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Project 2E

Mapping Energy Futures: The SuperOPF Planning Tool

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Network reductions from Dan Tylavsky, Di Shi, Yingying Qi*, Yujia Zhu* (ASU)
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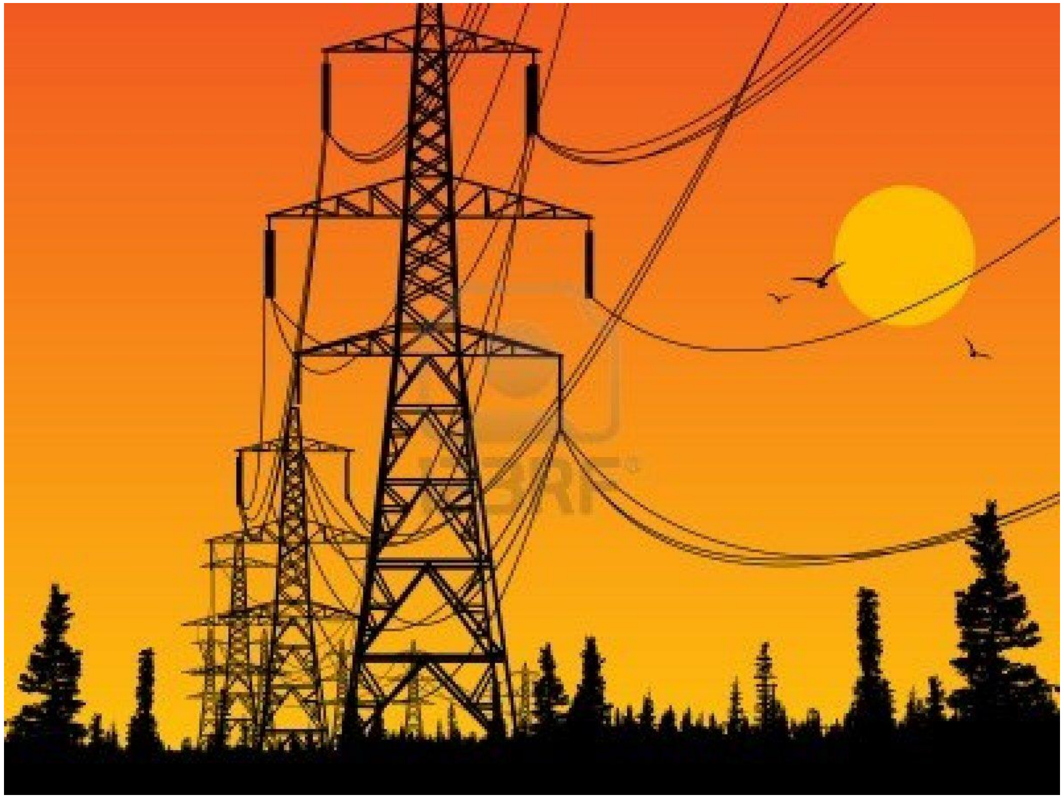
Existing Planning Tools

- Are very detailed but do not optimize investment over the planning region, or
- Are highly aggregated using bubbles and pipes (or only a small number of nodes) to represent the network, and
- None include environmental modeling of ambient pollution
- Few or none include joint variation of load, wind, and solar, by location

SuperOPF Planning Tool



Uses three network reductions (for the EI, ERCOT and WECC) from Dan Tylavsky to cover the entire nation. These reductions retain all high voltage lines of 230 KV and above.

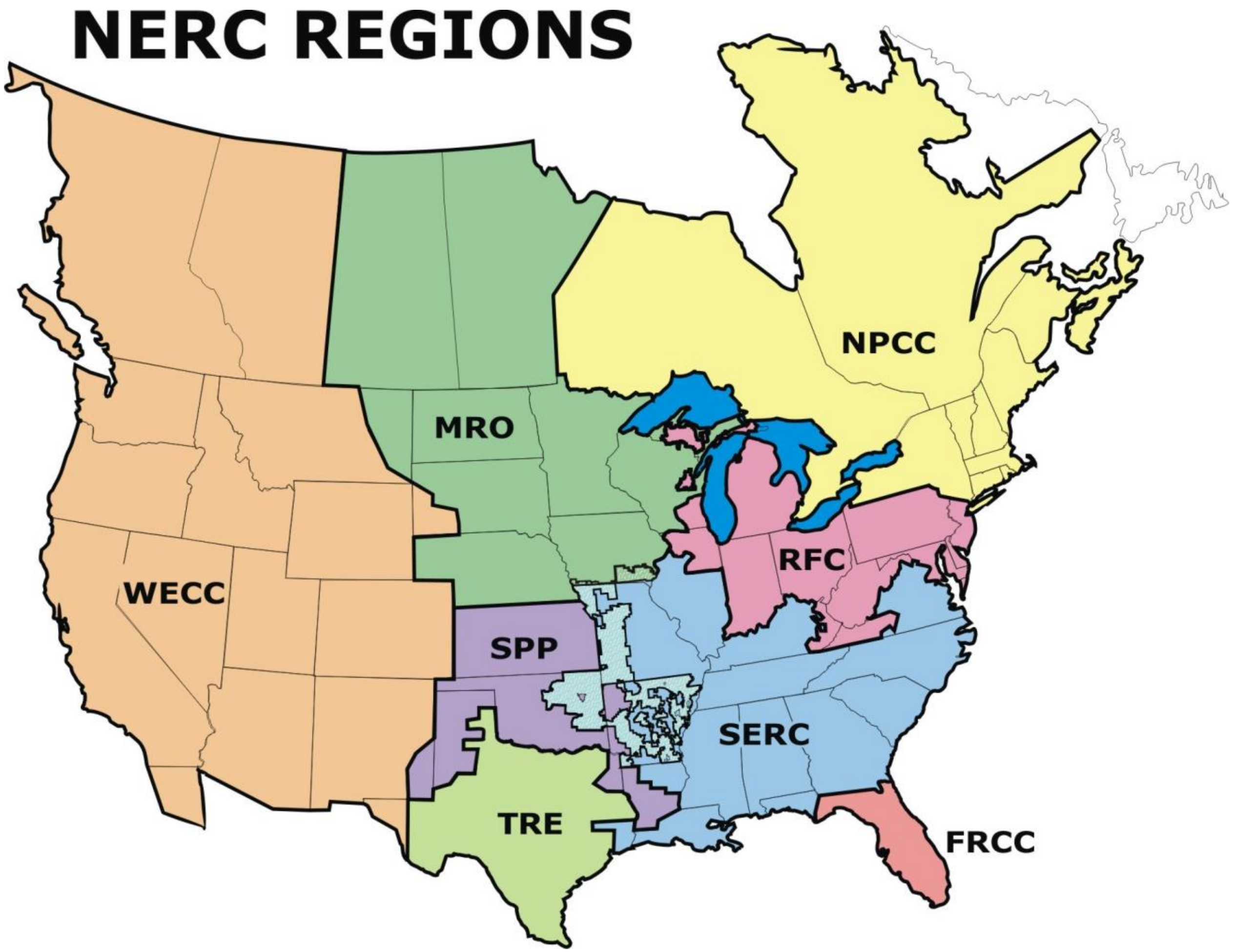
Features

- Maximizes expected net benefits
- Investment in new generation
- Retirement of old generation
- Emissions of CO_2, NO_X and SO_2
- Atmospheric modeling of fine particulates and resulting mortality

Features

- Network modeled with DC power flow
  - 5000+ bus equivalent of Eastern Interconnect
  - 2300+ bus equivalent for WECC
  - 1000+ bus equivalent for ERCOT
- Reliability maintained by generation investment driven by
  - 36 representative hours for load, wind and solar to model stochastic variability
  - Additional 10% reserve requirement via capacity factor
- Demand response

Regions



NPCC: New England, Western Canada

RFC: PJM

SERC: South East

FRCC: Florida (minus the panhandle)

