Analysis of Dynamic, Flexible NO_x and SO_2 Abatement from Power Plants in the Eastern U.S. and Texas

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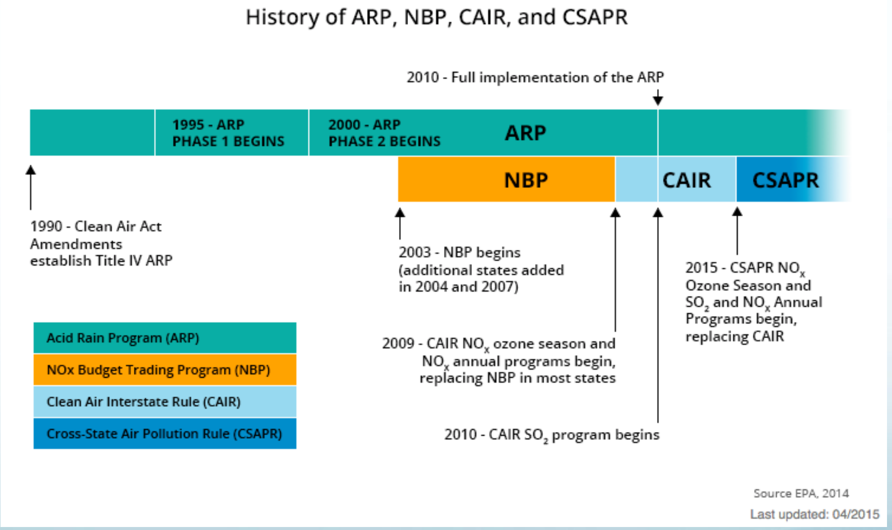
Background

- **Emissions cap and trade programs** have been applied as a federal policy instrument since the early 1990's.
- These programs have demonstrated their flexibility, effectiveness, and economic efficiency.
- Rules for such programs have been designed for **annual or seasonal emissions reductions**.
  - Previous studies have demonstrated that NO_x emissions have **variable damages** depending on where and when they occur during the summer ozone season.*



Source: http://www3.epa.gov/airmarkets/progress/reports/program_basics_figures.html

**Mauzerall et al. (2005); Muller (2011); Levy et al. (2009); Tong et al. (2006)*

Research Contributions

- **Develop methods** to evaluate the emissions and air quality effects and cost-effectiveness of **time-differentiated pricing** of **NO_x** and **SO_2 emissions** from power plants.

- **Compare** time-differentiated, season-wide, and combined **policies.**

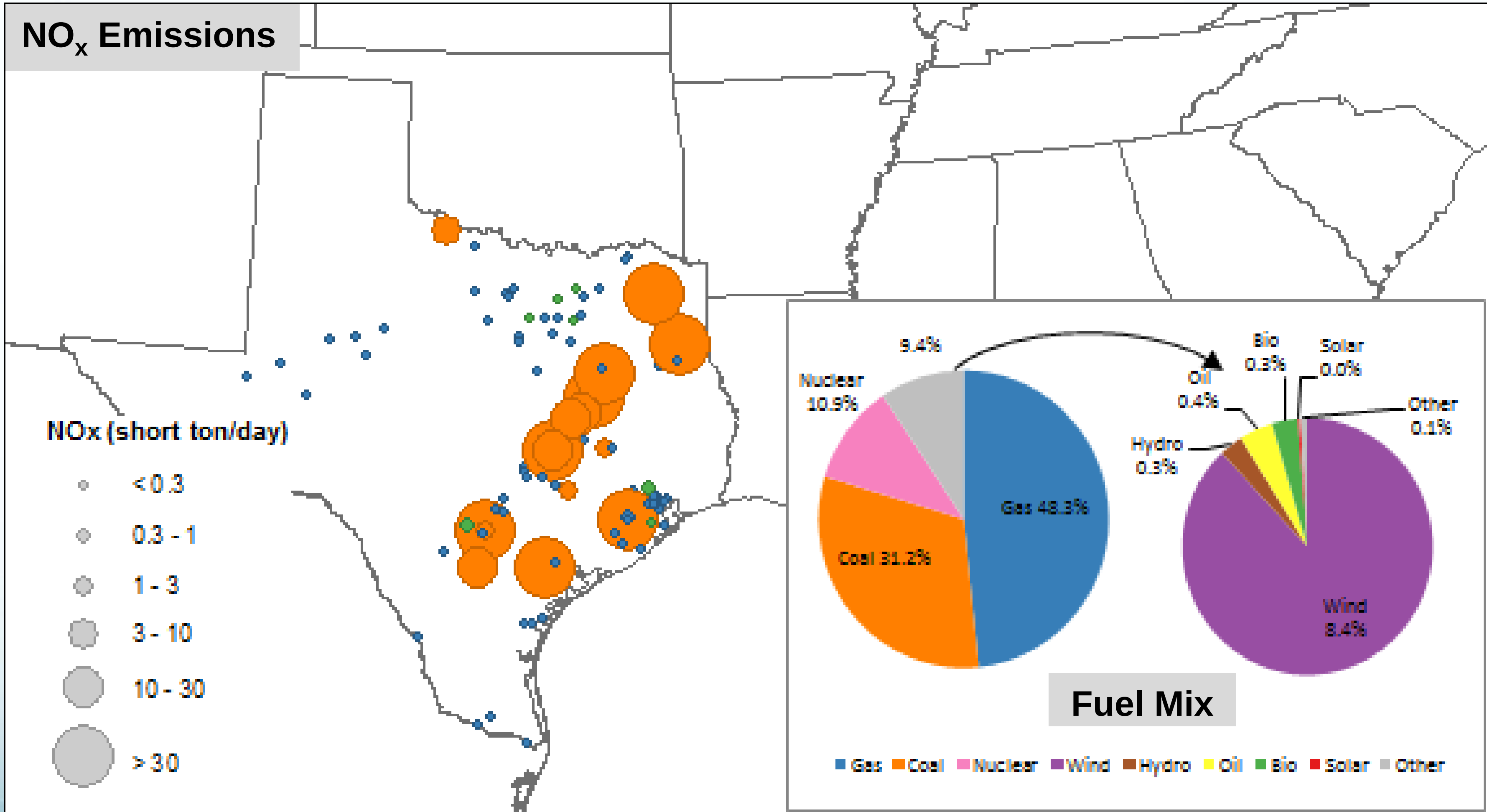
- Consider **realistic constraints** on power plants and **endogenous technology adoption**.

