

AN ENGINEERING AND ECONOMIC EVALUATION OF THE IMPACT OF CAP-AND-TRADE FOR CO₂ ON ELECTRIC POWER

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PSERC Tele-Seminar, Dec. 1, 2009

This research has been funded through two projects also involving the researchers listed below:

PSERC--Facilitating Environmental Initiatives While Maintaining Efficient Markets and Electric System Reliability

DOE-CERTS--Integrating Operational Reliability and Planning: The Effects of Regulatory Constraints on Reliability and the Impact of Environmental Regulation

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The Issues

- The electric power industry faces the possibility of
 - Increased loads from plug-in hybrids
 - Increased loads from other energy users trying to find less CO₂ emitting sources of energy
 - The possibility of ever more restrictive caps on CO₂ emissions from generation
 - The possibility of tighter standards on NO_x and SO₂ emissions to reduce ozone and fine particulates (some controversial studies suggest that 20,000-30,000 deaths occur each year in the US from fine particulates from power plant emissions.
 - An artificial \$1000 cap on offer prices in electricity markets that prevents a free market solution for optimal investment.
- These factors combine to create a potentially difficult situation. We first examine the problem by taking the 2007 Northeast Power System and stress testing its response to a range of emission prices for CO₂ (as well as NO_x, and SO₂) for both the Regional Greenhouse Gas Initiative and the proposed national program.

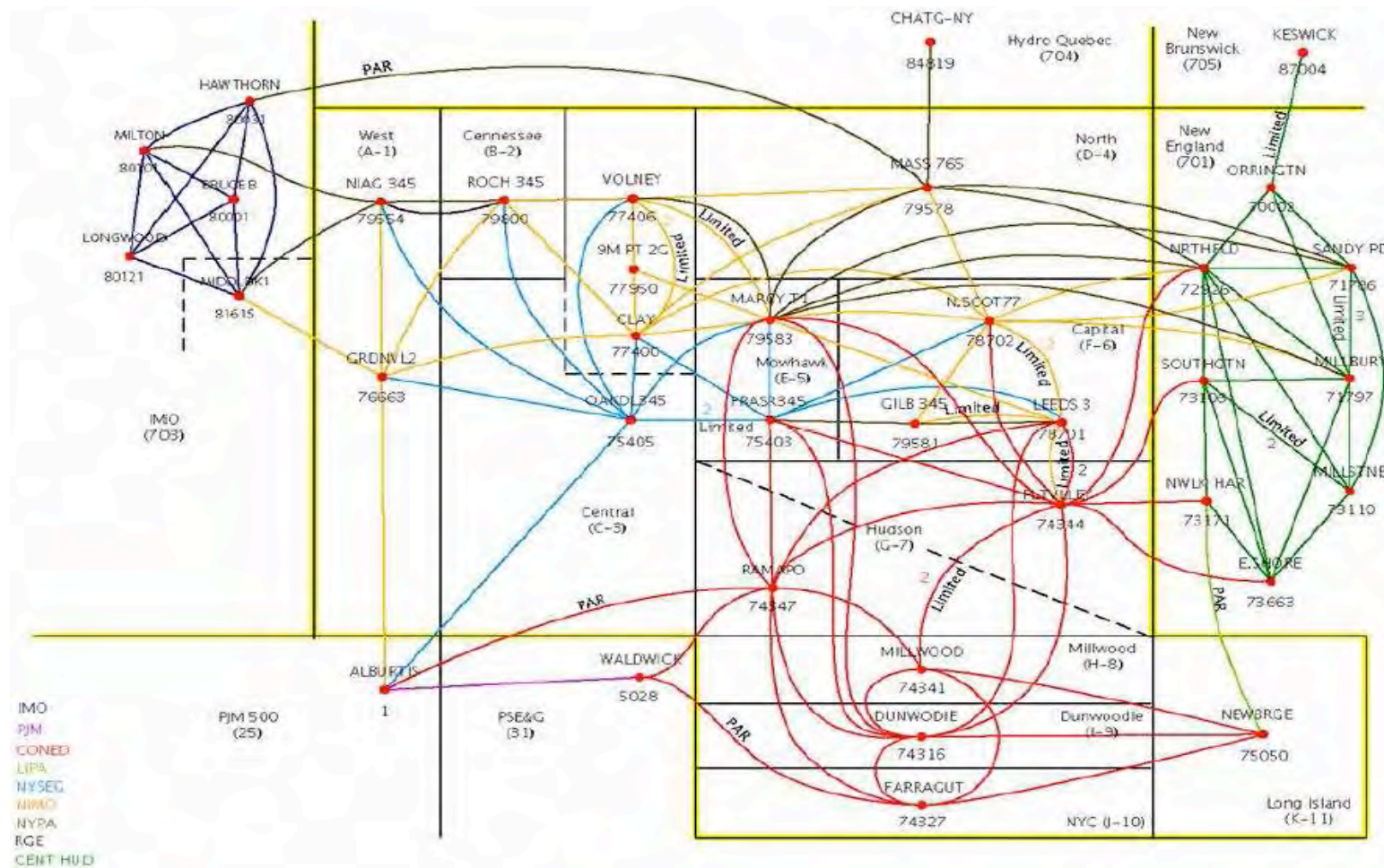


Overview

1. Model
2. AC versus DC versus “unconstrained” versions
3. CO2 policy questions
4. SO2 and NOX policy questions
5. Modeling demand response
6. Conclusions
7. Future research



Model of the Northeast Network



Eric Allen, Jeffrey Lang, and Marija Ilic, "A Combined Equivalenced-Electric, Economic & Market Representation of the Northeastern Power Coordinating Council (NPCC) US Electric Power System," IEEE Transactions on Power Systems, Vol. 3, Issue 3, 2008



AC model

The optimization problem can be expressed as follows:

$$\min_{x,y,z} \sum_i (f_{1i}(P_{gi}) + f_{2i}(Q_{gi}))$$

subject to

$$g_P(x) = P(\theta, V) - P_g + P_d = 0 \quad (\text{active power balance equations})$$

$$g_Q(x) = Q(\theta, V) - Q_g + Q_d = 0 \quad (\text{reactive power balance equations})$$

$$g_{S_f}(x) = |S_f(\theta, V)| - S_{\max} \leq 0 \quad (\text{apparent power flow limit of lines, } \textit{from} \text{ end})$$

$$g_{S_t}(x) = |S_t(\theta, V)| - S_{\max} \leq 0 \quad (\text{apparent power flow limit of lines, } \textit{to} \text{ end})$$

$$l \leq A \begin{bmatrix} x \\ z \end{bmatrix} \leq u \quad (\text{general linear constraints})$$

$$x_{\min} \leq x \leq x_{\max} \quad (\text{voltage and generation variable limits})$$

$$z_{\min} \leq z \leq z_{\max} \quad (\text{limits on user defined variables})$$

DC and “Unconstrained” Models

DC modeling

- No voltage or stability constraints
- Linear power flow approximations
- Lossless transmission lines

Unconstrained

- No constraints whatsoever on transmission
- Lossless transmission lines



Model Inputs

- Gen unit data: Energy Visuals; EPA; and Allen, Lang, and Ilic data sets matched up
- Sixteen hour types represent the year. Vary in terms of unit availability (from NERC) and load (from all ISOs).
- No demand response assumed.
- *To start we are stress-testing the 2007 system and using it for policy analysis.*



Seasonal Availability for Coal Units

- Many generation units have minimum outputs when they are on.
- Coal-fired units typically remain on because restarting is slow and costly.
- We have each coal-fired unit on or off for whole season.
- Procedure:
 1. Start with all coal units on
 2. Simulate season
 3. Remove the least profitable unit
 4. Repeat from 2 until
 - a. The time-weighted mean objective function increases or
 - b. Meeting load is infeasible in at least one of the representative hours.



