PJM STUDY OF CARBON PRICING & POTENTIAL LEAKAGE MITIGATION MECHANISMS

Version #2: Updated with additional clarification based on stakeholder feedback. Original version posted for 10/27/2020 CPSTF.

Objective

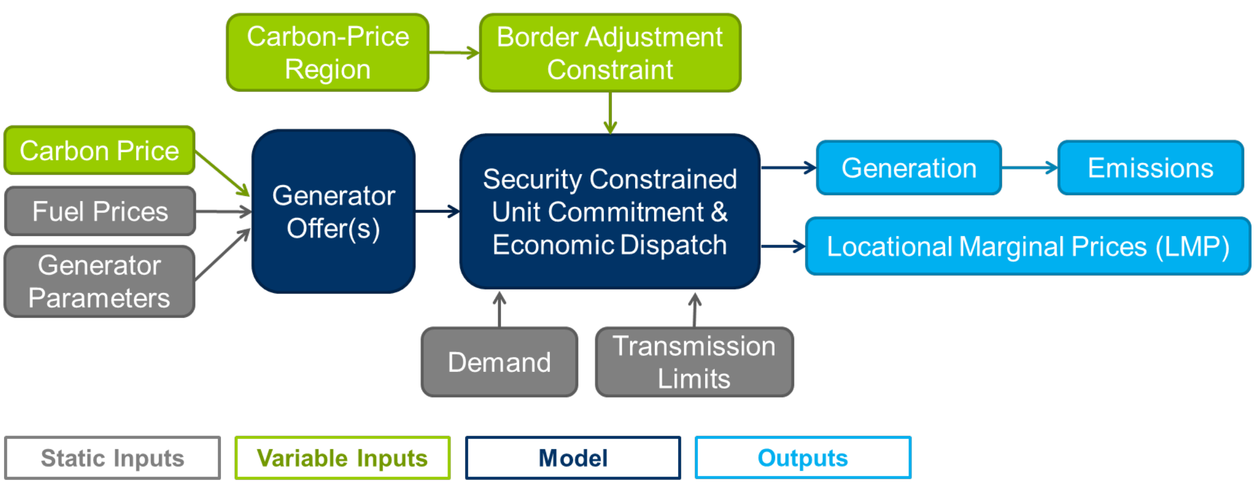
PJM studied the impacts of potential carbon prices and leakage mitigation mechanisms in PJM's wholesale electricity market in order to inform stakeholders and policymakers. PJM is not proposing to establish a carbon price. This study is intended to provide education as part of the Carbon Pricing Senior Task Force. Policy-makers in the PJM region are ultimately responsible for environmental policy, and any associated revenue generated through its application.

Methodology

PJM analyzed scenarios examining different carbon prices, carbon price applicability (regional vs. sub-regional) and border adjustment approaches using a production cost model[1] of the 2023 PJM system. This modeling is not intended to match historical system behavior or predict future conditions. The focus of the methodology was identifying the magnitude and direction of the deltas (shifts in generation dispatch, emissions, and locational marginal prices) between scenarios with different variables, and for these trends to inform stakeholders.

In order to simulate the impacts of pricing carbon in PJM's wholesale electricity markets, PJM used Energy Exemplar's PLEXOS® Integrated Energy Model (PLEXOS). PLEXOS is a production cost model that performs both a security constrained unit commitment and dispatch over a given time horizon. The software provided the needed flexibility to simulate the complexities of PJM's system while allowing the development of custom constraints to apply carbon adders and border adjustments on a regional and sub-regional basis. Each scenario simulated the dispatch of the PJM system over a one-year time horizon in order to evaluate the impacts on generation dispatch, emissions, and locational marginal prices. The modeling methodology is summarized in Figure 1.

Figure 1: Modeling Overview



[1] Competitive bidding behavior and priced-based offers that ultimately impact prices are not modeled. Units are dispatched based on cost only.