- Demonstrate **implication**s for predicted **regional ozone** and **fine particulate matte**r concentrations.

- Investigated opportunities for joint abatement of NO_x and SO_2 emissions through **single pollutant** or **multipollutant time-differentiated price signals**.

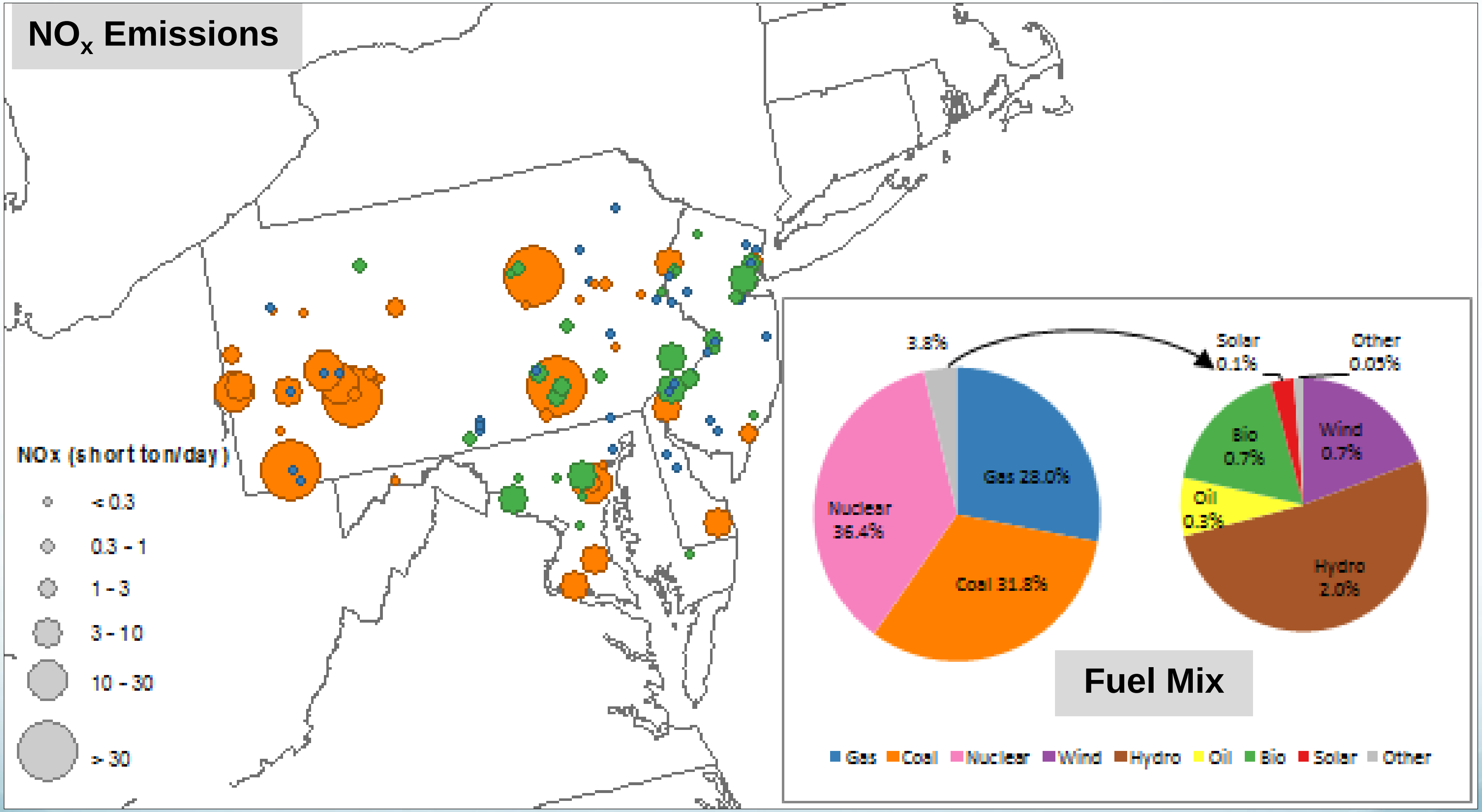
- Evaluated **spatial differentiation** of time-differentiated NO_x pricing signals for ozone nonattainment areas.

ERCOT Power System: NO_x Emissions and Generation Fuel Mix



Source: Demand & Energy Report (http://www.ercot.com/ content/news/presentations/2013/ERCOT2012D&E-full.xls)

Mid-Atlantic or Classic PJM Power System: NO_x Emissions and Generation Fuel Mix



Source: "Operational Analysis: Capacity by Fuel Type 2012", retrieved April 23, 2014 from http://pjm.com/~/media/markets-ops ops-analysis/capacity-by-fuel-type-2012.ashx.

Integrated Power System and Air Quality Modeling

Control Technology Investment at Nash Equilibrium with Unit Commitment (CONTINU) Model

- Developed to investigate **generator responses** to policies and effects on **emissions** and **producer costs** using 2012 representations of the ERCOT and Mid-Atlantic PJM grids.
- **Realistic operational constraints** (ramping limits, minimum load, minimum uptime and downtime).
- **Endogenous dispatching** and **control technology** (SCR and/or FGD) **adoption** decisions.
- **Open-loop Nash equilibrium** approach allows individual generators to evaluate their decisions based on those of all others in the system.

