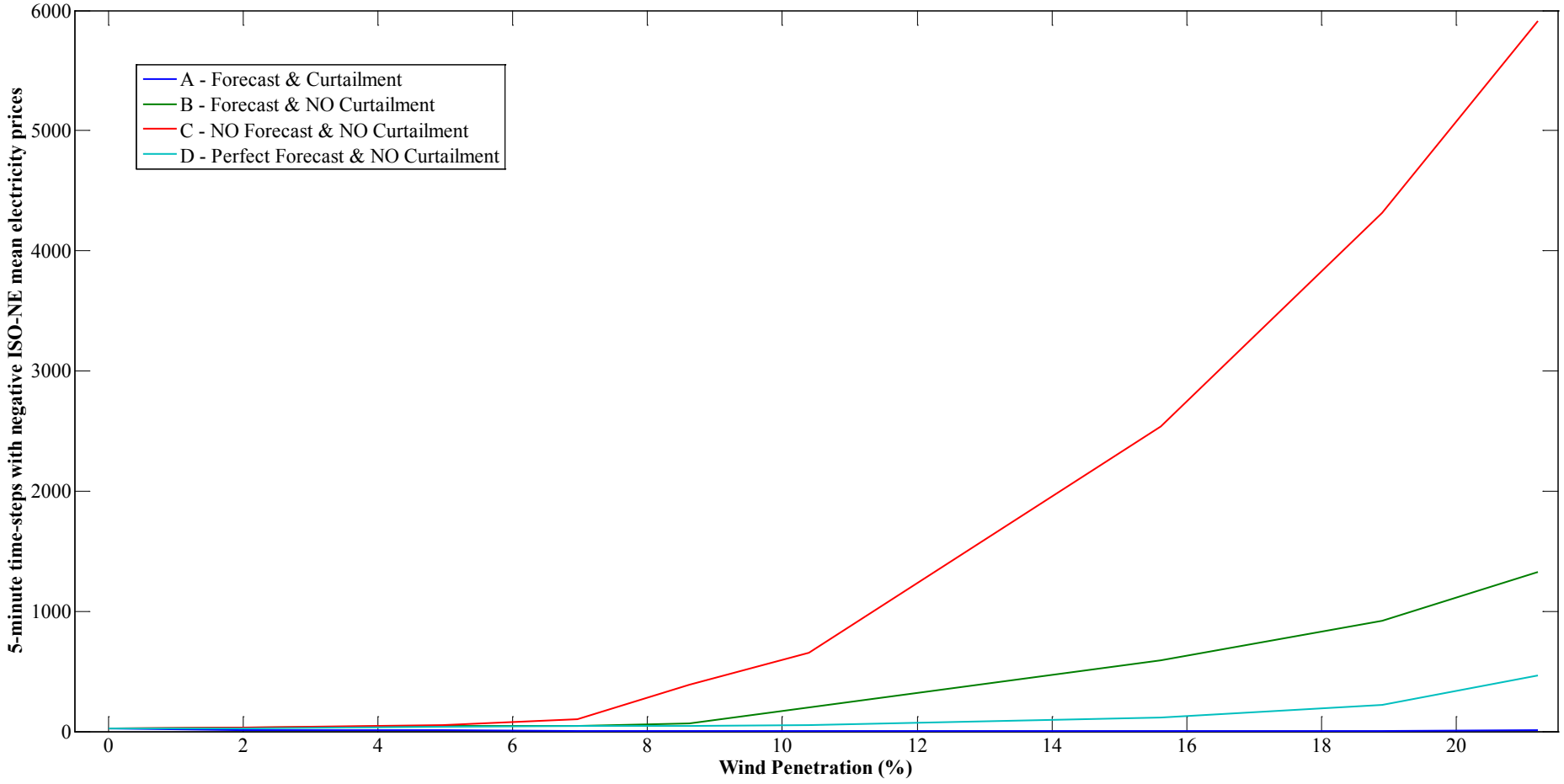
Negative Electricity Prices



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Conclusions

Higher penetrations of distributed wind reduce:

- **Coal- and gas-fired electricity generation**
- **CO_2 emissions**
- **Electricity imports**
- **Total variable electricity generation costs**

The variability and uncertainty of wind power also increase:

- **Start-up and shutdown costs**
- **Gas GT & IC and oil-fired electricity generation**
- **Ramping of most conventional generators**
- **Wind curtailment**

The impact of distributed wind on bulk power system operations depends on the knowledge and control that the system operator has, therefore on wind power forecasts and curtailment.

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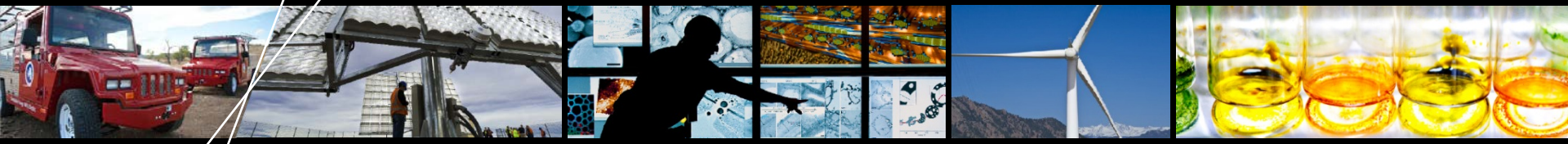

Thank you!