Key Study Variable Assumptions

Carbon Prices

The study assumed that a carbon price in PJM comes from the Regional Greenhouse Gas Initiative (RGGI), as it does today. Each scenario used a single uniform carbon price applied as an adder in generator offers, and did not include broader modeling of RGGI allowance trading. Five different carbon price points were modeled:

- A counterfactual scenario of $0/ton.
- $6.87/short ton of CO_2 as a low-end RGGI price reference. This is the trigger price for the RGGI Emissions Containment Reserve (ECR) in 2023.[2]
- $14.88/short ton of CO_2 as a high-end RGGI price reference. This the trigger price for the RGGI Cost Containment Reserve (CCR) in 2023.[2]
- $25/short ton as an incrementally increasing carbon price point, based on stakeholder feedback.
- $50/short ton as a carbon price at the level of the Social Cost of Carbon[3], based on stakeholder feedback.

The carbon price is applied to the offers of resources that meet the RGGI program's "CO_2 Budget Source" definition: a fossil-fuel-fired electric power generator with a capacity of 25 MW or greater within a RGGI state.[4] When a border adjustment is simulated, this definition is extended to resources in other states for making available an offer that includes the carbon price.

Carbon-Price Regions

For scenarios that modeled a carbon adder and border adjustments on a sub-regional basis, assumptions for states that are in or out of the "carbon-price sub-region" were based on whether or not the states have or are considering regulations to price greenhouse gas emissions from the power sector though RGGI. Additional variations in the regions in which a carbon price was applied were identified based on stakeholder feedback. Carbon-price sub-regions included different combinations of DE, IL, MD, NJ, PA and VA. A set of scenarios also applied a carbon price across all states within the PJM RTO.

The simulated impact of sub-regional carbon prices and border adjustments heavily depend on the generation mix, and relative emissions intensities, of each sub-region.

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[2] RGGI program price floors and caps to take effect beginning in 2021, https://www.rggi.org/sites/default/files/Uploads/Program-Review/12-19-2017/Principles_Accompanying_Model_Rule.pdf. The ECR, which acts as the program price floor, is a quantity of allowances that are withheld from circulation to secure additional emission reductions if allowance prices fall below established trigger prices.

[3] August 2016 update of the Social Cost of Carbon by the Inter-Agency Working Group on Greenhouse Gases (https://19january2017snapshot.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf).

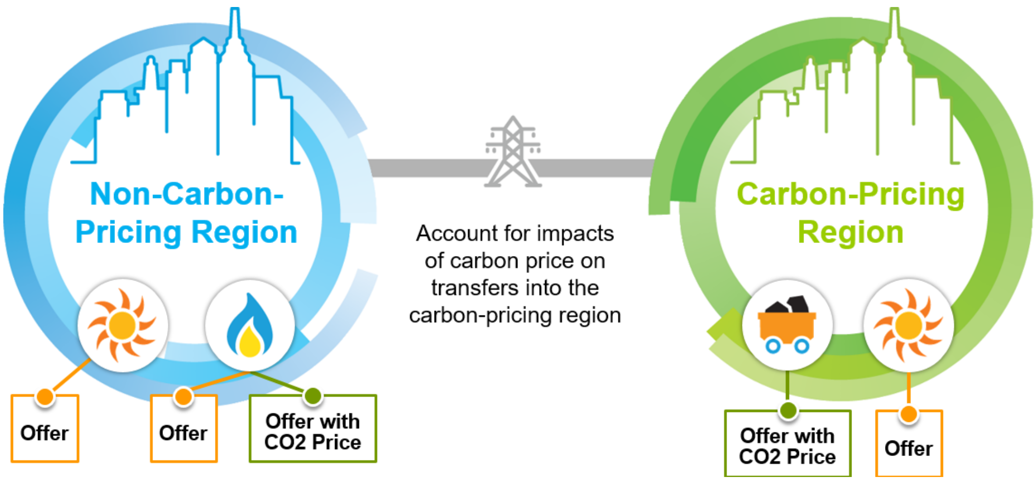
[4] RGGI 2017 Model Rule, https://www.rggi.org/sites/default/files/Uploads/Design-Archive/Model-Rule/2017-Program-Review-Update/2017_Model_Rule_revised.pdf.

