Cost Effectiveness of CO$_2$ Mitigation Strategies: A Carbon Price and Renewable Portfolio Standards in Traditional and Restructured Markets

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Metric for measuring cost effectiveness

\[
\Rightarrow \left[ \frac{\$}{\text{Tonne of } \text{CO}_2 \text{ Mitigated}} \right]
\]

\[
\Rightarrow \frac{\$/\text{MWh}_{(\text{Low Carbon})} - \$/\text{MWh}_{(\text{High Carbon})}}{\text{Tonnes } \text{CO}_2/\text{MWh}_{(\text{High Carbon})} - \text{Tonnes } \text{CO}_2/\text{MWh}_{(\text{Low Carbon})}}
\]

\[
\frac{\Delta \text{System Level Costs}}{\Delta \text{CO}_2 \text{ Emissions}}
\]
Assumptions

• Use economic dispatch model to estimate difference in system level costs and CO$_2$ emissions from carbon taxes and RPS
• Assume no transmission constraints and no ramping constraints
• Assume sunk costs
• Vary cost of gas from $4/MMBTU to $8/MMBTU
Perspective: Vertically Integrated Utility

SRMP, PJM

Market Clearing Price [$/MWh]

Capacity [MW]

Fuel Costs

Coal
Gas
Nuclear
Fuel Switching: Cost Effectiveness of a Carbon Price in PJM
Perspective: RoR Regulation

![Graph showing the cost effectiveness of a carbon price in PJM. The graph plots the decrease in carbon intensity against the cost per tonne of CO2. Key points include:
- $25/t CO2
- $50/t CO2
- $75/t CO2
- $100/t CO2
The graph illustrates the cost effectiveness of carbon pricing, with higher prices leading to greater decreases in carbon intensity.]
Fuel Switching: Cost Effectiveness of a Carbon Price in PJM
Perspective: RoR Regulation

$100/\text{t CO}_2$

$75/\text{t CO}_2$

$50/\text{t CO}_2$

$25/\text{t CO}_2$

$8/\text{MMBTU}$

$7/\text{MMBTU}$

$6/\text{MMBTU}$

$5/\text{MMBTU}$

$4/\text{MMBTU}$

[Graph showing the cost effectiveness of fuel switching based on different carbon prices and decrease in carbon intensity. The x-axis represents the decrease in carbon intensity in percentage, ranging from 0% to 40%. The y-axis represents the cost in dollars per tonne of CO2, ranging from 0 to 70. Different lines represent different costs per MMBTU and carbon prices.]

$6$
Perspective: Restructured Markets

SRMP, PJM

Market Clearing Price [$/MWh]

$25/t CO2 Tax

Raised Market Clearing Price

Capacity [MW]

Coal

Gas

Nuclear
Perspective: Restructured Markets

SRMP, PJM

Market Clearing Price [$/MWh]

0 10 20 30 40 50 60 70 80 90 100 110 120

Capacity [MW]

0 50,000 100,000 150,000 200,000

Producer Surplus

$25/t CO2 Tax

Neutral Tax Revenue

Fuel Costs

Coal

Gas

Nuclear
Cost Effectiveness of a Carbon Price in PJM
Perspective: Restructured Markets

Cost per Tonne of CO2 [$/t CO2]

Percent Decrease in CO2 Intensity
Assumptions for RPS

- Wind generators operate through bilateral contracts outside of energy market
- Wind generators receive $100/MWh total (including variability, transmission, curtailment)
RPS Standard in PJM

SRMP, PJM, Low Cost Gas

Short Run Marginal Price [$/MWh]

Capacity [MW]

Coal
Gas
Nuclear

Wind offsets most expensive generator
Wind’s Effect On Market Clearing Prices

SRMP, PJM, Low Cost Gas

Decreased Producer Surplus

Decreased Marginal Costs (Fuel and O&M)
Do Results Translate to MISO or ERCOT?