Incentive-Based CO₂ Regulations: Some Upcoming Policy Decisions

- Same or different policy stringency across parts of same grid? (we consider US, “RGGI” region, and Canada)--leakage
- Exempt some generation units? (in US, customary to exempt units < 25 MW)
- Emission Tax, Cap and Trade, or Cap and Trade with Price Floor and/or Ceiling?
- What to do about interacting CO₂, SO₂, and NO_x cap-and-trade programs?



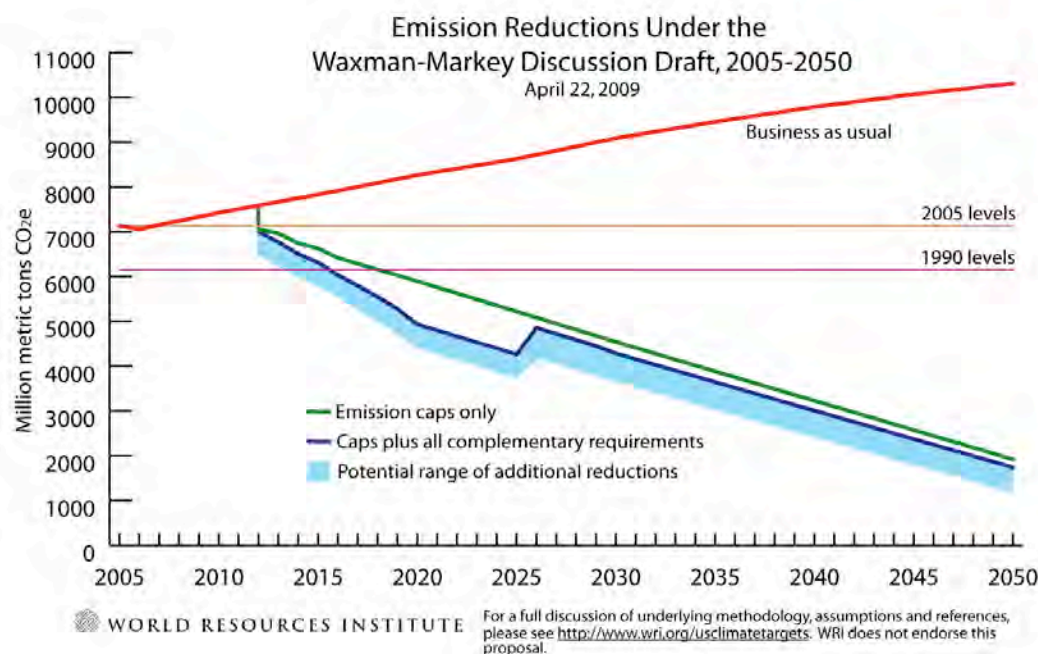
Regional Greenhouse Gas Initiative

- 10 States
- Canada, Ohio, Pennsylvania, and West Virginia are not included so concerns over leakage.
- Cap-and-trade reduces power sector emissions of CO₂ by 10% between 2009 and 2018. 2009-2014 capped at 2009 levels.
- The first three quarterly auctions have been completed.



Proposed National Legislation: American Clean Energy and Security Act of 2009

- Proposed cap-and-trade auction for CO₂ starts in 2012.
- 1% reduction in 2012, compared to 2005, rises to 17% in 2020, 36% in 2030, 55% in 2040 and 73% in 2050.
- Initially supercedes regional programs but will allow regional allowances to be traded for Federal allowances.





Prices of CO₂, SO₂, and NO_x **PSERC**

- Wide range of prices chosen to cover movement in prices over time
- RGGI at \$3.36 on CCFE (20 May 2009)
 - \$3.51 is the last RGGI auction price (17 March 2009)
- 2009 EPA SO₂ auction cleared at \$62
 - \$380.01 in 2008, \$860.07 in 2006
- \$1,230 current NO_x price
 - Peaked at \$5,851 on 2 January 2009, but usually about \$2,500