SPP: Southern Power Pool (Kansas and Oklahoma)

MRO: Midwest

Long Run Price Response (Conservation)

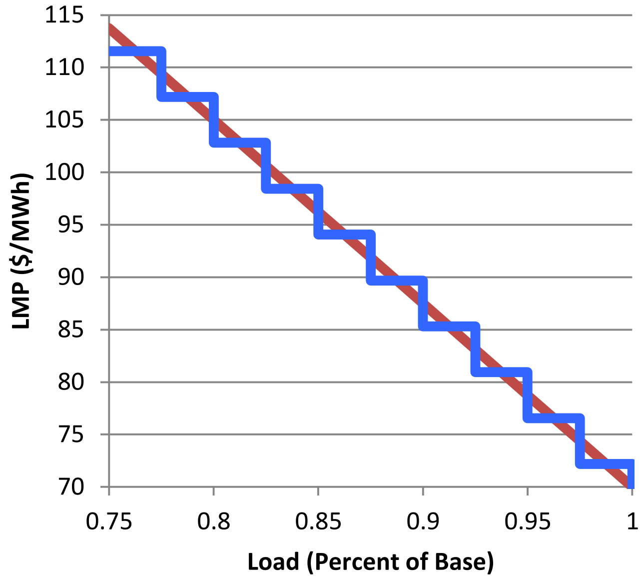
Actual Demand Response (Red)
Modeled Demand Response (Blue)

25% total demand response

10 blocks, each 2.5% of load

Effective price is at the midpoint of each interval

Consistent with piecewise-linear benefits function



We use an elasticity of 0.6 to combine the short and long run.

The delivered price equals the LMP for each bus, for each representative hour in 2012, plus estimated distribution costs ($70/MWh)

Typical Run

- Select a given policy scenario
- Sequential optimization of three periods
  - Year 0 current fleet
  - Year 10 allowing retirement and new investment
  - Year 20 allowing retirement and new investment

Problem Size

- For 5222-bus Eastern Interconnect model, has 3800 aggregated generators and a largest island (4856 buses)
- Largest LP with
  - 2,334,909 variables, 6,382,608 constraints
- Sequence of 3 periods solves in about 3 hours with two parallel runs on 12-core, Mac Pro workstation (1.5 hours/case)

Generator and Load Data Overview

- Information about existing units combined from 12 sources
- Investment costs from EIA
- Fuel cost projections from EIA
- Pollution transfer coefficients from EPA-funded model
- Fine PM mortality effects and valuation from NRC
- 36 hour types represent the year. Vary in terms of unit availability (from NERC) and load (from ISOs and NERC).
- Load grows (before long run demand response) per ISO projections

http://www.nyiso.com/public/webdocs/newsroom/press_releases/2009/NYISO_2009_Summer_Outlook__05212009_(2).pdf

Converting pollution into estimated mortality cost

- Seventy million county-to-county transfer coefficients from EPA-funded model
- Population per county, and percentage over 30, from US and Canadian censuses
- Dose-response functions from NRC
- Valuation per premature death from US EPA standard value

Accomplishments In Last 12 Months

1. Completed and improved generator dataset of Eastern Interconnection: finished matching data from 12 sources, included many generator characteristics, filled in missing values using regression analysis.
2. Created similar generator datasets for WECC and ERCOT.
3. Improved generator aggregation that preserves diversity.
4. Calculated hourly solar output at hundreds of potential solar sites.
5. Matched 1200 potential windfarms and hundreds of solar sites, each with hourly data, to grid model.

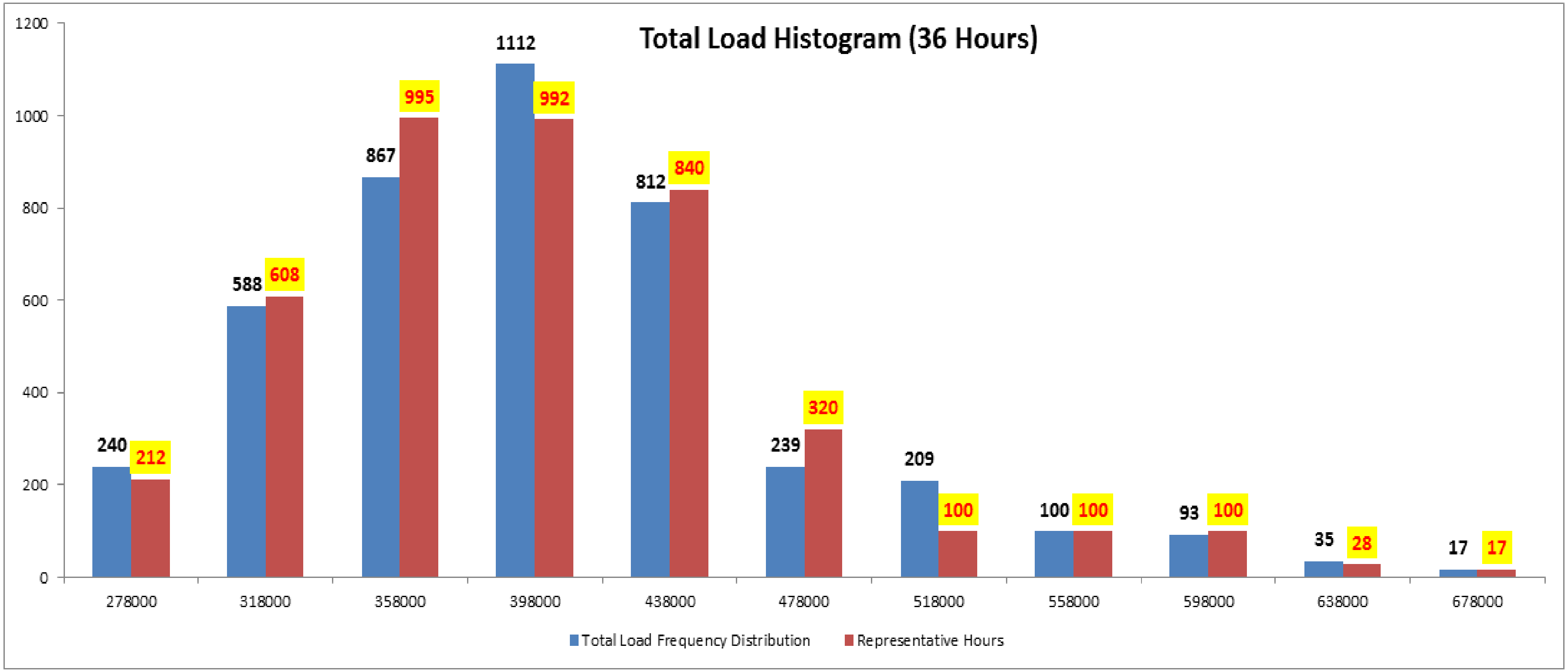
Accomplishments In Last 12 Months

6. Developed sets of representative hours to represent joint distribution of location-specific load, wind, solar, and availability, from historical data.
7. Through experimentation and innovations, enabled Gurobi barrier solution method to solve SuperOPF Planning Tool problems, shortening solution time by a factor of approximately 100 compared with simplex method.
8. Tested and analyzed performance of 300- and 1-bus reduced models of Eastern Interconnection compared with 5000-bus model.
9. Multiple improvements to SuperOPF Planning Tool.

Representative hours

- 36 hour types represent load, solar, and wind joint variability
- Each is also day, night, or shoulder, for future modeling of electric vehicles
- Load varies independently in each region of the EI, based on actual 2010 data for each region and representative hour bin

Representative Hours in EI Model



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Investment and Retirement

- Base year is year 0. Investment allowed in year 10 and year 20. New plants must pay for capital.
- Underused plants are retired.
- Note that old plants must only cover variable costs and taxes while new plants must additionally cover investment costs. If old plants go bankrupt, they are sold at a discount, and keep generating.
- Millikin Station

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Fuel Costs

Price of gas to generators is about $1 per mmBtu higher than price at the Henry Hub because of delivery.