Border Adjustments

To implement the border adjustment constraints in PLEXOS, the following custom constraints were added to the model[5]:

One-Way Border Adjustment
Internal to the carbon-pricing sub-region, all generators have one cost/price offer pair that takes into account the costs of its carbon emissions. External to the carbon-pricing sub-region, all generators maintain two pairs of offers: one with and one without the cost of carbon included.

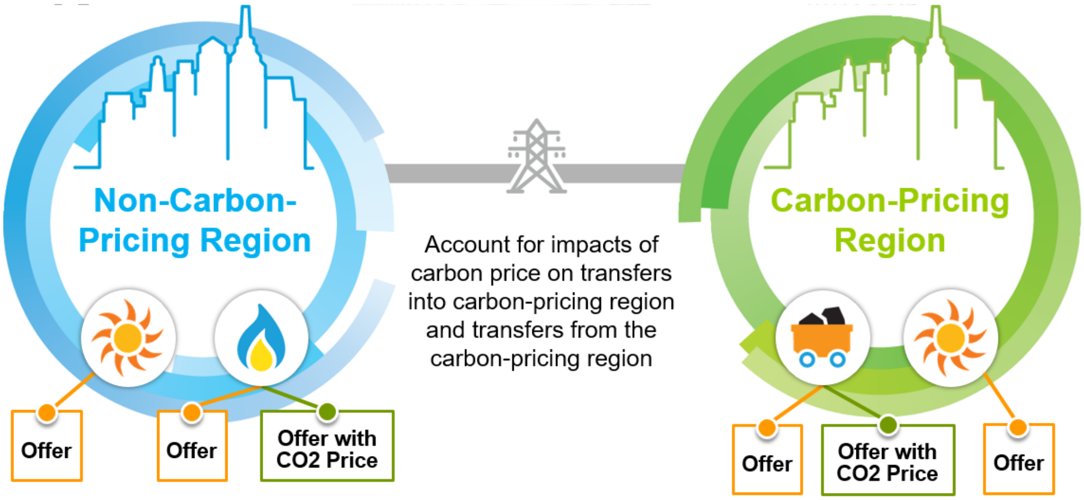
Constraint formulation: *Σ(Generation without the cost of carbon included {units can only belong to non-carbon-pricing sub-region }) ≤ (Load in non-carbon-pricing sub-region)*



Two-Way Border Adjustment
All generators have two cost/price offer pairs, one pair that takes into account the cost of its carbon emissions and one that does not take into account the cost of its carbon emissions.

Constraint formulation: *Σ(Generation without the cost of carbon included {units can belong to either the carbon-pricing sub-region or the non-carbon-pricing sub-region }) ≤ (Load in non-carbon-pricing sub-region)*

[5] Example Problem Formulations for border adjustments, discussion of Plexos application in slides 18 – 21: https://www.pjm.com/-/media/committees-groups/task-forces/cpstf/2020/20200225/20200225-item-05-example-problem-formulations.ashx



External regions that price carbon were taken into account – namely New York, which is part of RGGI. External region resources were optimized based on the underlying modeling assumptions that (1) external resources were included in the commitment and dispatch optimization and (2) that the emissions of external resources are known on a unit basis.

The analysis included determining the value of the carbon residual fund resulting from border adjustments. Based on the states that make up the carbon-price sub-region, and whether the carbon price sub-region is net importing or net exporting, there may not be any carbon residual funds. Non-zero carbon residual funds can result in:

- Surplus, when there are net transfers into the carbon-pricing region, or
- Deficit, when there are net transfers from the carbon-pricing region.

Analysis results did not include any partitioning of the carbon residual fund. In practice, states, not PJM, would need to determine how these funds would be allocated.