CO ₂	0	3.51	10	25	50	100	175	250
SO ₂	0	50	100	250	500	750	1,000	2,000
NO _x	0	250	500	1,000	2,000	3,000	4,000	5,000

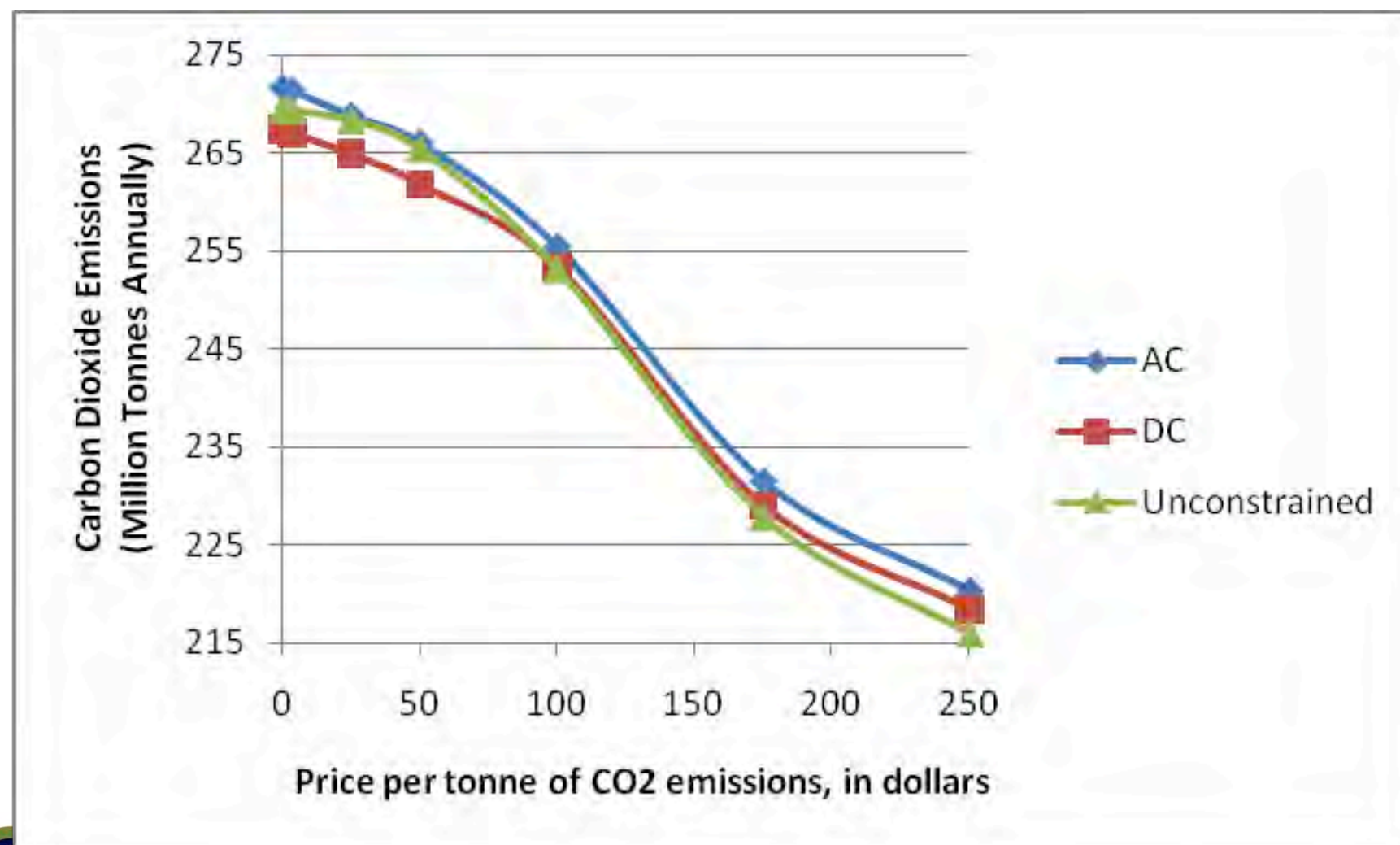


Emissions Costs

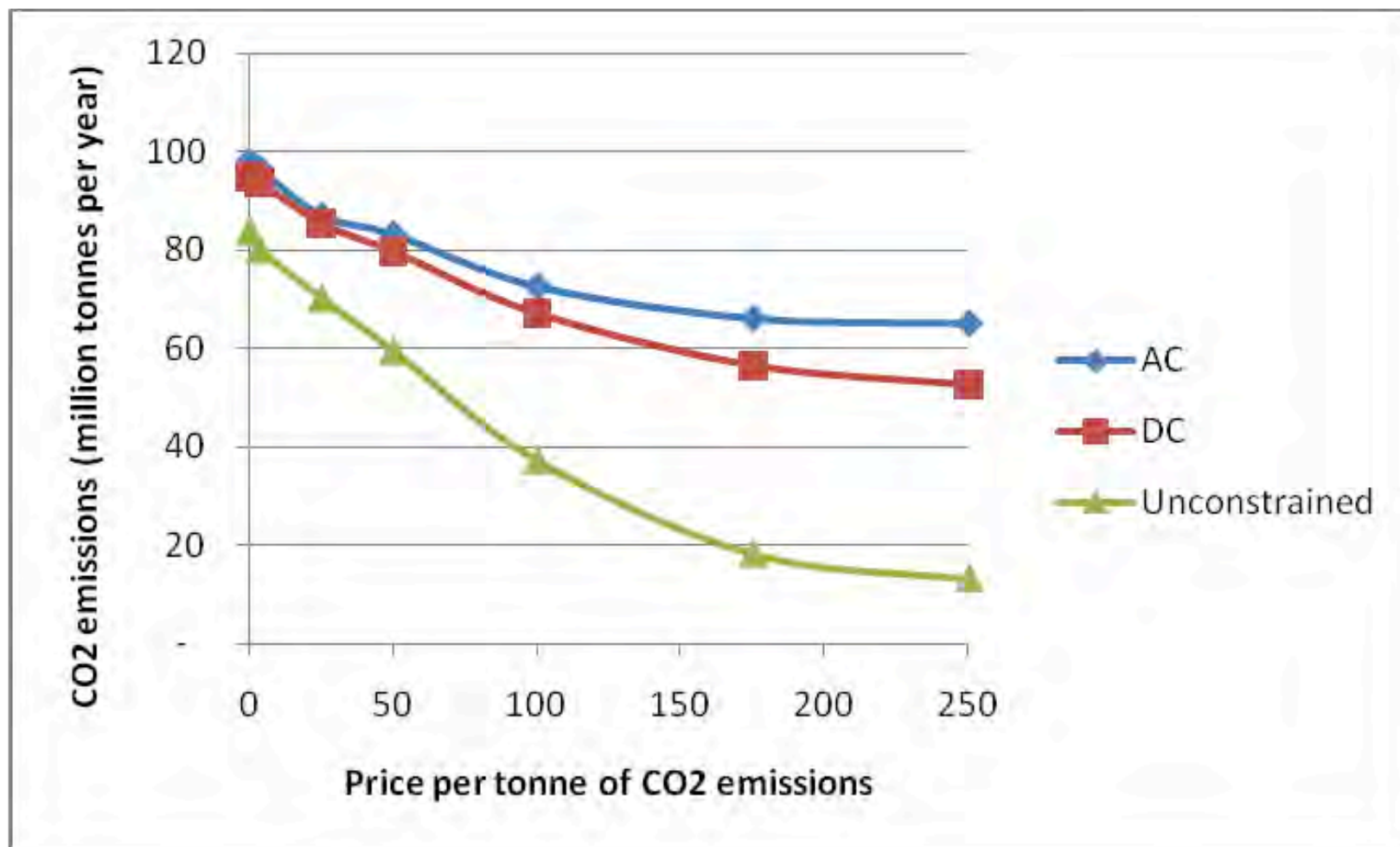
- For the national program apply all emissions costs to all generators
- For regional programs leakage is a concern
 - Apply CO₂ costs only to generators in RGGI
 - One of the buses includes generators from both inside (NJ, MD and DE) and outside (PA and DC) RGGI.
 - To maintain flow constraints the entire bus is considered outside of RGGI



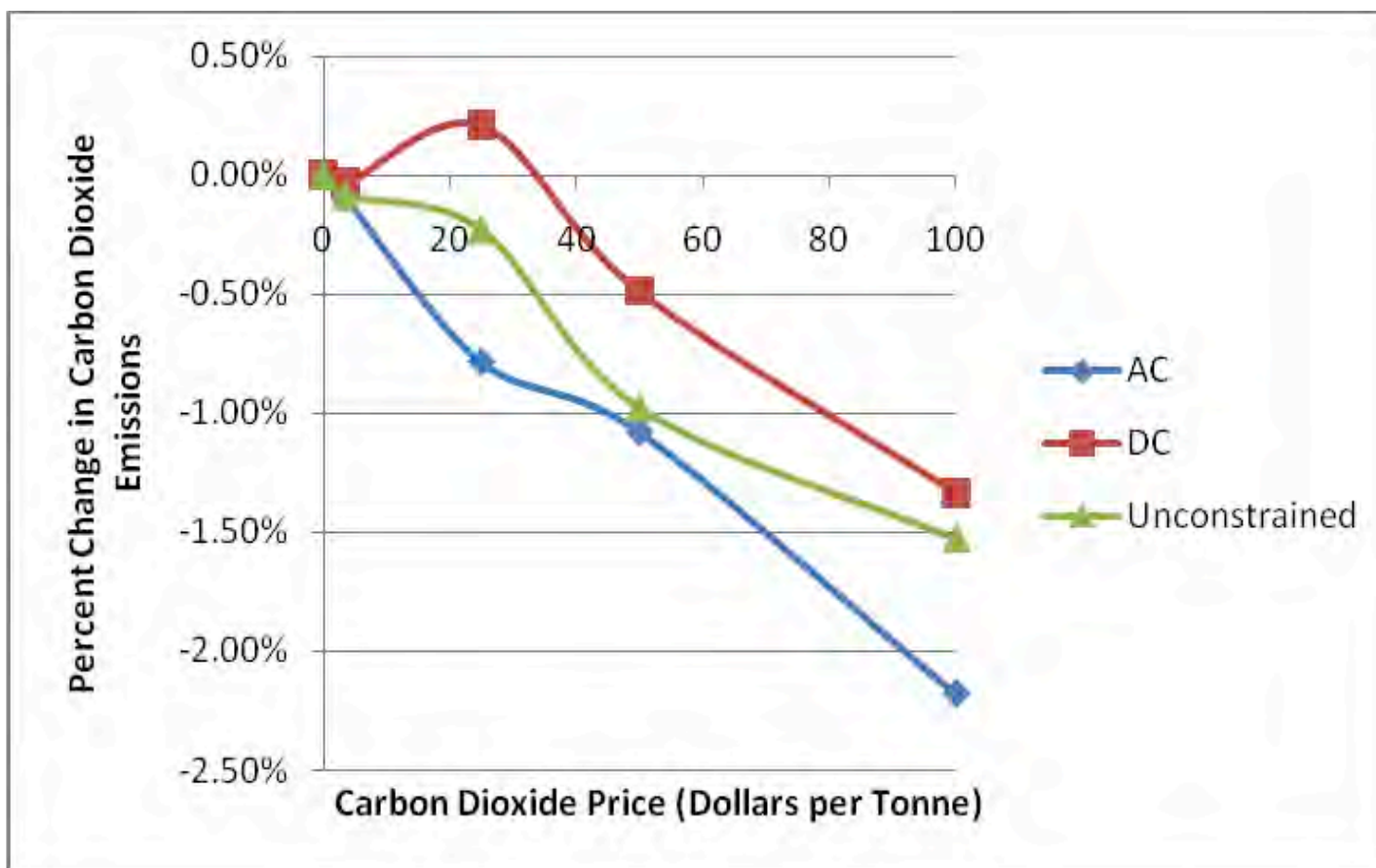
AC vs DC vs Unconstrained: Demand for CO₂ Permits in Entire Northeast Region