Air Quality Model

- Updates were made to a 2005 annual **CAMx** configuration developed to support EPA's assessments for the Transport Rule and CSAPR.
- Anthropogenic emissions replaced with those from CONTINU for affected power generation sources and with the 2011v6 inventory from the EPA and LADCO for all other sources.

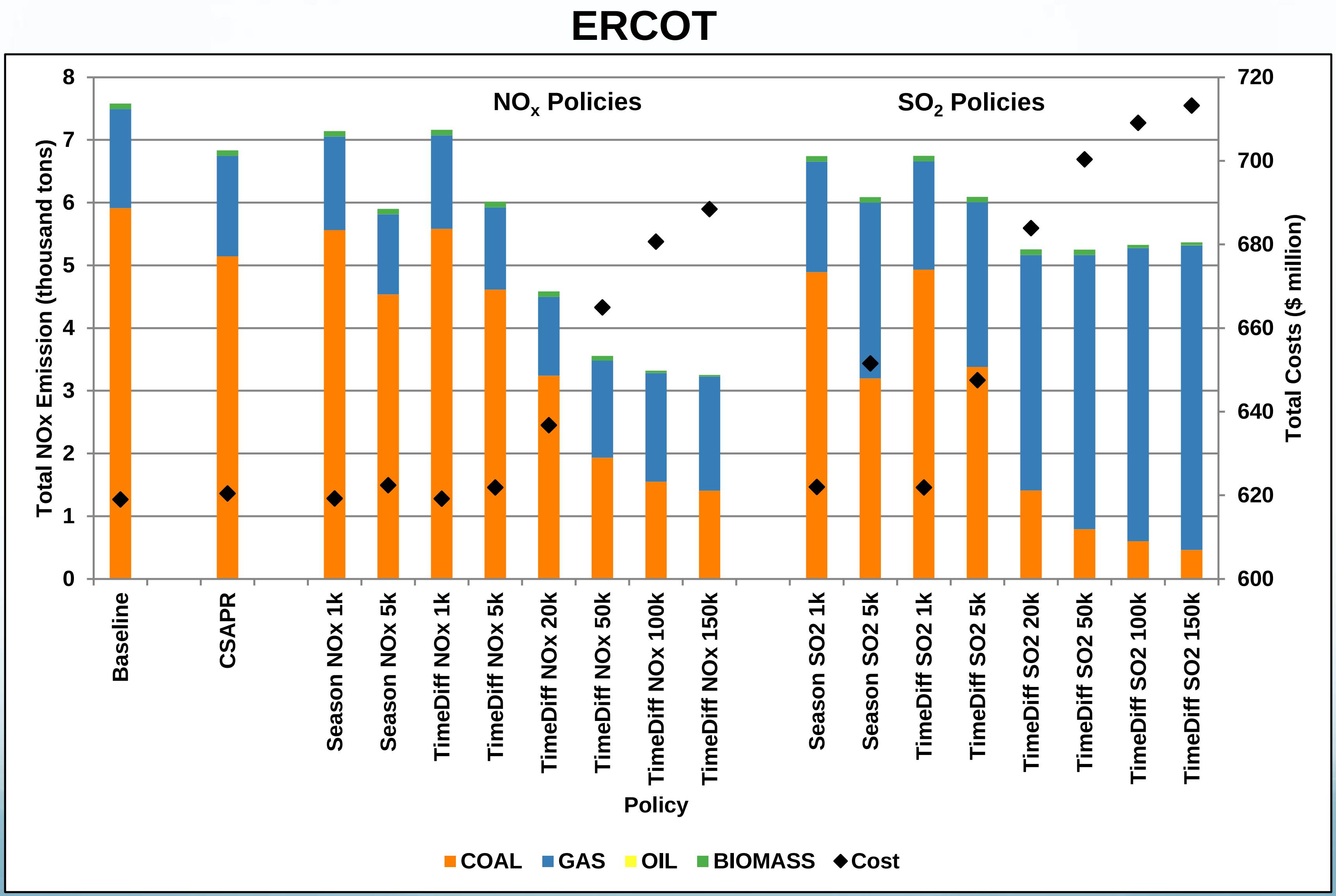
Time-Differentiated and Season-wide Policies

Policy	NO_x Price ($/ton)	SO_2 Price ($/ton)	Notes
Baseline	20	1.50	2011 Allowance Prices; Applied Daily
CSAPR	500	500	Applied Daily
Season-wide NO_x			
1K	1,000	1.50	Applied Daily
5K	5,000	1.50	Applied Daily
Season-wide SO_2			
1K	20	1,000	Applied Daily
5K	20	5,000	Applied Daily
Time-Differentiated NO_x			
1K	1,000	1.50	High Ozone Days
5K	2,000	1.50	High Ozone Days
20K	20,000	1.50	High Ozone Days
50K	50,000	1.50	High Ozone Days
100K	100,000	1.50	High Ozone Days
150K	150,000	1.50	High Ozone Days
Time-Differentiated SO_2			
1K	20	1,000	High Ozone Days
5K	20	5,000	High Ozone Days
20K	20	20,000	High Ozone Days
50K	20	50,000	High Ozone Days
100K	20	100,000	High Ozone Days
150K	20	150,000	High Ozone Days

Layered Policies

Policy	NO_x Price ($/ton)	SO_2 Price ($/ton)	Notes
Layered Policies			
CSAPR + 5K Time-Differentiated NO_x	500 (CSAPR); 5,000 (Time-Differentiated)	500 (CSAPR)	CSAPR Price Applied Daily; Time-Differentiated Price Layered Only on High Ozone Days
CSAPR + 5K Time-Differentiated SO_2	500 (CSAPR)	500 (CSAPR); 5,000 (Time-Differentiated)	CSAPR Price Applied Daily; Time-Differentiated Price Layered Only on High Ozone Days
CSAPR + 5K Time-Differentiated NO_x and SO_2	500 (CSAPR); 5,000 (Time-Differentiated)	500 (CSAPR); 5,000 (Time-Differentiated)	CSAPR Price Applied Daily; Time-Differentiated Price Layered Only on High Ozone Days