Base Assumptions

Study Year	2023
Demand	Load profiles for 2023 were determined through the 2019 PJM Load Forecast development process.[6] This accounts for Distributed Energy Resources and Energy Efficiency.
Generation Portfolio	The generation portfolio used in the simulations included generation retirements announced by Oct. 1, 2018, and new generation in the PJM interconnection queue and slated to be in operation by 2023. Wind and solar generation are modeled as net energy injections that are constant across all scenarios, with the exception of small amounts for curtailments due to transmission constraints.
Transmission Topology	2023/24 case from the Region Transmission Expansion Plan and Market Efficiency processes. Includes monitored contingencies included in the 2023/24 Market Efficiency Case.[7]
Fuel Prices	IHS Markit fuel price forecasts for 2023.[8]
Emissions Rates	Due to the methodology needed to model the border adjustment constraints, carbon dioxide (CO_2) emissions were modeled based on carbon content (lb/mmBtu) by fuel type.[9] CO_2 emissions on a unit basis are calculated via simulation based on unit dispatch, fuel use and heat rate. Nitrogen oxides (NOx) & sulfur dioxide (SO_2) were modeled on a unit basis using EPA emissions data from 2018.[10] SO_2 rates are an annual average. NOx rates are averaged separately for ozone season (May through September) and remainder of the year.
Demand Response	Modeled locationally based on cleared Capacity Performance DR.
Outages	Forced and maintenance outage profiles were derived stochastically and evaluated for consistency with historical outage profiles.
External Interchange	The model allowed flow over external interfaces up to the total transfer capability, assuming perfect market to market coordination. Hurdle rates that aim to produce external interchange that aligns with historical level were not used. All external transmission zones that directly neighbor PJM were included in the model.

[6] PJM, 2019 Load Forecast Report. https://www.pjm.com/planning/resource-adequacy-planning/load-forecast-dev-process.aspx
[7] https://www.pjm.com/planning/rtep-development/market-efficiency.aspx
[8] IHS Markit, August 2019
[9] EPA, GHG Emission Factors Hub. https://www.epa.gov/climateleadership/center-corporate-climate-leadership-ghg-emission-factors-hub
[10] EPA, Air Markets Program Data. https://ampd.epa.gov/ampd/

Summary of Results Materials

Analysis of RGGI Carbon Price in sub-regions of PJM & border adjustment constraints for leakage mitigation

Carbon Price Region	Case Numbers	Carbon Prices*	CPSTF Materials
DE, MD, NJ	1, 2, 3	• $0/short ton (counterfactual) • $6.87/short ton (2023 RGGI ECR trigger price) • $14.88/short ton (2023 RGGI CCR trigger price)	1.14.2020
DE, MD, NJ, VA	1, 4, 5		2.25.2020
DE, MD, NJ, VA, PA	1, 6, 7		2.25.2020
DE, MD, NJ, PA	1, 8, 9		5.19.2020
DE, MD, NJ, VA, PA, IL	1, 16, 17		8.21.2020

Analysis of increasing carbon price points

Carbon Price Region	Case Numbers	Carbon Prices*	CPSTF Materials
DE, MD, NJ, VA, PA	1, 10, 11	• $0/short ton (counterfactual) • $25/ton • $50/ton	5.19.2020
RTO-wide	1, 12, 13, 14, 15	• $0/short ton (counterfactual) • $6.87/short ton (2023 RGGI ECR trigger price) • $14.88/short ton (2023 RGGI CCR trigger price) • $25/ton • $50/ton	5.19.2020

Additional Material

- Additional data spreadsheet including generation by state, emissions by sub-region, emissions by state, LMP by sub-region, and LMP by zone: https://www.pjm.com/-/media/committees-groups/task-forces/cpstf/postings/carbon-study-results-summary.ashx

Other Studies

- MJB&A & Environmental Defense Fund (EDF) Electric Sector Modeling – Summary of Results: https://www.pjm.com/-/media/committees-groups/task-forces/cpstf/20191024/20191024-item-06-carbon-pricing-modeling.ashx