AC vs DC vs Unconstrained: Emissions in RGGI States Under RGGI



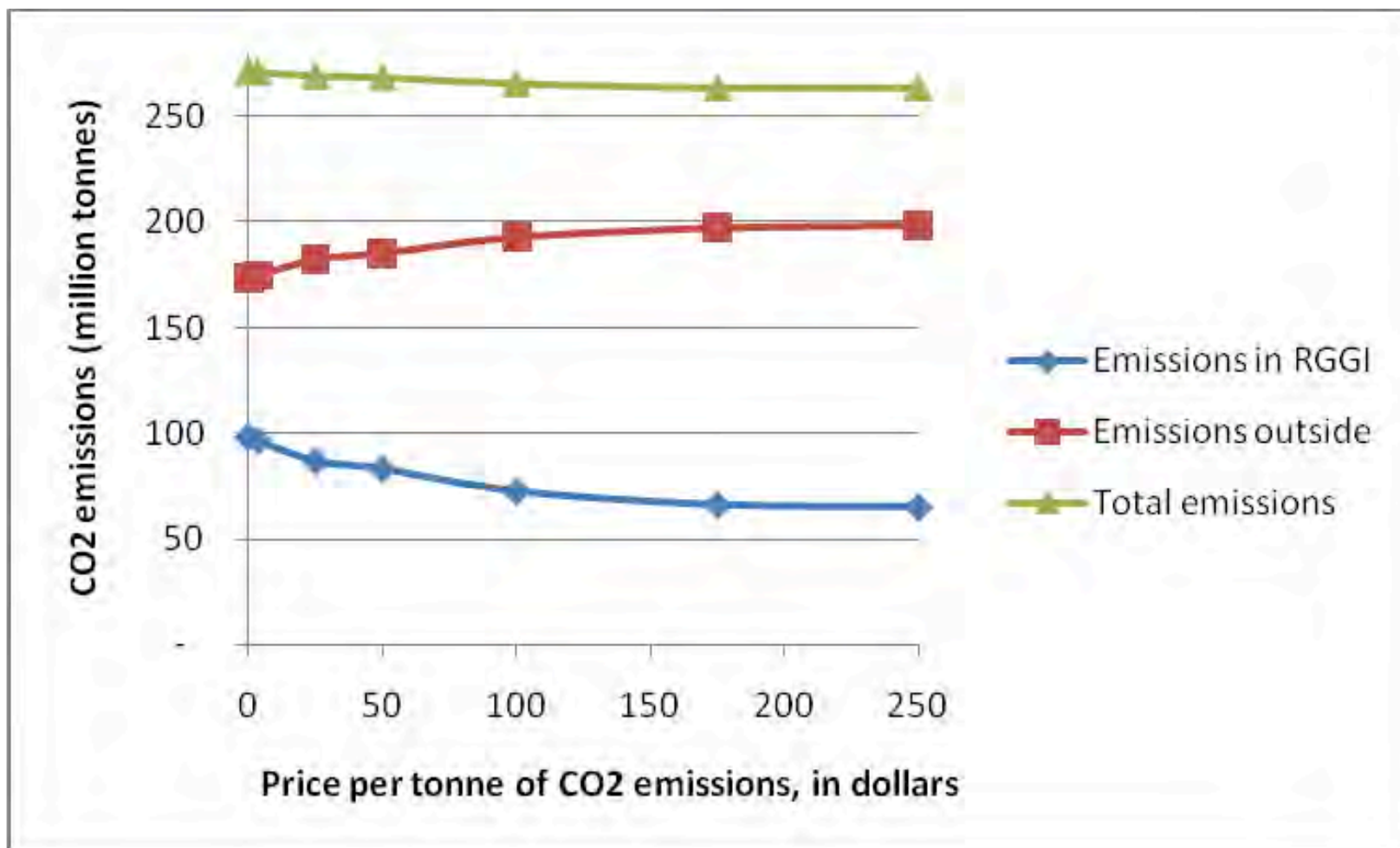
AC vs DC vs Unconstrained: Systemwide Emissions Under RGGI Emission Price Range of \$0 to \$100



Modeling approach appears to matter more for policies that involve the potential for high flows from one region to another.