Total System-wide Emissions (column) by Fuel Type and Production Costs (diamond) on High Ozone Days



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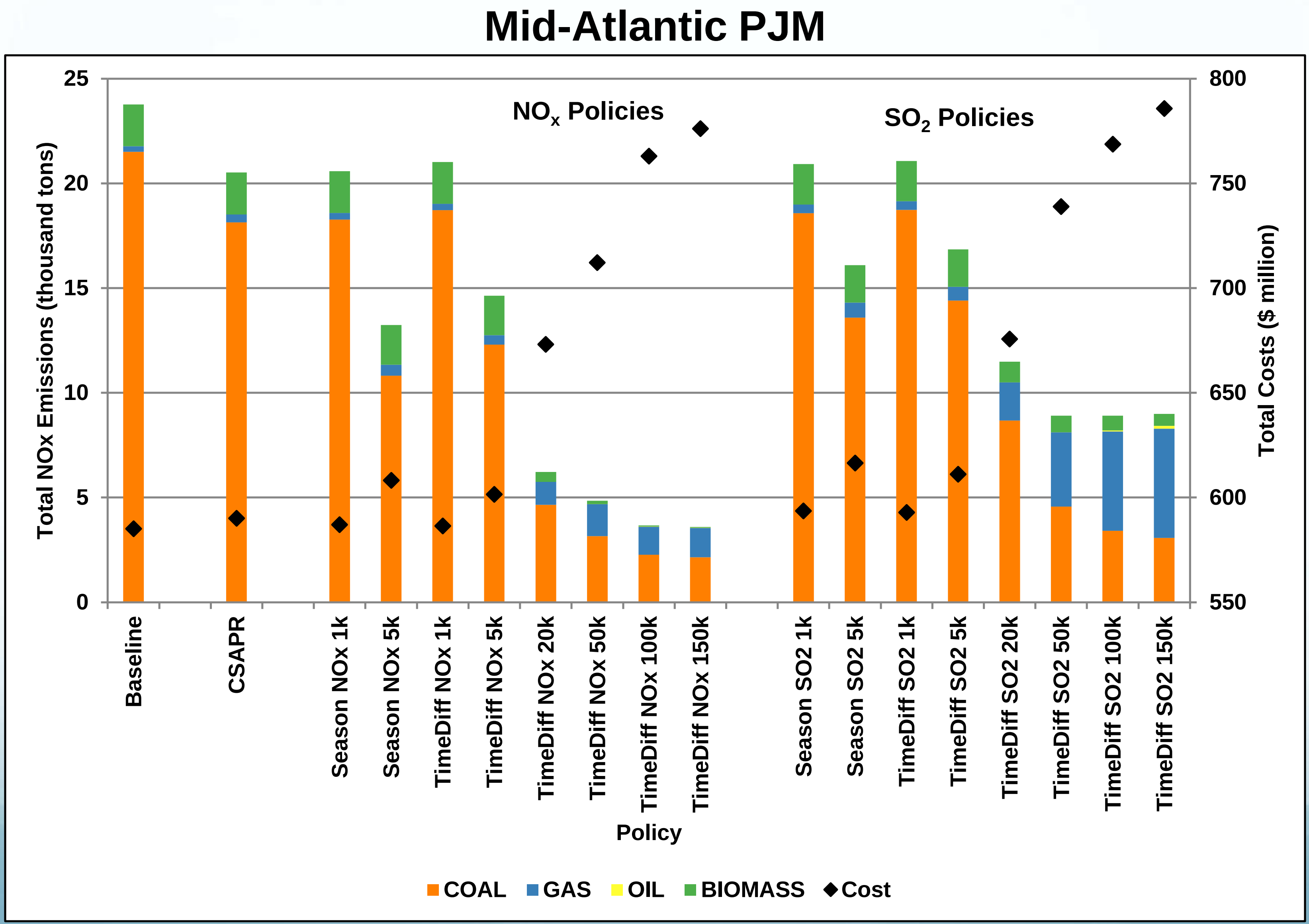
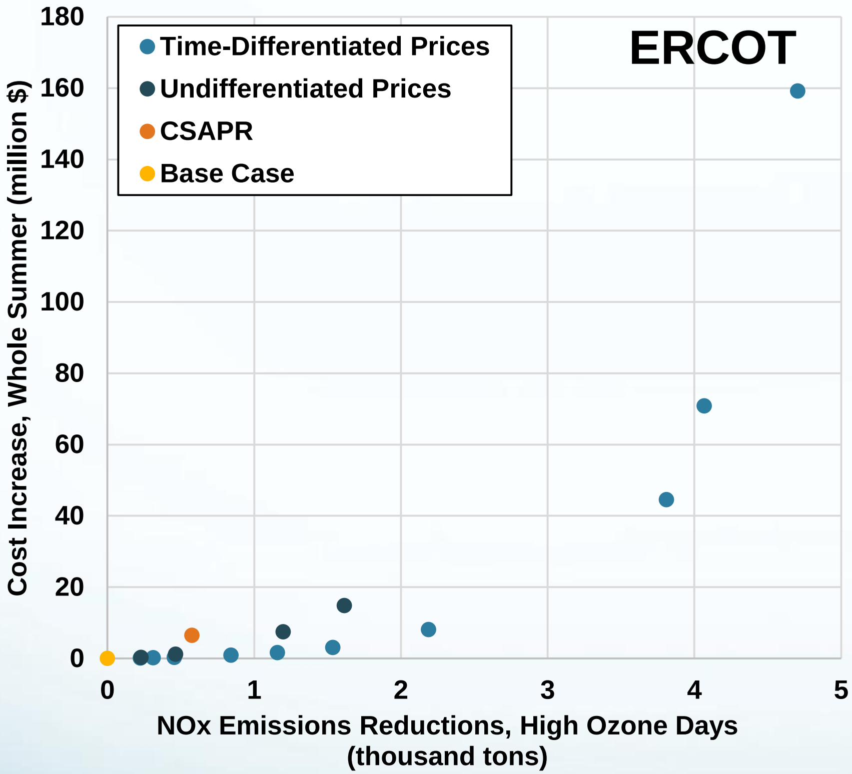
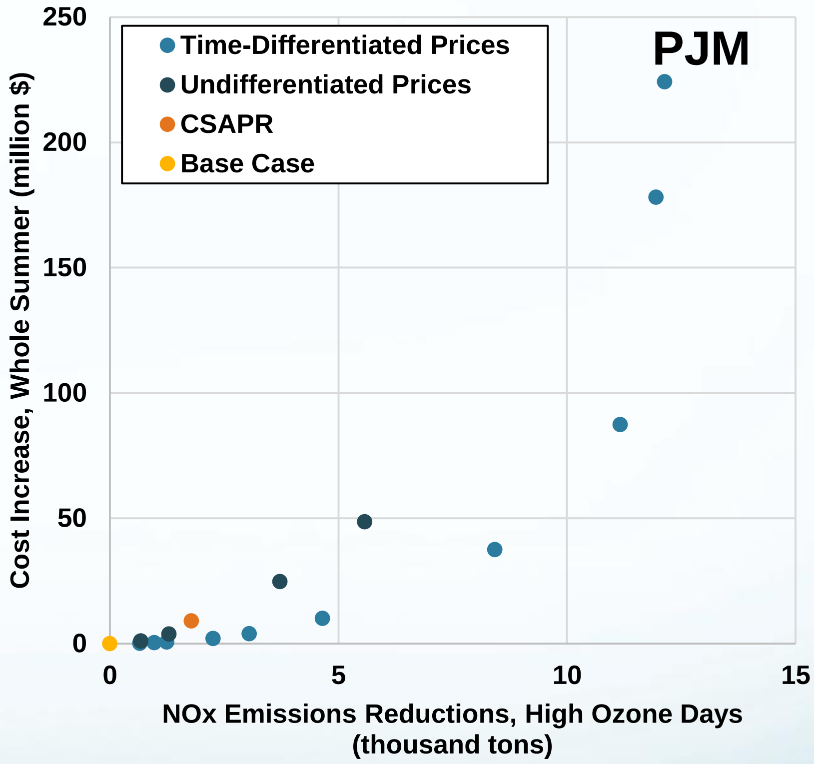
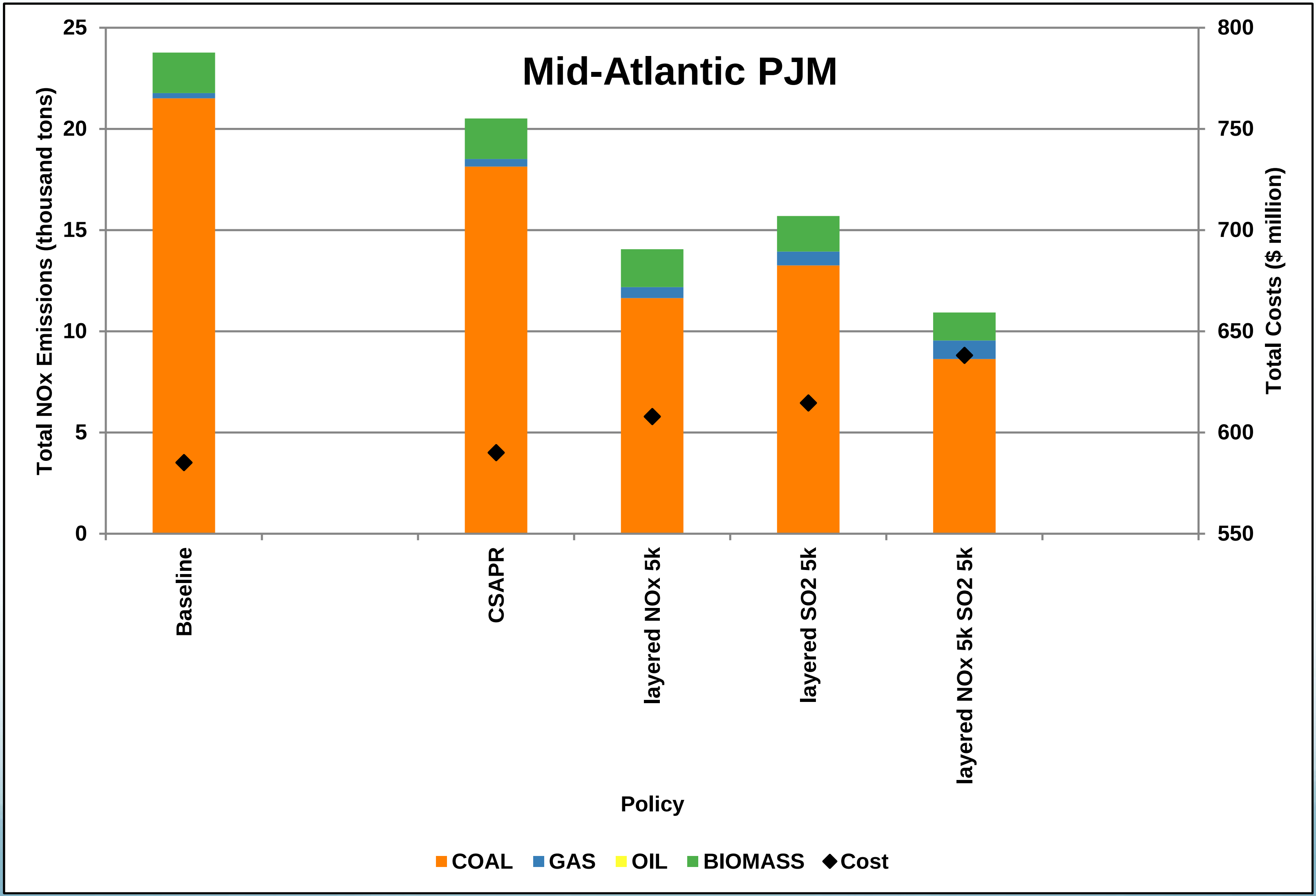