With sufficient export capacity, US price would approach world price in the next 20 years.

Coal and oil costs are assumed to remain unchanged.


PHOTO: MLADEN ANTONOV/AFP/GETTY IMAGES

$/MBTU	Year 0	Year 10	Year 20
Natural Gas (EIA)	$2.50	$4.77	$5.86
Natural Gas (Higher Path)	$5.50	$5.50	$10.00

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New Power Plant Costs

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Fuel Type	Annual Capital Cost, Years 1-10 ($/MW/Year)	Annual Total Fixed Costs ($/MW)	Total Variable Cost $/MWh (in 2012)
Coal (Dual Unit Advanced PC)	$495,245	$35,255	$29.05
Natural Gas (Advanced NGCC)	$167,859	$20,661	$38.48 (if $5.50 per mmBtu; varies)
Natural Gas (Advanced NGCT)	$107,173	$12,741	$63.50 (if $5.50 per mmBtu; varies)
Wind	$352,720	$10,236	$2*
Nuclear	$959,328	$95,571	$2.04
Solar	$765,175*	$5,849	$2

*Excluding tax credit for wind and solar (included in some runs)

Updated Capital Cost Estimates for Electricity Generation Plants
November 2010, U.S. Energy Information Administration,
Office of Energy Analysis

Annual Energy Outlook 2011
April 26, 2011, U.S. Energy Information Administration

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Why bother using such a complex and detailed model?

- 5200 nodes for the EI adds enormous and challenging computational difficulties
- Required shift to interior point solver (Gurobi) rather than using the Simplex method
- Objective function is very flat….
- But the average annual LMP maps for 300 versus 5000+ nodes tell the story:

To show importance of a detailed model of the grid we looked at RGGI

- RGGI CO_2 Cap is to be lowered in 2014
- Assume low gas prices
- What is predicted impact in and out of RGGI of lowering the cap using a 1 versus ~300 versus ~5000 node model of the grid on
  - CO_2 produced in total and by region noting if leakage occurs total can increase
  - LMP, etc.

Results Are Very Different!

(Short Tons of CO_2)

		Year 0	Year 10	Year 20
1 Node – Policy Effect	In RGGI	-55,020,247	-48,535,057	-54,408,007
	Outside RGGI	+79,026,267	+54,287,354	+55,735,423
	Leakage Percent	144%	112%	102%
300 Node – Policy Effect	In RGGI	-25,433,526	-35,510,483	-49,754,186
	Outside RGGI	+36,278,990	+38,155,900	+43,329,451
	Leakage Percent	143%	107%	87%
5k Node – Policy Effect	In RGGI	-18,282,576	-30,869,475	-61,262,677
	Outside RGGI	+26,208,921	+33,505,346	+43,312,049
	Leakage Percent	143%	109%	71%

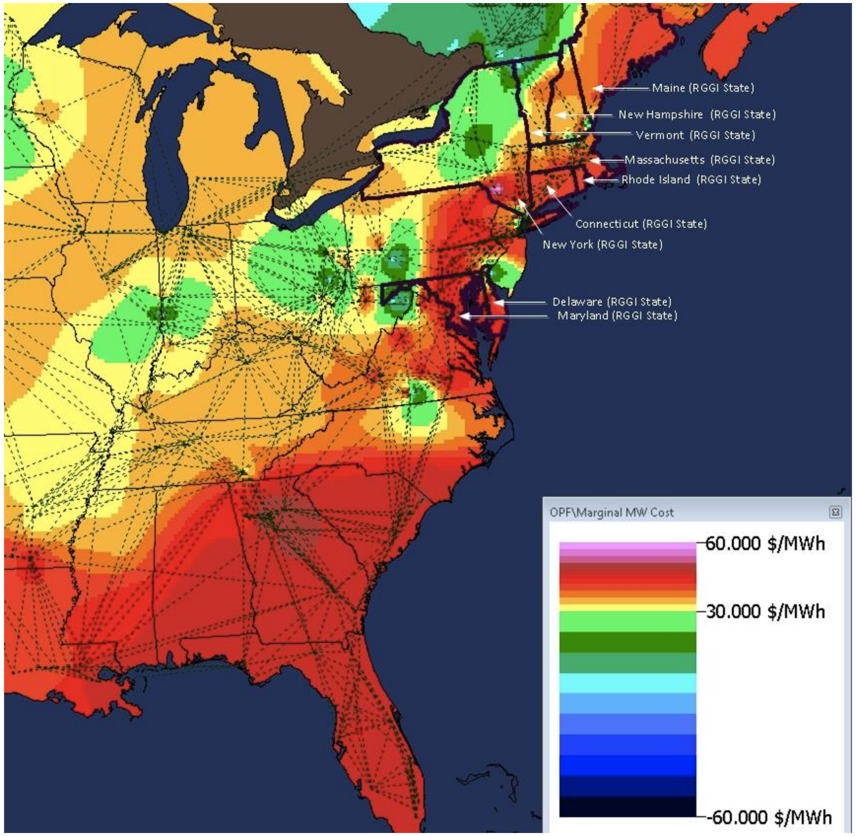
*$10 permit required for each short ton of CO_2 emissions

**Leakage Percent=*CO2 Emission Increment Outside RGGI/CO2 Emission Decrement Inside RGGI*

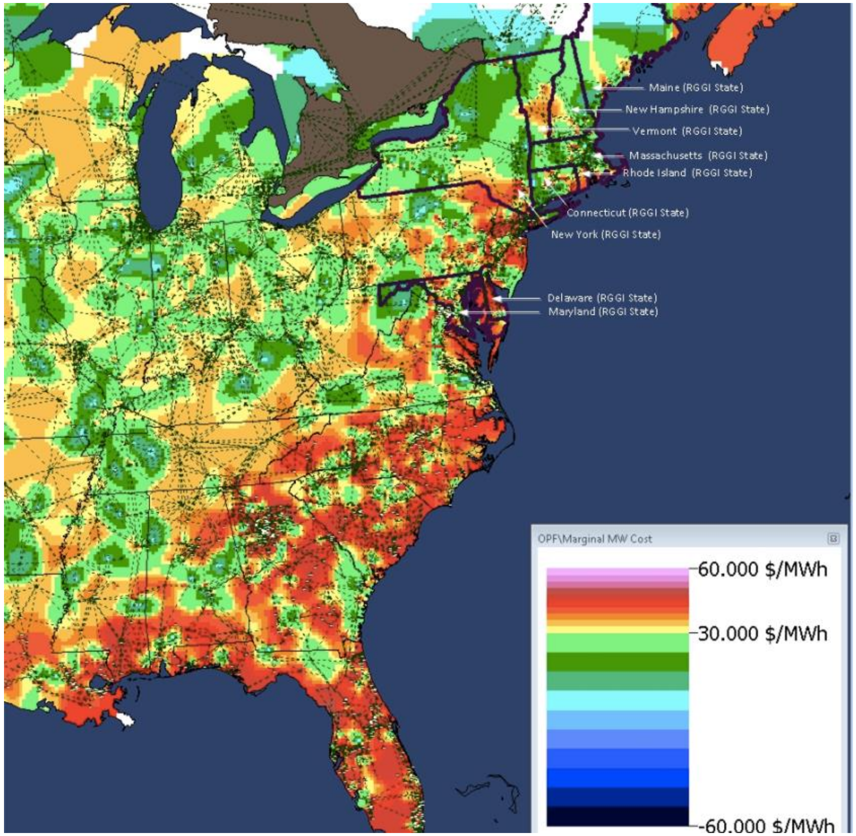
Why?