- MISO results somewhat similar to PJM
- ERCOT results far different
Cost Effectiveness of Carbon Price in PJM and ERCOT
Perspective: Restructured Markets
Cost Effectiveness, Restructured Market, ERCOT, RPS

Percent Reduction in Carbon Intensity

$\$/t CO2

15% RPS
20% RPS

$4/MMBTU
$5/MMBTU
$6/MMBTU
$7/MMBTU
$8/MMBTU
Fixed O&M in PJM

Capacity Supply Curve without revenues from Energy Market
Capacity Supply Curve with Differing E&AS Scenarios, PJM

- **No energy Market**
- **2012 Revenue**

$\text{Dollars per KW-Year}$

$\text{Capacity [GW]}$
Capacity Supply Curve with Differing E&AS Scenarios, PJM

- 2012 Revenue
- 20% Wind
Capacity Supply Curve with Differing E&AS Scenarios, PJM

Change in capacity costs with 20% wind

- 2012 Revenue
- 20% Wind
Conclusions

• Cost effectiveness dependent on:
  – Price of natural gas
  – Change in producer surplus, if applicable
  – Ability to manipulate free market principles
  – Degree one believes carbon price will lead to innovation
Will PJM change with forthcoming coal retirements?

Cost Effectiveness of Carbon Price in PJM with 18 GW of Coal Replaced
Perspective: Restructured Markets (Gas at $5/MMBTU)
Cost Effectiveness, Restructured Market, RPS Standard, PJM, $5/MMBTU

With capacity costs taken into account

Percent Reduction in Carbon Intensity [%]

[$/t CO2]
Conclusions

- At $5 gas, a 20% RPS in PJM: $65/tonne CO$_2$
- a 20% CCS std in PJM: $80/tonne CO$_2$
- Since an RPS and CCS standard are about the same cost, and since consumers (in some states) have decided to pay for an RPS, a CCS standard is economically feasible.
- Carbon taxes in PJM are twice as costly.
- Cost effectiveness of mitigation strategies dependent on whether the market is traditional RoR or restructured, and on the generation mix.
Would a CCS standard be as cost effective as wind?

• Like wind under an RPS, CCS coal (or gas) under a low-carbon standard would have bilateral contracts above market clearing price.

• Assume bilateral contracts for CCS plants at $110/MWh.

• Assume 90% capture rate.
Back up Slides

SRMP, PJM, Low Cost Gas

![Graph showing market clearing price vs. capacity for different energy sources]
Capacity Supply Curve with 2012 Revenue, PJM

Dollars per kW-Year vs. Capacity [GW]

- No energy Market
- 2012 Revenue
Capacity Supply Curve with Differing 20% RPS, PJM

- **Sub. coal**
- **Sup. coal**
- **No energy Market**
- **2012 Revenue**
- **20% Wind**
Results Unclear

Capacity Supply Curve with CCS Standard, PJM

- No energy Market
- 2012 Revenue
- CCS Standard

 Raises but shifts supply curve
Raised Market Clearing Prices... will they spur new generation?

Average Market Clearing Price

![Graph showing the relationship between carbon tax and average market clearing price for different emission prices.](image)
Probably not:

Capacity Payment Needed for New Natural Gas Power Plants

- 5 GT
- 8 CC
- 5 CC
Cost Effectiveness, Carbon Tax, Consumer Perspective, MISO

- Dollars per Tonne Offset [$/t CO2]
- Percent Reduction in Carbon Intensity

Graph shows the relationship between the cost per tonne offset and the percent reduction in carbon intensity for different carbon tax rates. The lines represent different tax rates: $8/MMBTU, $7/MMBTU, $6/MMBTU, $5/MMBTU, and $4/MMBTU.
PJM, 18 GW Coal replaced w NGCC

SRMP, PJM, $6 Gas, 18 GW Coal Replaced

Market Clearing Price [$/MWh]

0  20  40  60  80  100  120

0  50000  100000  150000  200000

Capacity [MW]
SRMP, PJM, $6 Gas, $25/t Tax, 18 GW of Coal Replaced
Cost Effectiveness, Carbon Tax, Consumer Perspective, PJM, 18 GW Replaced
Cost Effectiveness, Consumer Perspective, PJM, RPS, 18 GW Coal Replaced

$/t CO₂ vs Percent Reduction in Carbon Intensity

- $4/MMBTU
- $5/MMBTU
- $6/MMBTU
- $7/MMBTU
- $8/MMBTU
Restructured Markets

SRMP, PJM, Low Cost Gas

- Costs to consumers
- $25/t CO2 Tax
- Neutral Tax Revenue
- Fuel Costs

Market Clearing Price [$/MWh]

Capacity [MW]