Cost and Emissions Tradeoffs

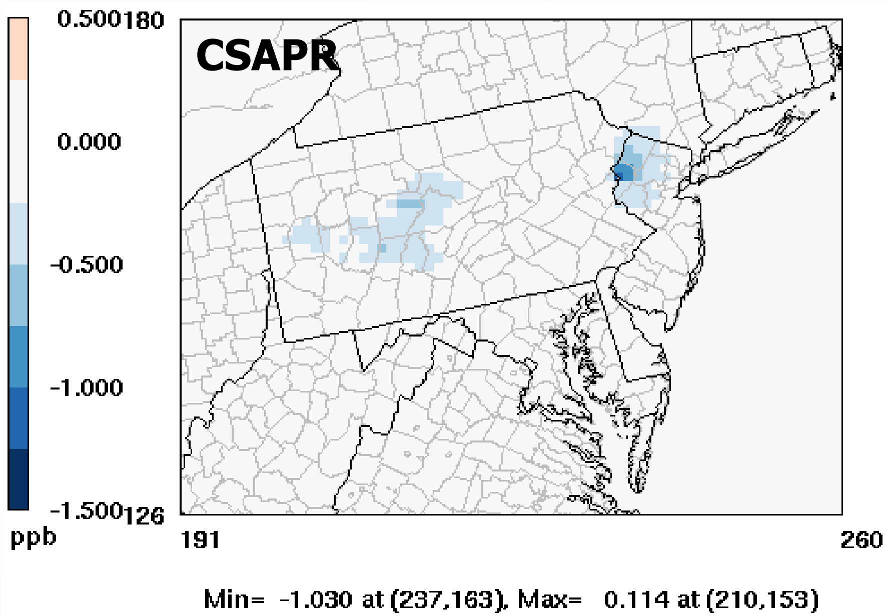


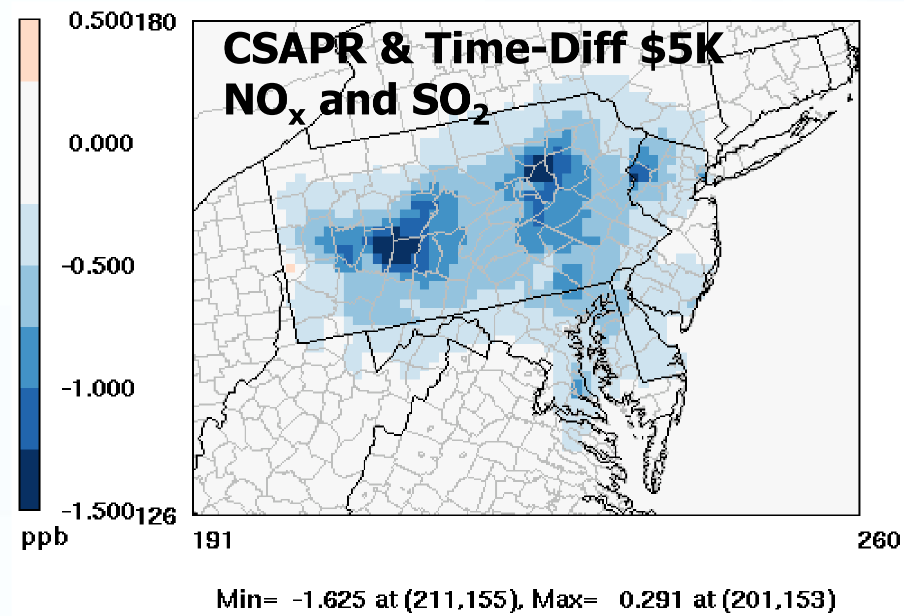


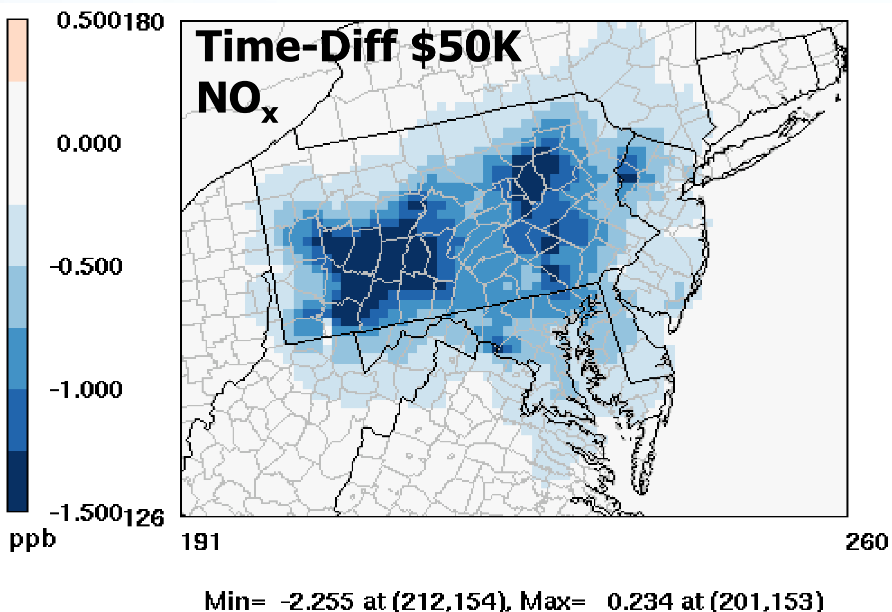
Emissions and Production Costs: Layered Single- or Joint-Pollutant Pricing Policies