Wholesale Price Maps for Year 10

300 Node LMP Map



5200 Node LMP Map



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Example Case Descriptions

- High Gas Prices
- PTC: Federal Tax Credits for wind
  - Central solar is too costly for model to build; will add behind-the-meter solar
- Damage Charge: Marginal Damages for Fine Particulates
- Cases
  - Base Case
  - PTC for Wind
  - Damage Charge
  - Damage Charge and PTC for Wind

Incentives for Renewables

- Federal Production Wind Tax Credit of $22/MWh and 30% Solar Investment Tax Credit, Ignore State-level programs
- Central Power Plant Solar Not Cost-Competitive (will add behind-the-meter solar that likely will be)

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Damage Charge = Marginal Damages

- Study also reviews
    - Heating ($1.4 billion in damages)
    - Transportation ($56 billion in damages)
    - Damages from mining and related activity
    - Damages related to climate change
    - Infrastructure Risks and Security

- Hidden Cost of Energy (NAS)
    - Large damages caused by power generation
        - SO2, NOx,->Fine Particulates
    - Average coal plant causes $156 million in damages annually
        - 10% of coal plants produce 43% of damages
    - Average natural gas plant causes $1.5 million in damages
        - Smaller plants, less damage per kWh
        - 10% of NG plants produce 65% of damages
    - Does not include a network model for transmission and distribution

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Damages by Coal-Fired Plant

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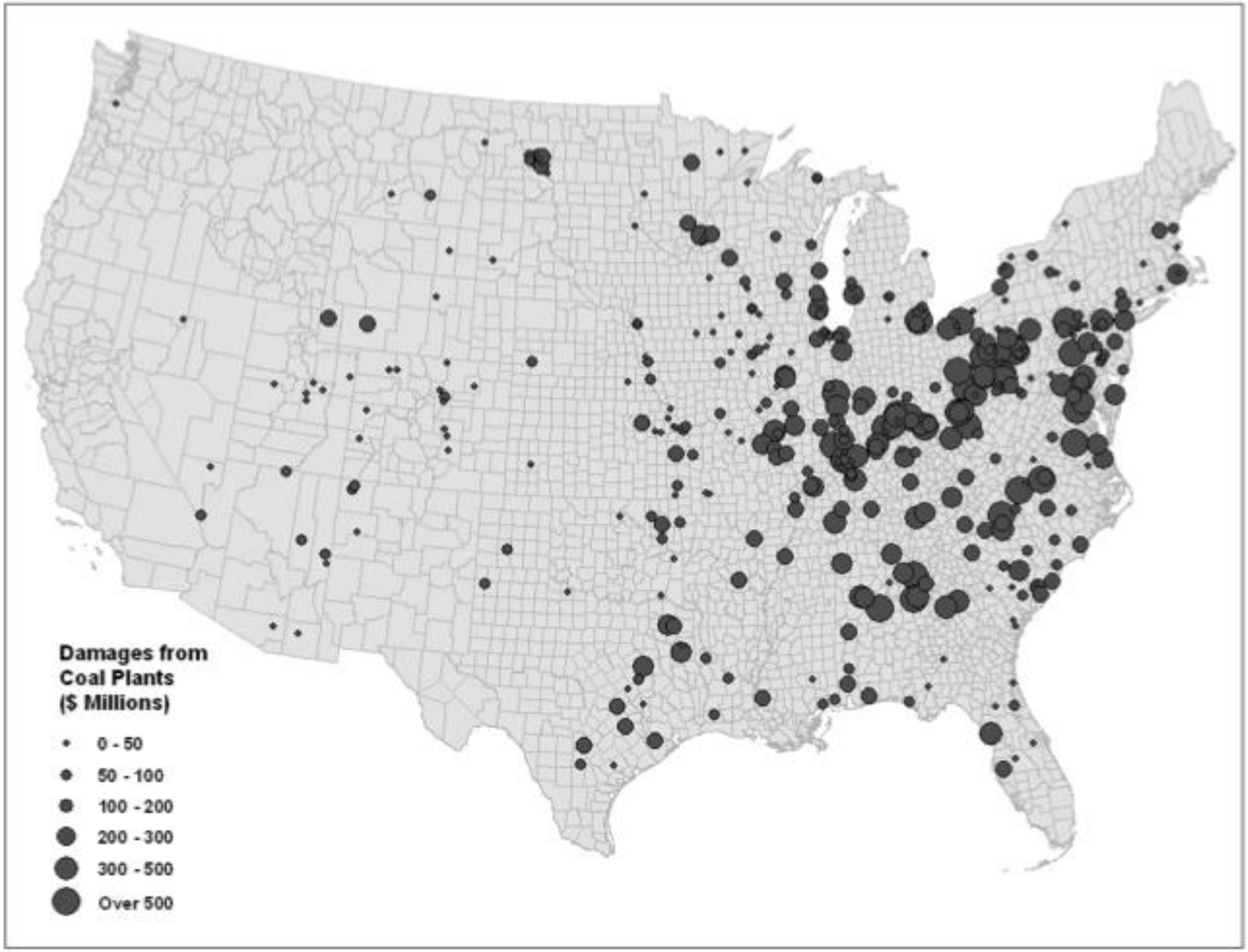

FIGURE 7-2 Air Pollution damages from coal generation for 406 plants, 2005. Damage estimates are reported in 2007 USD. Damages related to climate-change effects are not included.

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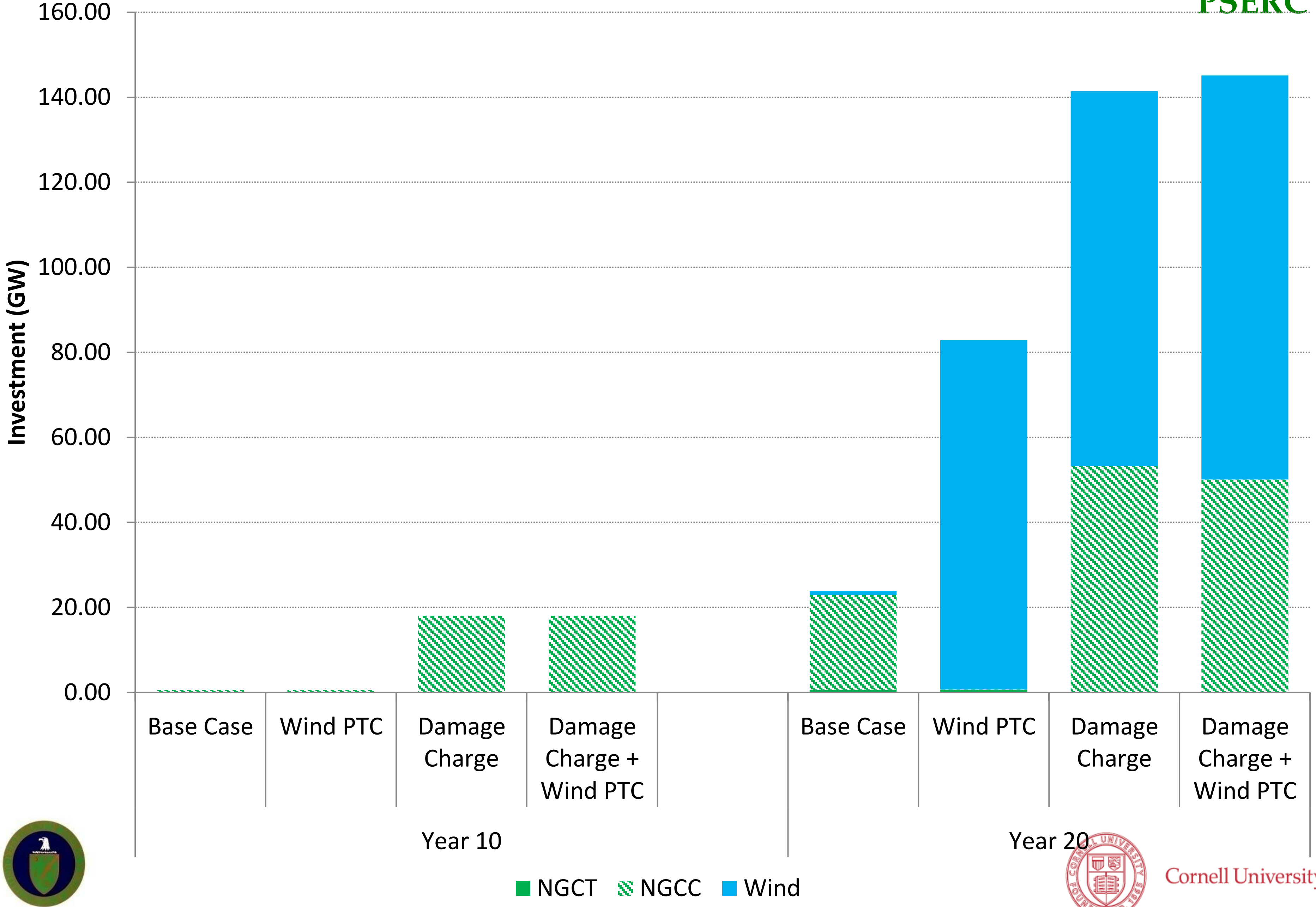
Marginal Damages