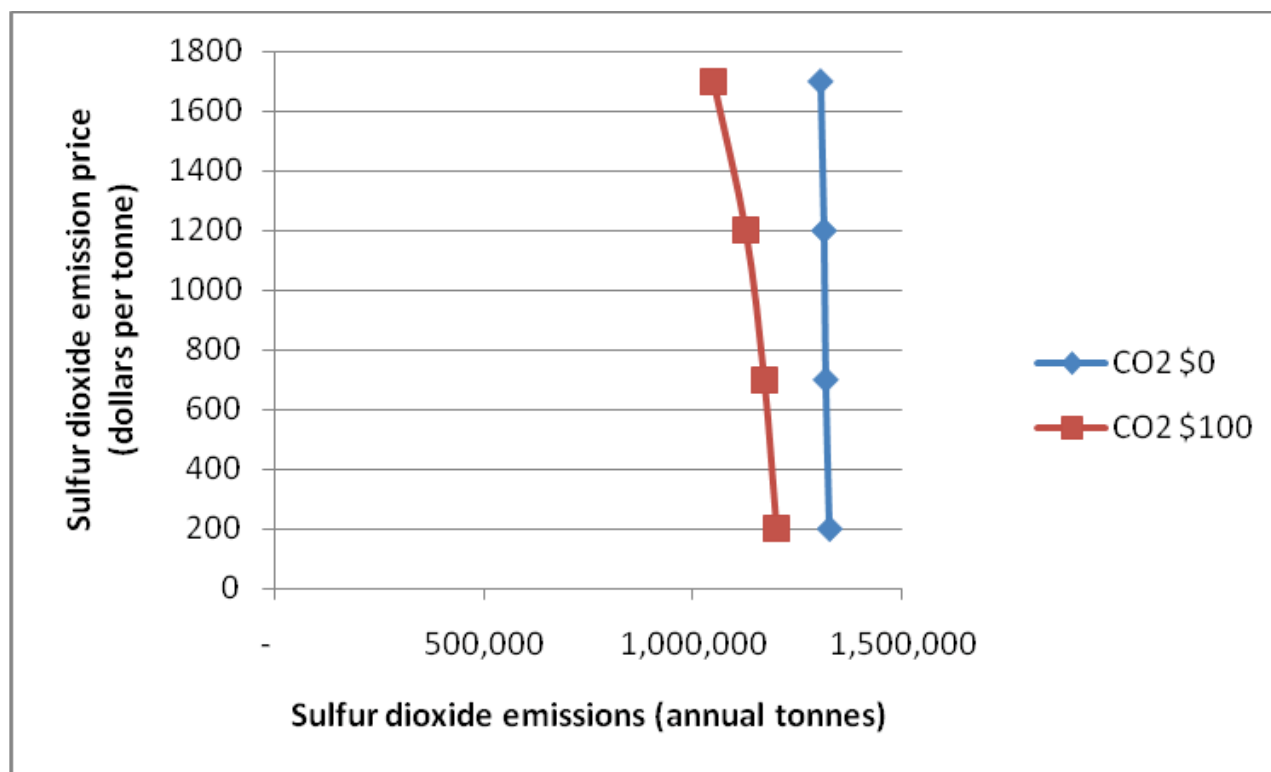
RGGI Leakage (with AC model)



This and all remaining slides use the AC model.



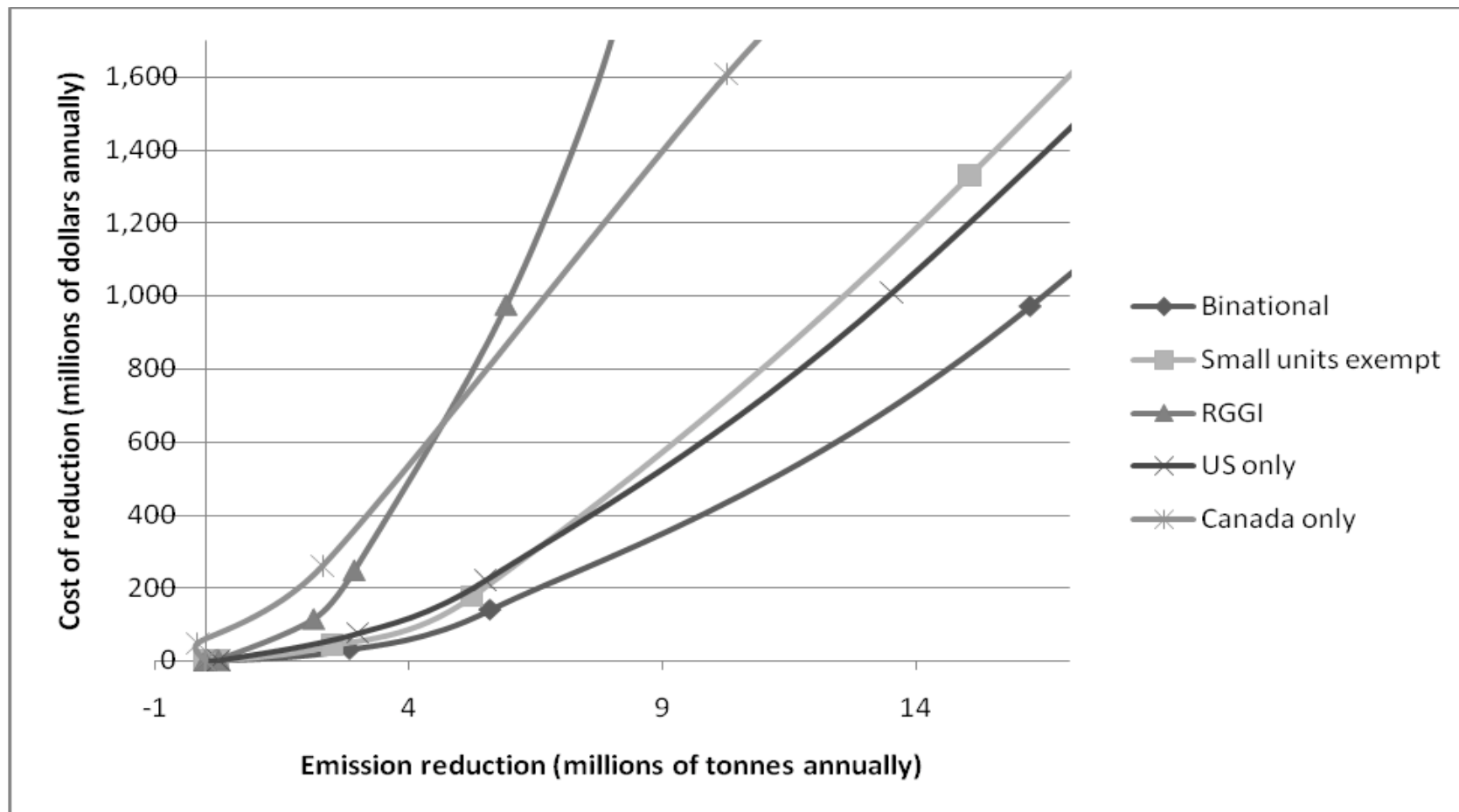
Cross-effects of Emission Regulation PSERC



- CO₂ price reduces SO₂ permit demand, would cause price of permits to decline.
- Could reduce use of low-sulfur coal and cause scrubbers to be turned off.
- Similar result for NO_x.