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“Markets”

	DA	4HA	RT
Horizon	1 year	1 year	1 year
Time Step	1 hour	1 hour	5 minutes
Optimization Window	1 day	4 hours	5 minutes
Look-Ahead (Resolution)	1 day (4 hours)	10 hours (2 hour)	-

Generators' Commitment

DA:	4HA:	RT:
Nuclear	CC	Gas_GT
Coal_ST	Gas_ST	Gas_IC
Biomass	Oil_ST	Jet_Oil_GT
		Oil_GT
		Oil_IC
		Wind

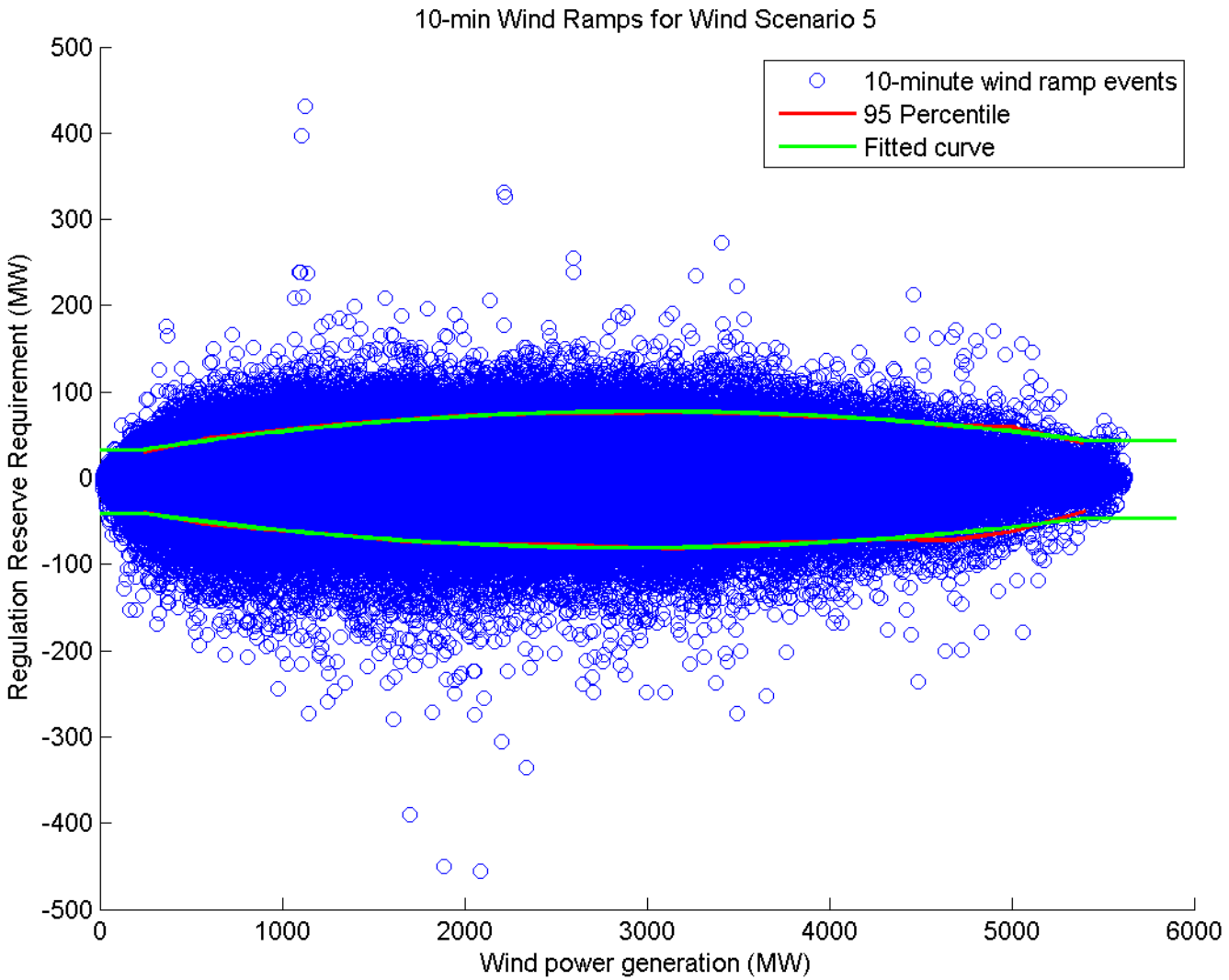
Hydro: DA generation is passed on to 4HA and RT

Pumped Storage: Special commitment based on pumped load, available capacity, and price received in previous market

Reserves

	Contingency (Spin)	Up Regulation	Down Regulation	Flexibility
On	Yes	Yes	Yes	?
Time Frame (seconds)	600	300	300	3,600 (?)
Minimum Provision	824 MW	1% load + 95% 10-minute wind ramps	1% load + 95% 10-minute wind ramps	?
Available Generation	All (except for nuclear and wind)			

Regulation Reserves



WIND Toolkit

- The Weather Research and Forecasting Model V.3.4.1
- 6-km nest for forecasts, 2-km for re-analysis
- Model output: 1 hour for forecasts, 5 minutes for re-analysis
- 100+ TB model output: Parallel asynchronous I/O to improve output speed 50:1

- **Power Data Set:**
  - Power output at 126,000 sites
  - Onshore and offshore for CONUS
  - 2-km by 2-km spatial resolution
  - 5-minute temporal resolution
  - Years: 2007–2013
- **Meteorological Data Set**
  - Wind speed and direction
  - Temperature
  - Atmospheric pressure
- **Forecast Data Set**
  - Day-ahead forecasts
  - 6-hour-ahead forecasts
  - 4-hour-ahead forecasts
  - 1-hour-ahead forecasts