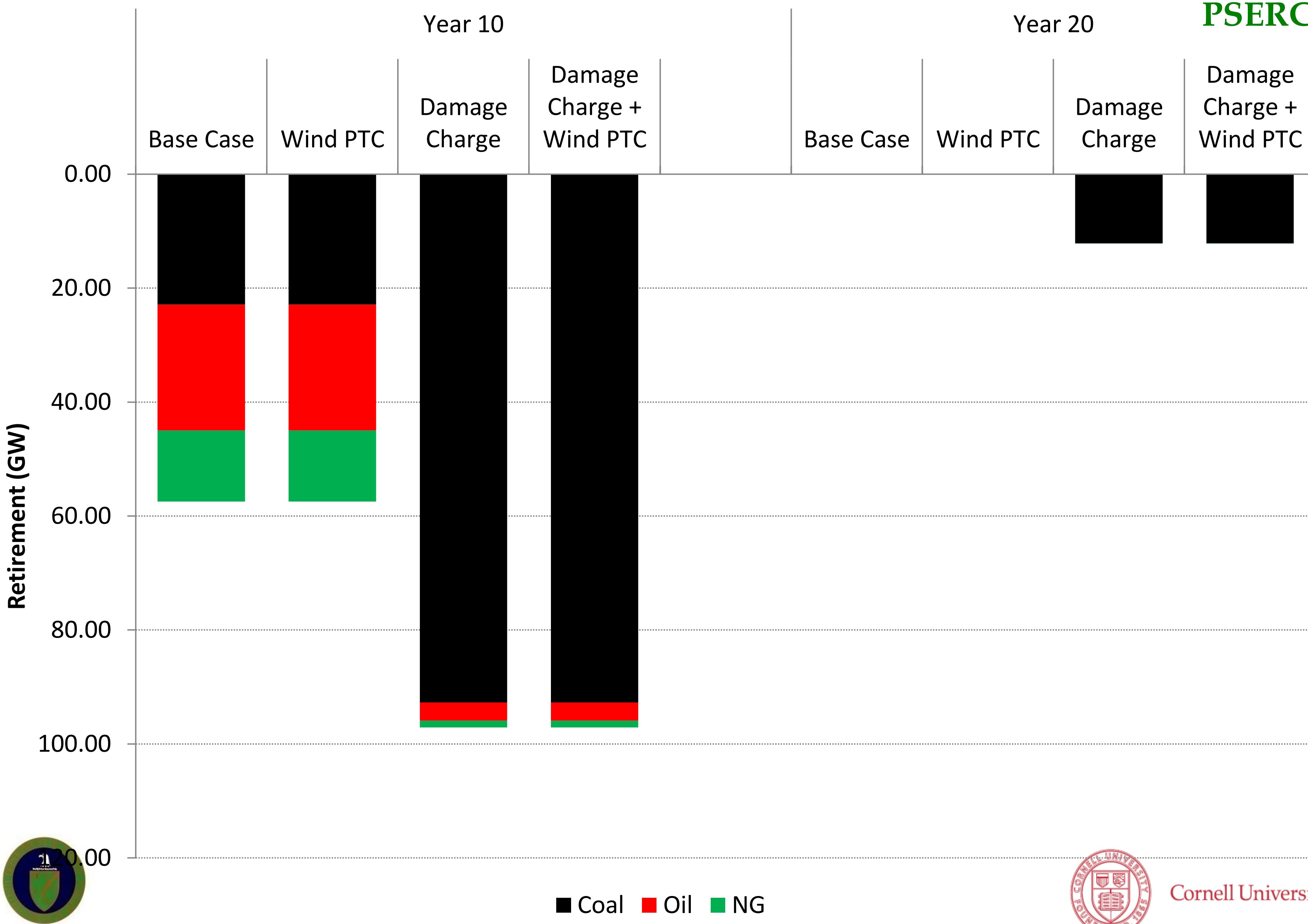
- Use same air transport model as in *Hidden Costs of Energy*
  - Transport coefficients from/to every county in the US and Canada
- Summed over all counties and combined with information about value of statistical life, mortality, and morbidity rates to generate

Unit Name	CO_2 Rate Tonnes/MWh	SO_2 Rate Tonnes/MWh	NO_x Rate Tonnes/MWh	Health Damage $/MWh
Cayuga Coal Plant	0.98	<0.001	<0.001	7.22
Average Coal Plant	1.05	0.0065	0.001	89.87
Max Damage Coal Plant	0.9984	0.0134	0.0012	232.20
Average NG Plant	0.65	<0.0001	<0.001	2.36