Cost vs Emission Reductions Under Five Policy Scenarios

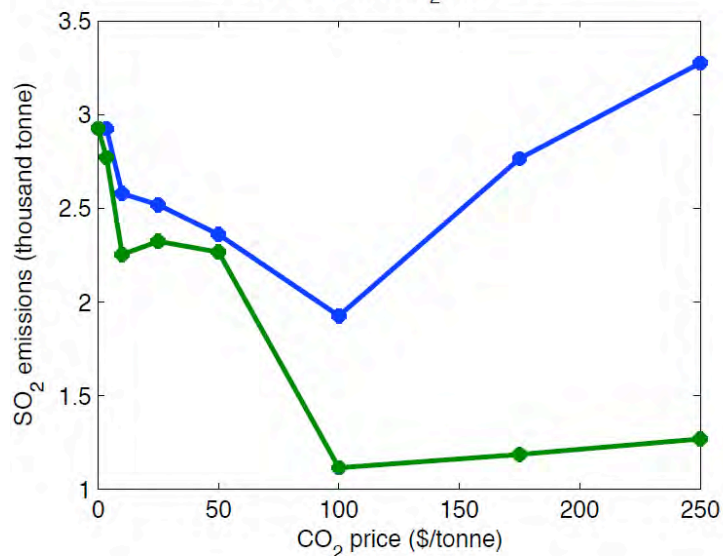


NYC and Boston SO₂ and NO_x

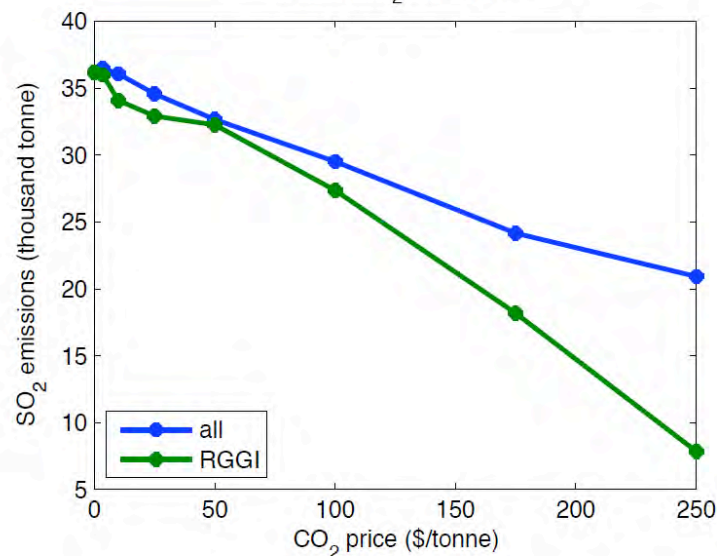


PSERC

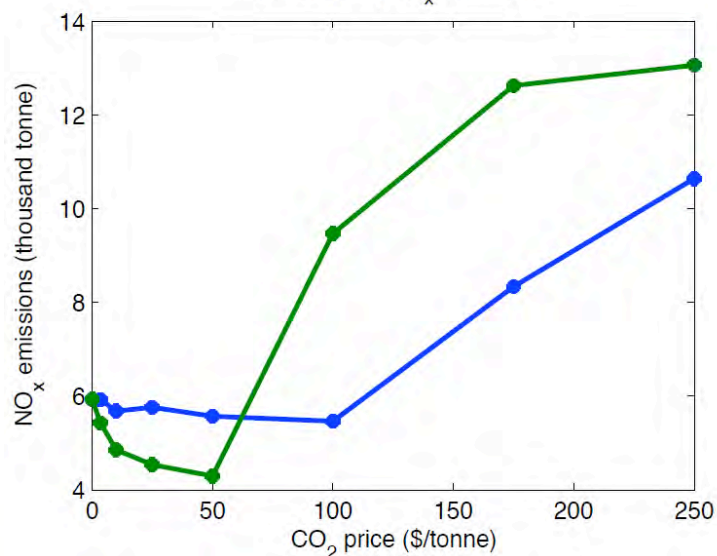
New York City SO₂ emissions



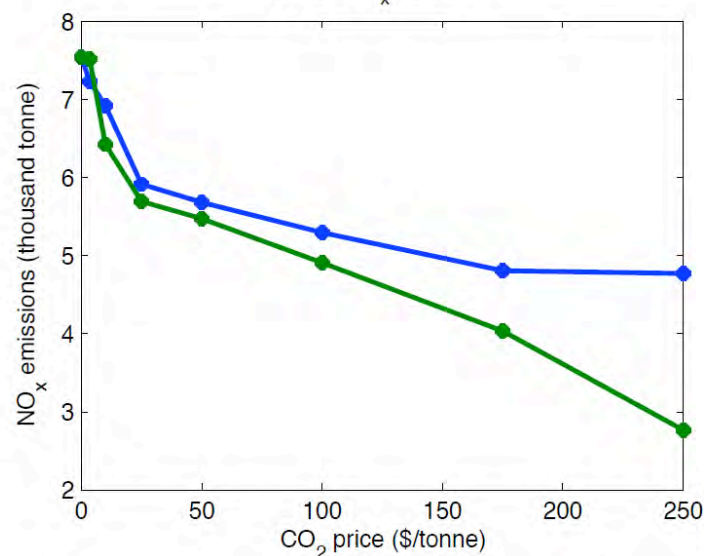
Boston SO₂ emissions



New York City NO_x emissions



Boston NO_x emissions

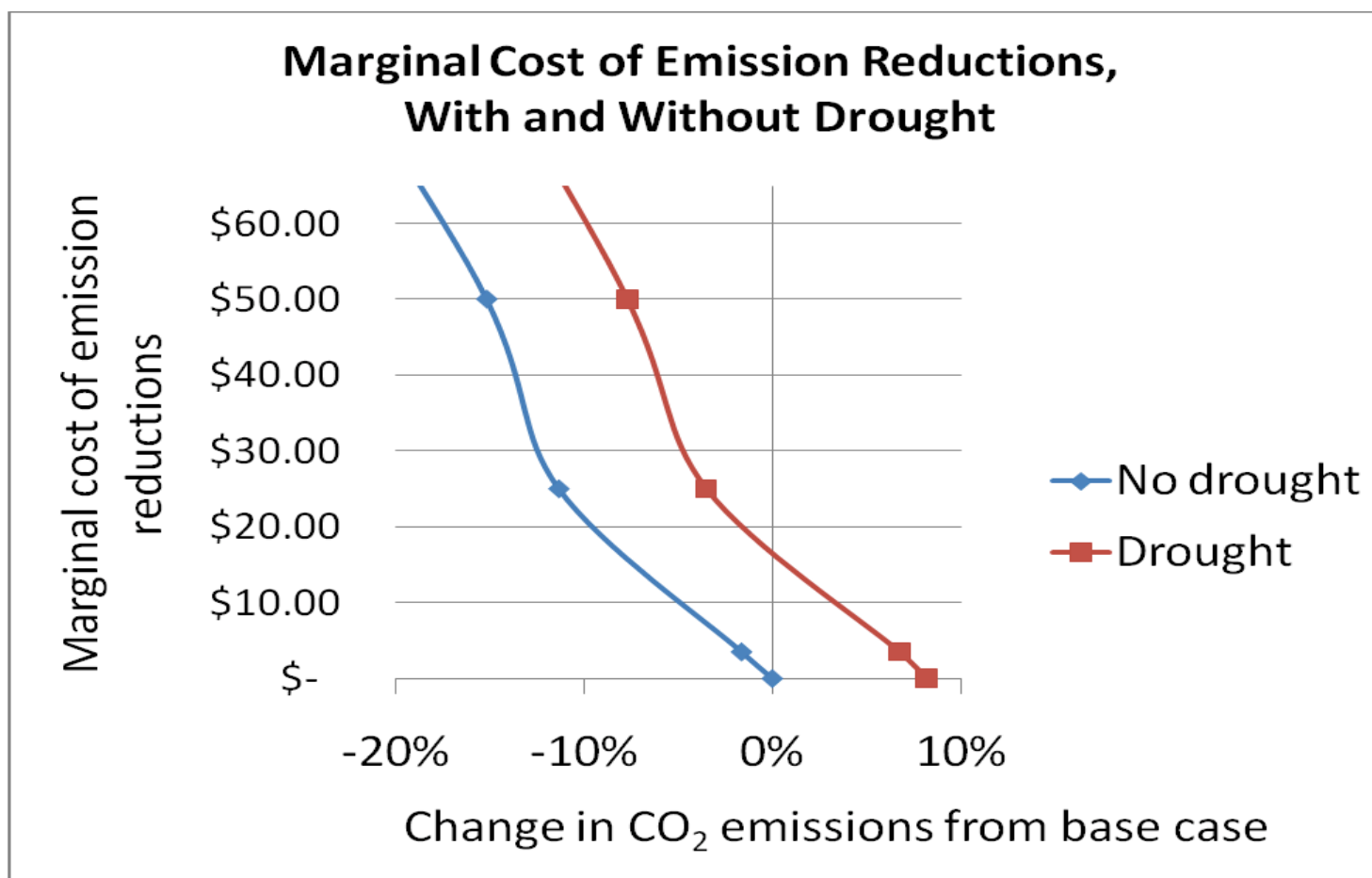


Drought

- Hydropower is the second-largest “zero-emission” generation type
- We model drought as a 20 percent reduction in hydropower generation in the modeled region
 - Four severe droughts in the Northeast U.S. in the last 40 years, each lasting 1-5 years and associated with at least a 20 percent reduction of rainfall