Regional Mean Differences in MDA8 Ozone on High Ozone Days in the Mid-Atlantic PJM System



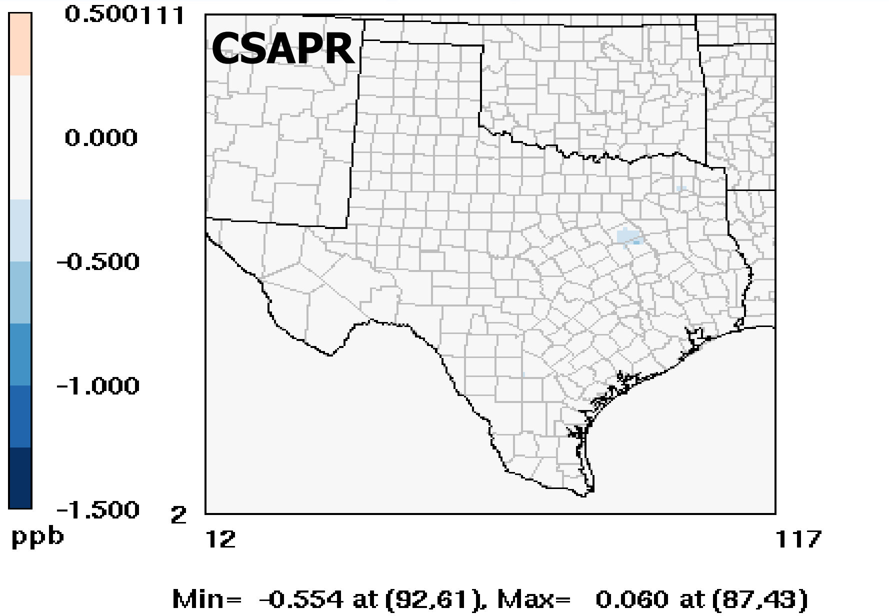


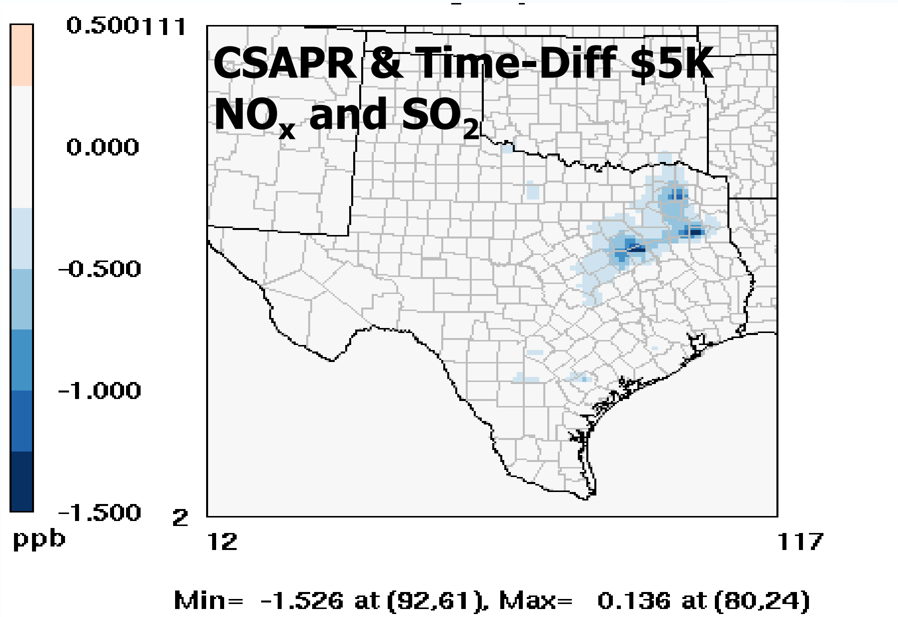


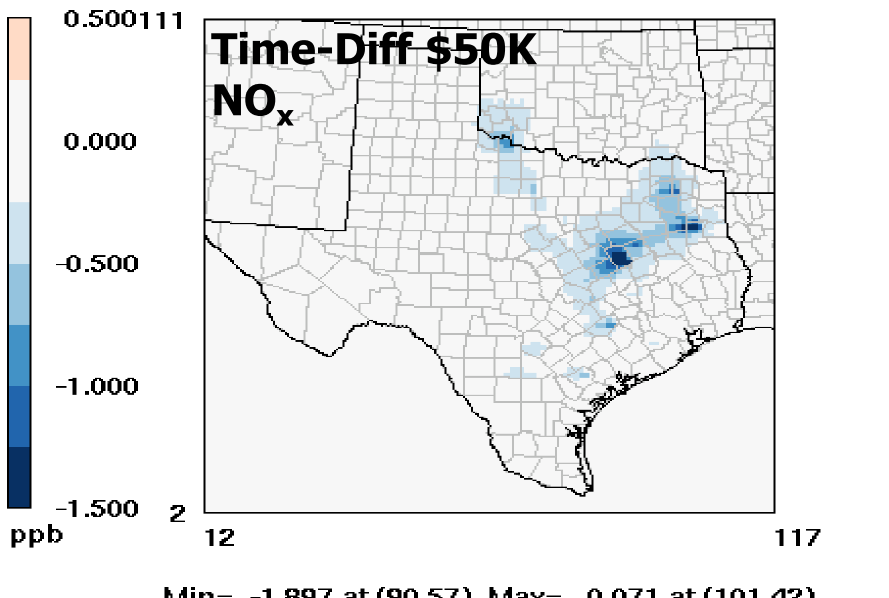
Time-differentiated pricing of NO_x and/or SO_2 produced **widespread ozone reductions**, especially in Pennsylvania.