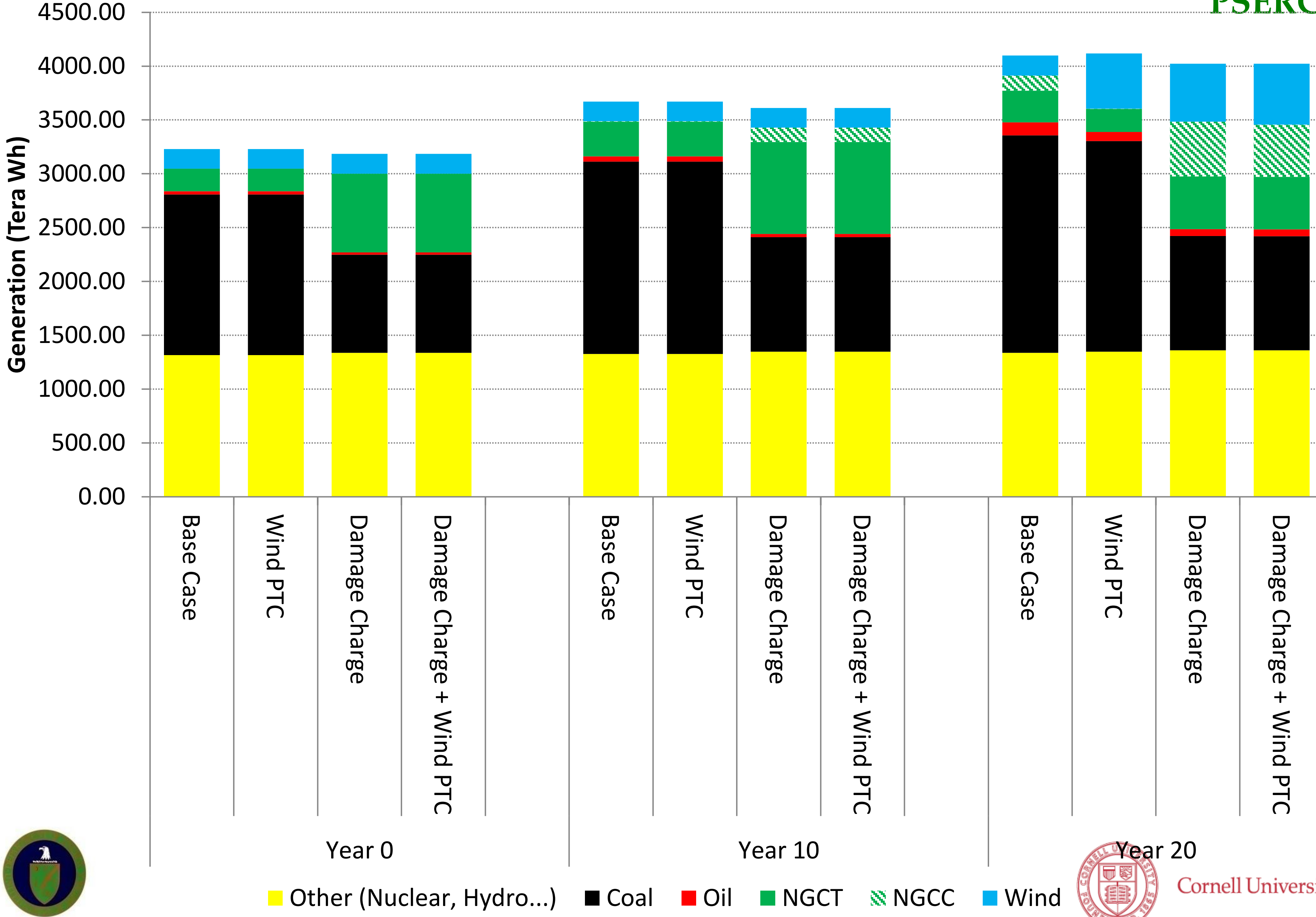
Investment by Fuel Type



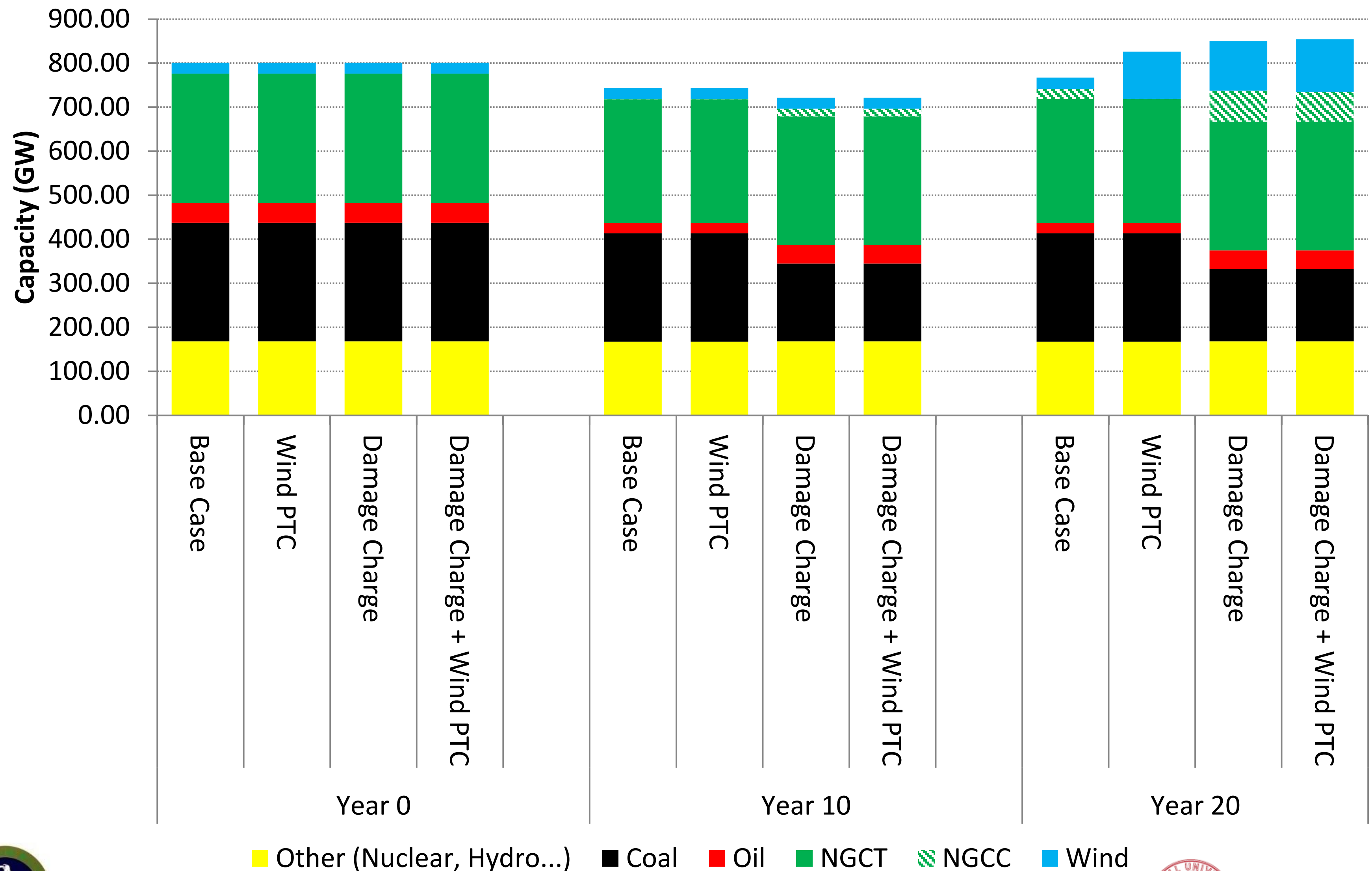
Retirement by Fuel Type



Generation by Fuel Type



Capacity by Fuel Type



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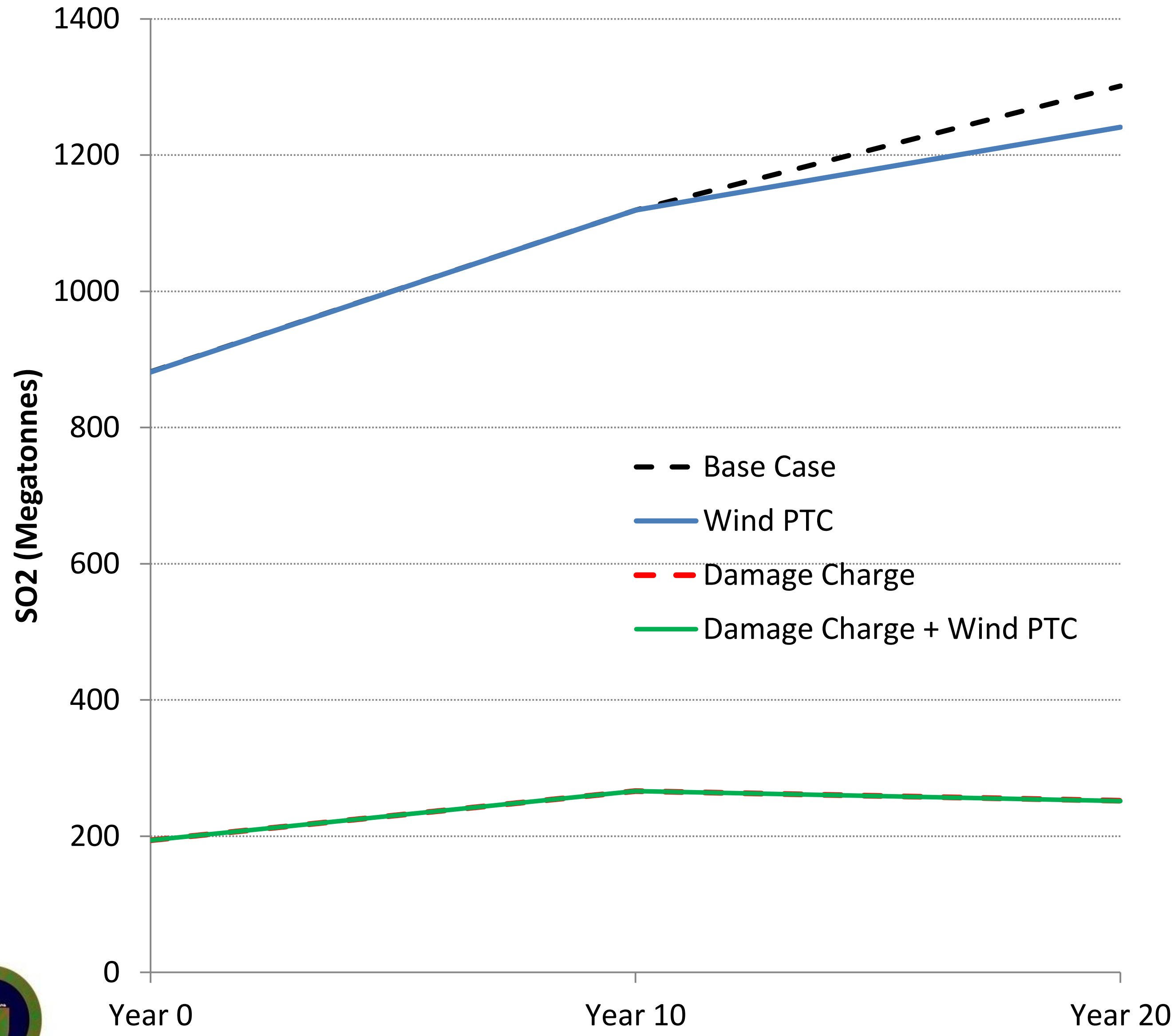
SO_2 Emissions