Demand for CO₂ Allowances under RGGI, with and without Drought



Thought Experiment: Simulate Waxman-Markey for the NE with a Long-Run Demand Response

- A linear statistical model fits the simulation outputs very well.
- Thus, CO₂, NO_x, and SO₂ emissions (and permit demand), as well as average LMP, can all be predicted by the three permit prices and system wide load ($R^2 \sim .9$).
- Quantity demanded for electricity is assumed totally inelastic in the short run but has a long run elasticity of -1 (supported by many studies) with an infinite distributed lag on past prices.
- NO_x and SO₂ allowance prices are fixed and CO₂ permit availability for the NE is cut back by the Waxman-Markey proportions from 2005 emissions.
- Given a slow economic recovery and RGGI there is likely to be some initial slack. Thus the \$10 CO₂ permit price floor plus 5% per year is likely to bind initially.
- Assumes the 2007 power system is in place and predicts with and without long run demand response (conservation).



- With demand response, CO₂ emissions decline from start and permit price stays at floor.

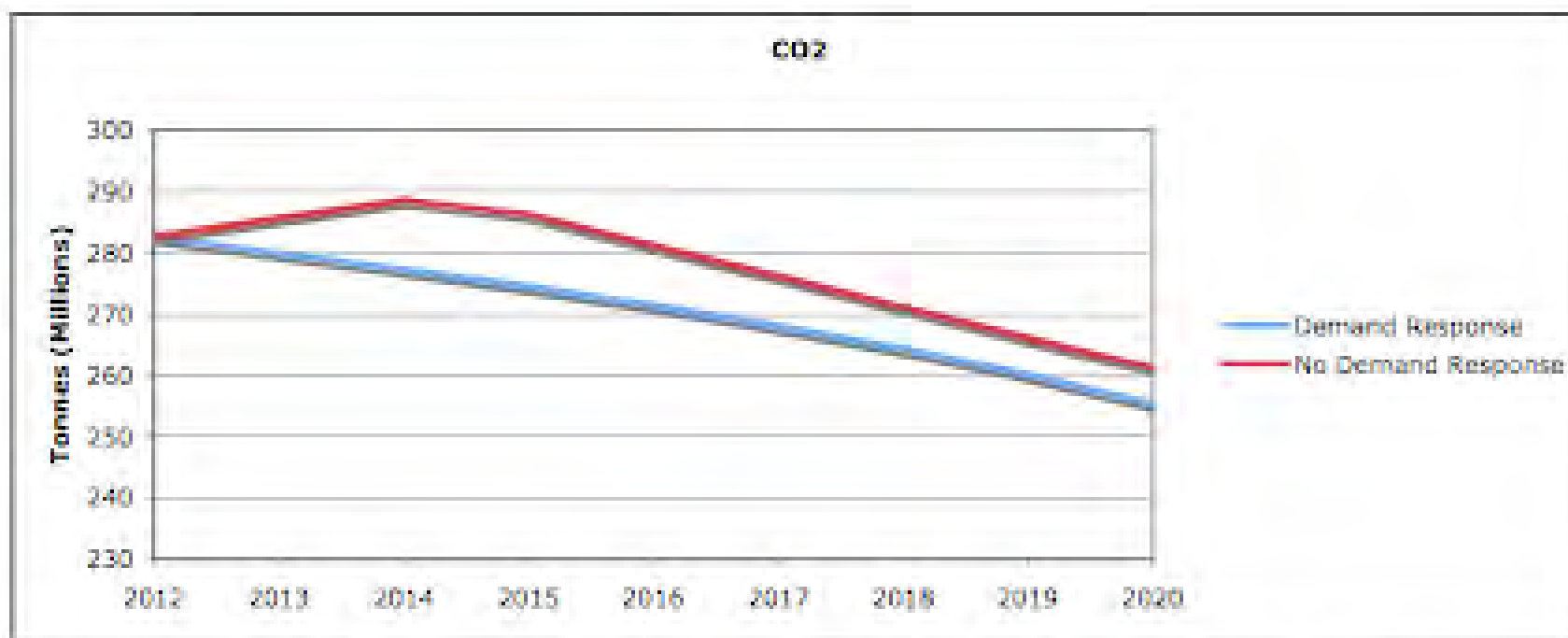


Figure 16: Estimated CO₂ emissions with and without demand response

- Without demand response, CO₂ and electricity prices rise sharply after first two years.