Reductions (> 0.5 ppb) on most of the 51 high ozone days at higher price signals.

Regional Mean Differences in MDA8 Ozone on High Ozone Days in the ERCOT System







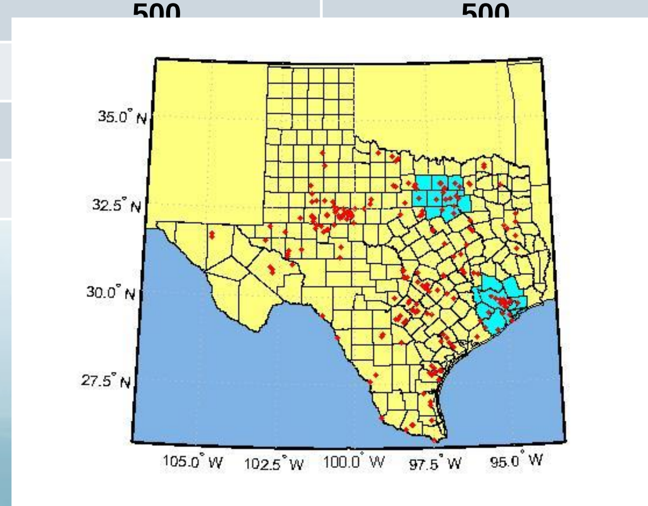
Benefits of time-differentiated pricing were primarily due to reductions in coal-fired generation in northeastern Texas.

Generation shifts to other areas where natural gas predominates as fuel.

Time- and Spatial-Differentiation

- What if we also differentiate **where** the emissions occur?
- Example: On high ozone days, make the price even higher for sources in non-attainment regions than in attainment regions

Scenario	Price of NOx ($ per ton)			
	Normal Summer Day		High Ozone Day	
	Attainment	Nonattainment	Attainment	Nonattainment
CSAPR	500	500	500	500
Time: $5,000	500	500	5,000	5,000
Time/Space: $5,000;$10,000	500	500	5,000	10,000
Time/Space: $5,000;$15,000	500	500	5,000	15,000
Time/Space: $5,000;$25,000	500	500	5,000	25,000
Time/Space: $5,000;$35,000	500	500	5,000	35,000
Time/Space: $5,000;$55,000	500	500	5,000	55,000
Time/Space: $5,000;$75,000	[illegible]	[illegible]	5,000	75,000
Time/Space: $5,000;$105,000	[illegible]	[illegible]	5,000	105,000
Time/Space: $5,000;$155,000	[illegible]	[illegible]	5,000	155,000



Results with Spatial-Differentiation of NO_x Emissions Pricing

(Relative to CSAPR)

Emissions

- Decrease in nonattainment
- Decrease in system-wide
- Small increase in attainment

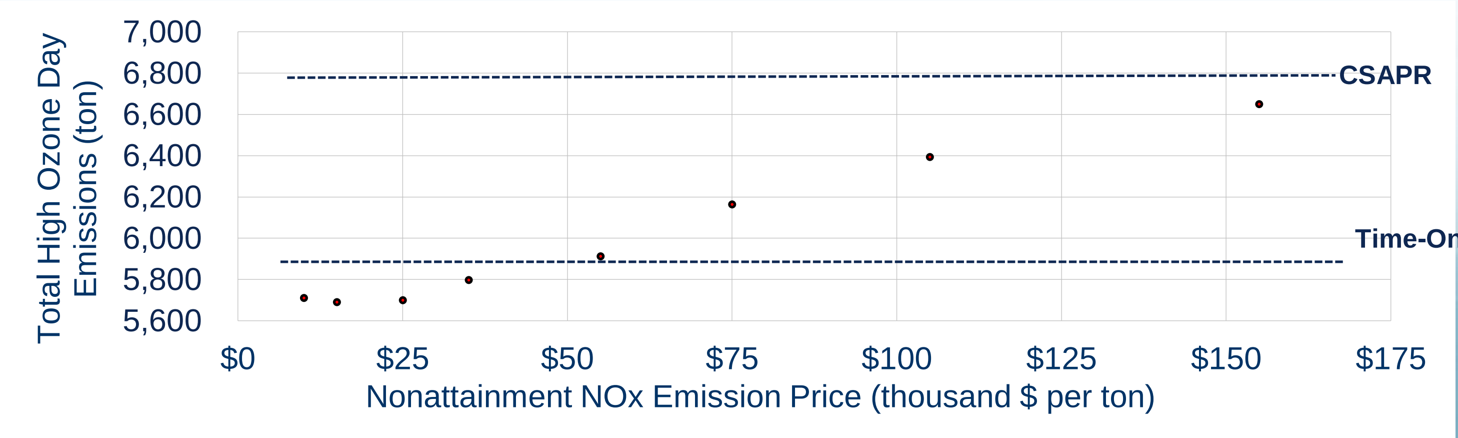
- Small decrease in nonattainment
- Large increase in system-wide
- Large increase in attainment

Small Price Differential → **Large Price Differential**

Generation

- Increase in shift to lower emitting within each region (i.e. coal to gas)
- Low shift between regions

- Large shift from low emitting in nonattainment (gas) to high emitting in attainment (coal)



Implications

- Policy goals must be carefully considered
  - Time-differentiated pricing is more cost-effective if the goal is reductions specifically on days conducive to high pollution levels.
  - Season-wide and time-differentiated policies can be complementary, especially for a coal-dominated system (Mid-Atlantic PJM).
  - Implement using higher redemption ratio for emission permits or entirely separate programs.
  - Spatial differentiation can reduce emissions in targeted areas but the design details are critical.
- Co-benefits of $PM_{2.5}$ reductions, but may require distinct time differentiation to fully address peak concentrations.

Regional mean differences in 24-hour average $PM_{2.5}$ concentrations on high ozone days