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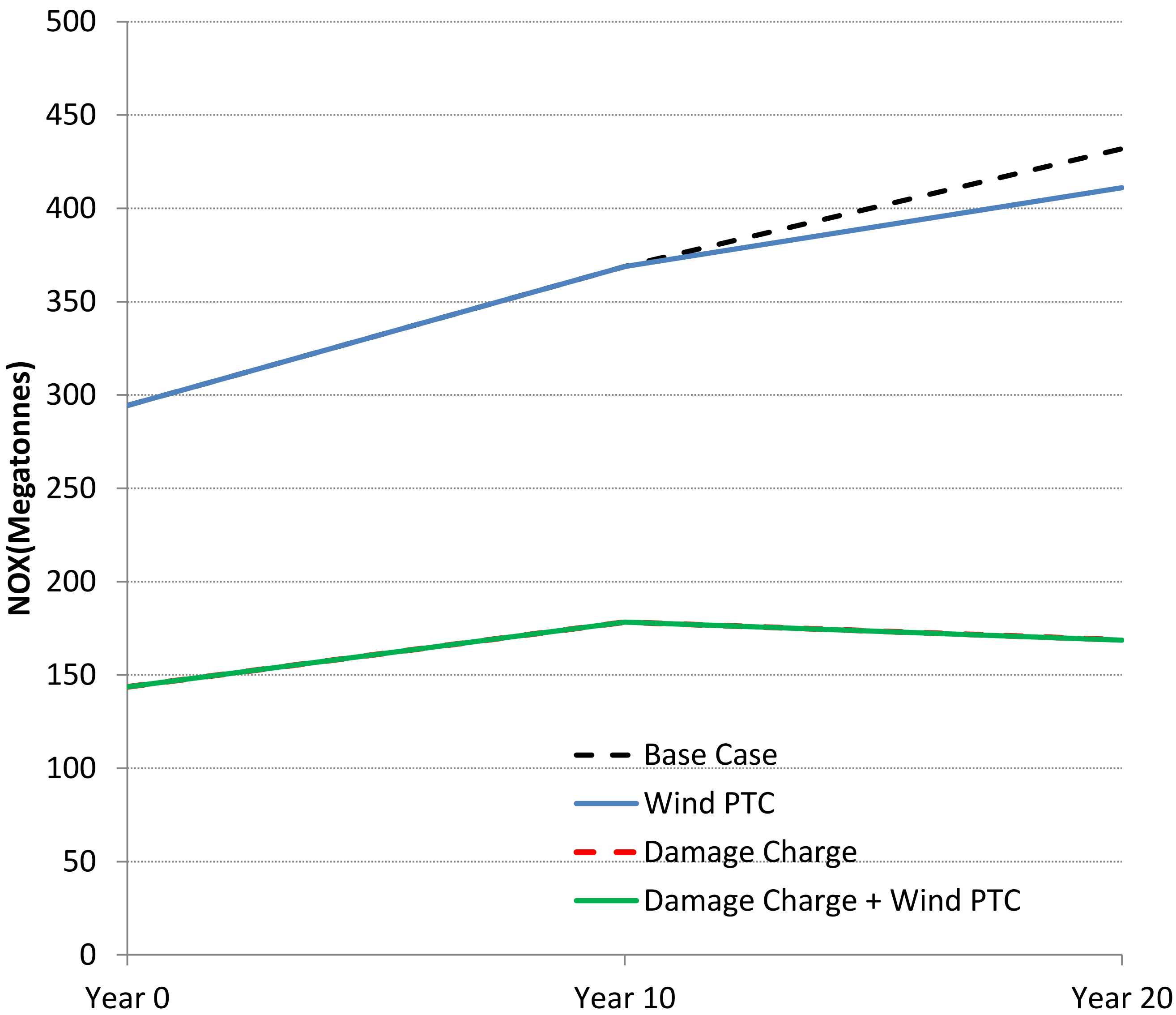
NO_X Emissions