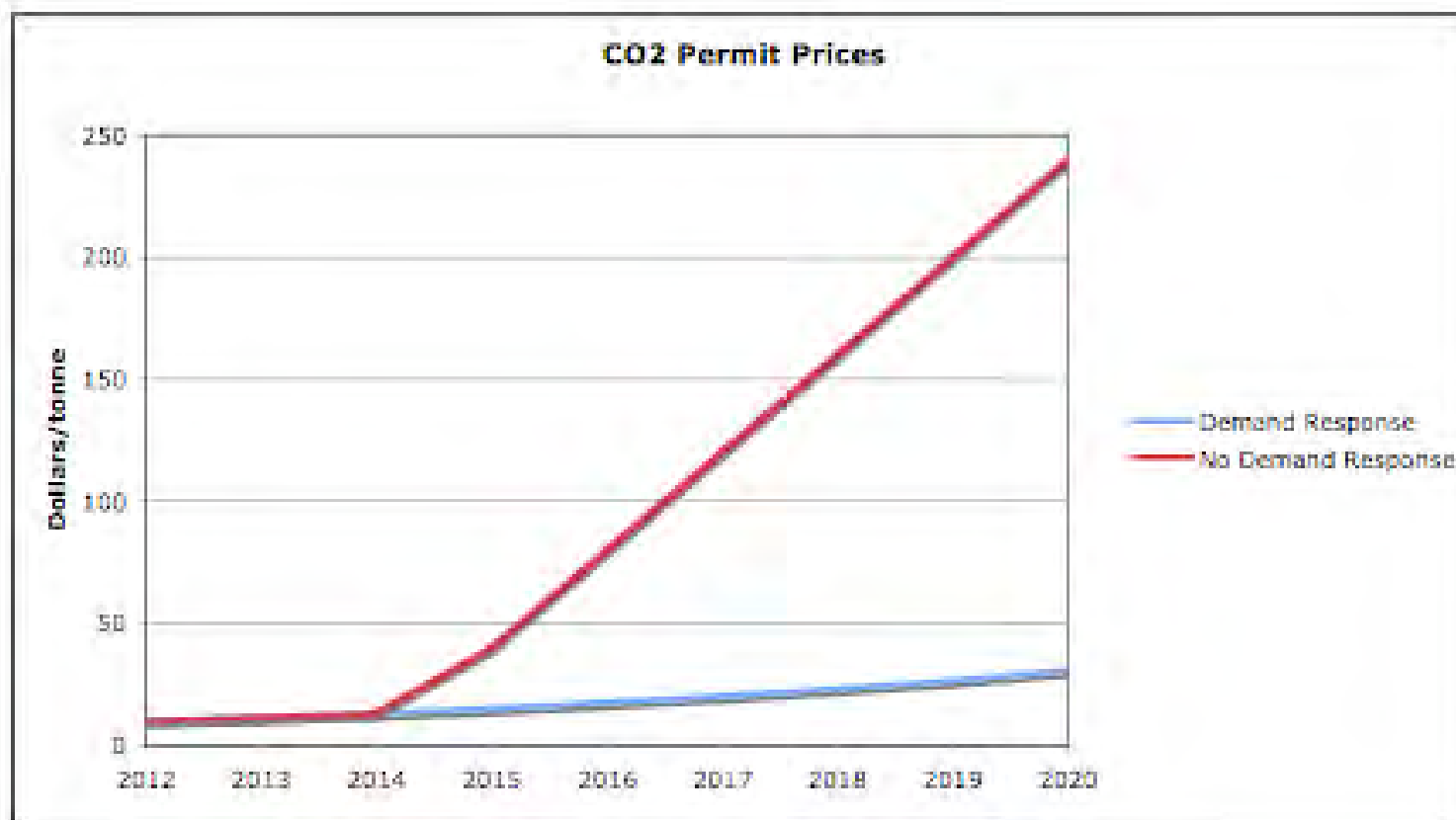


Figure 19: Estimated CO₂ permit prices with and without demand response



- With demand response, average LMP rises slowly and electricity demand falls, without....

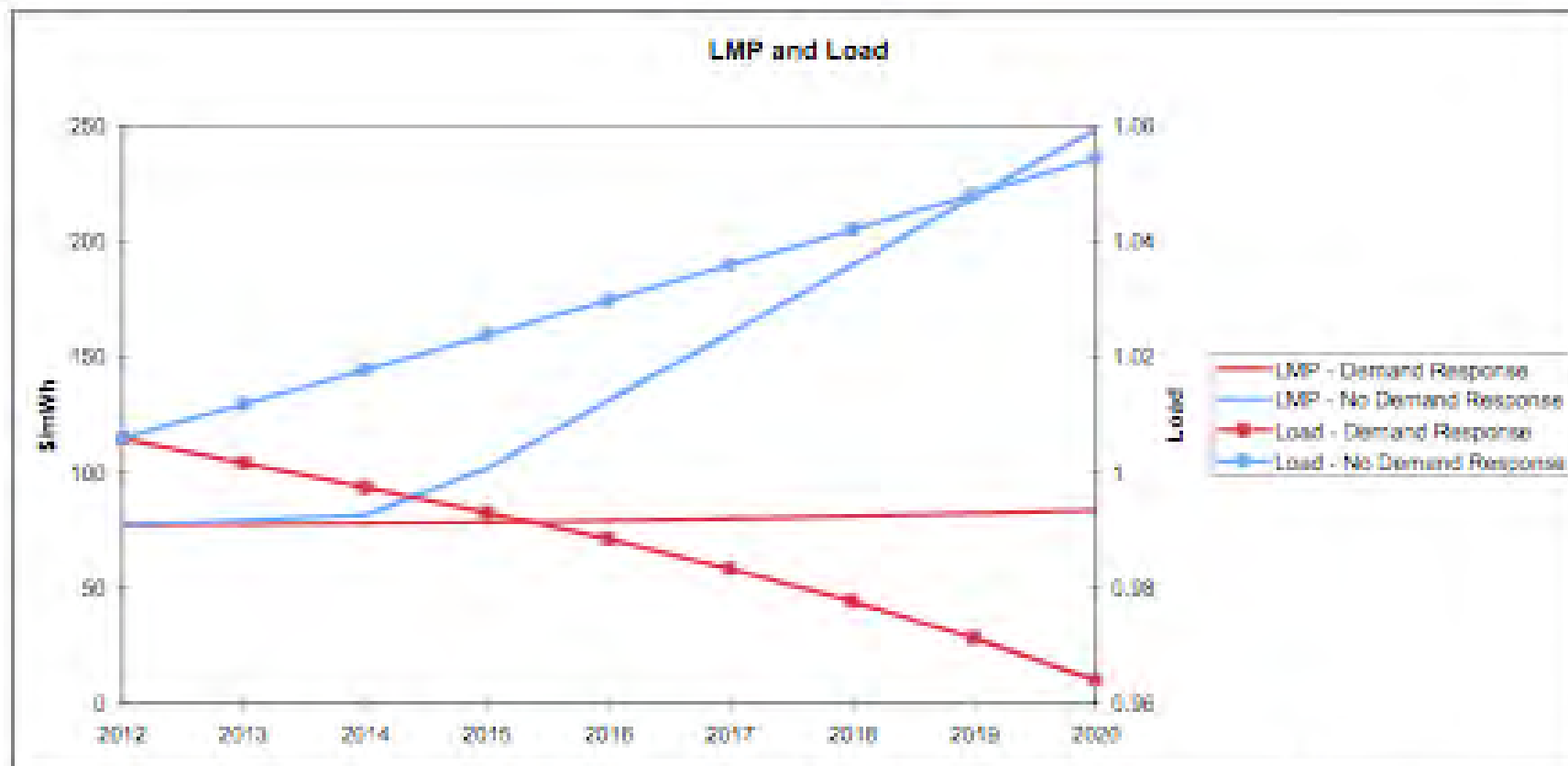


Figure 20: Estimated LMP and Load with and without Demand Response

Conclusions

- Short run demand for CO₂ allowances will be extremely inelastic.
- The current system cannot produce significant reductions in CO₂ emissions at acceptable electricity prices without demand response (energy conservation).
- CO₂ prices have a large impact on other emissions and the demand for allowances for SO₂ and NO_x
- Cap-and-trade has produced and will produce allowance price volatility and uncertainty for multiple pollutants. This raises cost of regulation. Generators would likely prefer the certainty of pollution fees for investment planning.
- AC and DC runs generally produce similar results.
- Leakage may be a major issue for RGGI or for CO₂ policies in the US and Canada that differ in stringency.
- A prolonged drought could severely impact CO₂ allowance prices in RGGI



Future Research

- Research using the *SuperOPF* will examine atmospheric fate and transport of emissions of NO_x and SO₂ for fine particulates and ozone.
- Contingencies will be added.
- Long run demand response will be incorporated.
- Optimal investment in response to environmental initiatives will be modeled.
- Model will incorporate flow constraints resulting from seams.
- Model will be extended to the Eastern Interconnect (250 node reduction in progress by Dan Tylavsky).
- Proposed new PSERC project will integrate with the existing project examining the Western Interconnection (Ward Jewell, lead) and add the Texas Interconnection (Dan Tylavsky).