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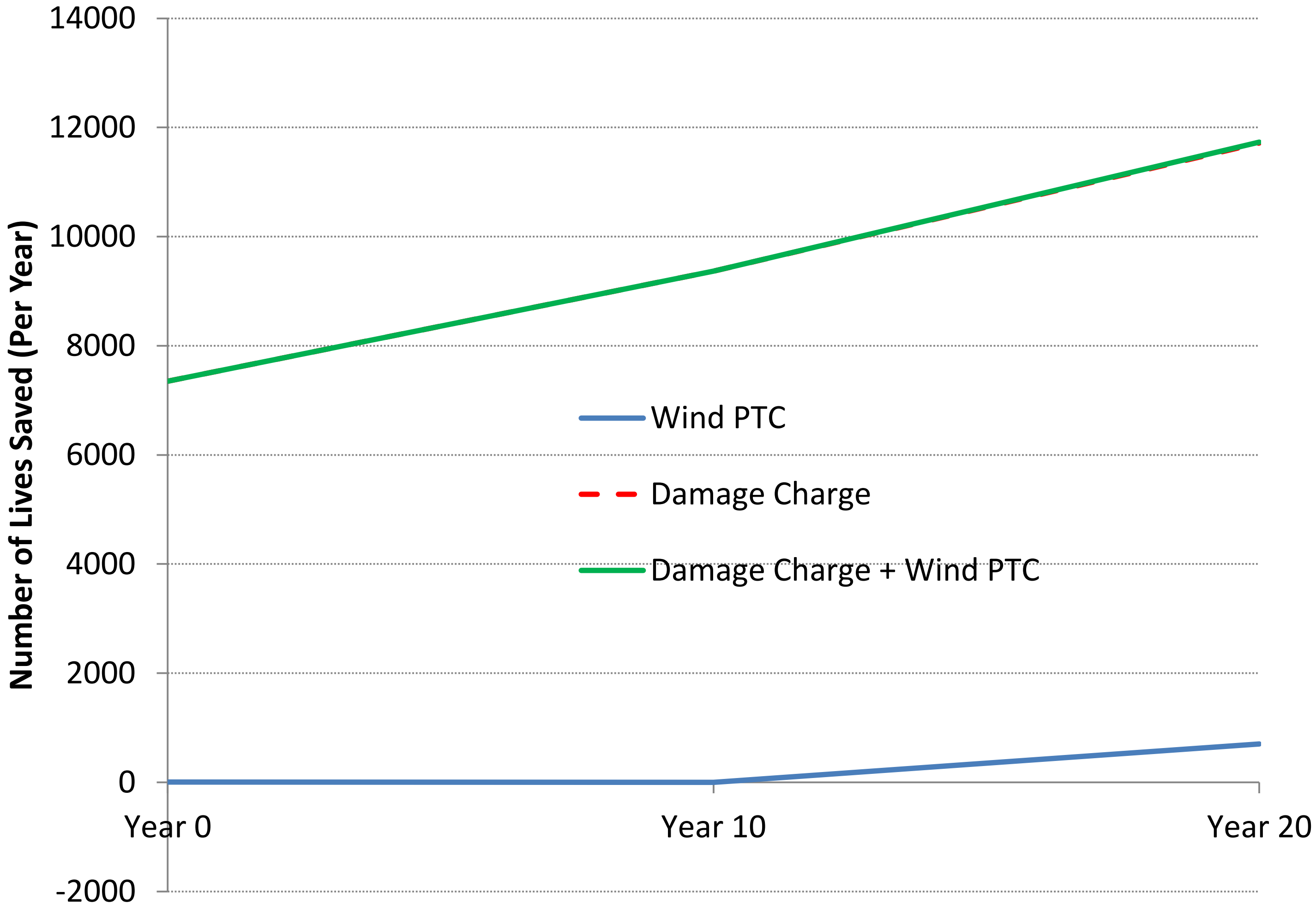
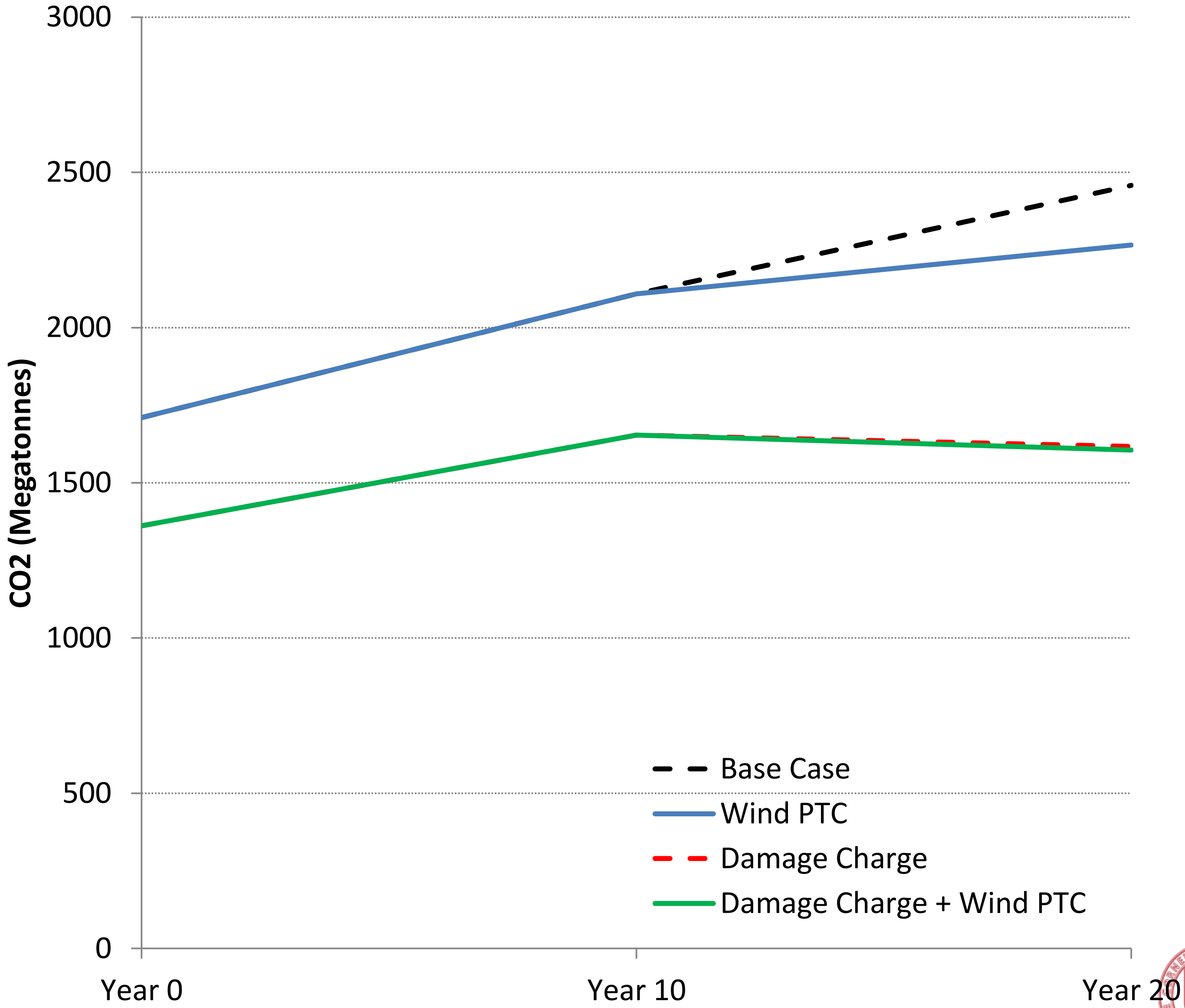
Lives Saved Compred to Base Case



CO_2 Emissions



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Recent and Planned Work

- **“Interactions of Multiple Market-based Energy and Environmental Policies in a Transmission-Constrained Competitive National Electricity Market” PSERC M-24 Sept. 16, 2012**
- **“Mapping Energy Futures Using The SuperOPF Planning Tool: An Integrated Engineering, Economic and Environmental Model” HICSS 2013**
- **“Estimating the Impacts of the Regional Greenhouse Gas Initiative: Does a Detailed Model of the Electricity Grid Matter?” revised for *Resource and Energy Economics***
- **“The Hidden Costs of Energy Revisited: Mitigating the Environmental and Health Effects of the Electric Power System,” in progress**
- **“Do the Environmental Benefits of Renewable Portfolio Standards and Subsidies Justify the Costs?” in progress**
- **“Mapping Energy Futures: The Role of the Electric Power System,” in progress**
- **“Benefits and Costs of Transmission Network Investment,” in progress**

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Additional Planned Work: Transmission Investment

- Look at transmission investment (with Ben Hobbs)
  - Possible study of the proposal in New York State for a new DC line under the Hudson river to connect Hydro Quebec to NYC—$2.2 Billion, 333 miles
  - Optimizing Lines is Complicated by Simultaneous Economic Interaction of Load, Generation, and Transmission
  - Think of a new freeway
    - Business will locate where consumers can now travel more easily to work or shop
    - Consumers will locate homes to be near jobs, shopping, and recreation
    - Resulting congestion will create need for more new roads
- Similarly, new load drives need for new generation that drives new line capacity that allows for more economic growth but also new technology (wind, solar, storage) may drive need for more or less transmission

EPA now uses bubbles and pipes to analyze environmental policies…

President Obama in his speech at Georgetown University on June 25th, 2013 said, "For the sake of our children and the health and safety of all Americans, I'm directing the Environmental Protection Agency to put an end to the limitless dumping of carbon pollution from our power plants and complete new pollution standards for both new and existing power plants,"

Conclusions

- Model Can Estimate Benefits and Costs of Policies, Transmission Lines, and Other Investments
- …Including Environmental Costs, Which are Significant
- Model Can Help Expansion Planning
- Model Can Predict Retirements and Fuel Use
- Transmission System Detail is Necessary for Accurate Modeling
- Importance of Modeling Price Responsiveness of Load
  - Important for Planning and Reliability
  - Reduces Impact of Policies on Prices
  - Increases Impact of Emission Pricing on Emissions
- Charging Each Generator For Damages From Its SO_2 and NO_X
  - Greatly Reduces Both, as Well as CO_2
  - Saves Estimated 12,000 Lives Per Year in Eastern Interconnection