Expanded Results of PJM Study of Carbon Pricing & Potential Leakage Mitigation Mechanisms

Carbon Pricing Senior Task Force

March 27, 2020

Version 2

Versions

- V1 – First posting on 3/27/2020
- V2 – data corrections on slide 20 & 21

Schedule

July 2019 Meeting:

Reviewed objectives and proposed assumptions for the PJM Carbon Study

January & February 2020 Meetings:

Reviewed objectives and initial modeling results

March 2020:

Results posted for additional of PA to carbon-price sub-region

Objectives of Analysis

PJM is studying the potential impacts of a carbon price and potential leakage mitigation mechanisms in order to inform stakeholders and policy-makers.

- PJM is **not** proposing to establish a carbon price.
- PJM is conducting this study to inform carbon pricing discussions in the CPSTF stakeholder process.
- Feedback on **initial & extended modeling** will be used to guide additional modeling efforts.
- Policy-makers in the PJM region are ultimately responsible for environmental policy, and any associated revenue generated through its application.

Review of Action Items

Modeling Sensitivities

1. Addition of VA to Carbon-Price Sub-Region *(2/25/2020 CPSTF)* ✓
2. Addition of VA & PA to Carbon-Price Sub-Region *(2/25/2020 CPSTF)* ✓
3. **Addition of PA to Carbon-Price Sub-Region** ✓
4. All of PJM included in Carbon-Price Sub-Region ●
5. Higher carbon prices ●

Additional Data Points & Clarifications

1. Additional information on border adjustment equations & modeling ✓
2. Impact of border adjustments on production cost ✓
3. Impact of border adjustments on uplift ✓
4. Additional information on external interchange ✓
5. Additional information on emissions rates *(summary document / spreadsheet)* ●
6. Results by state, zone *(summary document / spreadsheet)* ●

✓ Complete

● Future

Results Executive Summary

Results depend on the generation mix, and emissions intensities, of each sub-region.

Modeling of Carbon Prices from RGGI

Compared to counterfactual with no carbon price

- Generation & Emissions
  - **Decrease** in carbon-price sub-region
  - **Increase** in rest of RTO
  - Net RTO impact varies based on sub-region assumptions
- Energy Prices
  - On average, LMPs **increase** in both sub-regions as the carbon price increases

Impacts of Border Adjustments

Compared to no border adjustment

- Generation & Emissions
  - **Increase** in carbon-price sub-region
  - **Decrease** in rest of RTO
  - Net RTO impact varies based on sub-region assumptions
- Energy Prices
  - On average, as the carbon price increases, a two-way border adjustment results in greater price **decreases** than a one-way border adjustment.

Overview

Review of Context and Study Assumptions

Part 1: Impacts of a RGGI Carbon Price in the PJM Energy Market; **Addition of PA** to carbon-price sub-region

Part 2: Impacts of Potential Border Adjustments for Leakage Mitigation; **Addition of PA** to carbon-price sub-region

Review of Leakage Concepts

- **Leakage** - any shift in production and related emissions, from a regulated jurisdiction to a less-stringently regulated jurisdiction, due to differing compliance costs.

- In the context of the Regional Greenhouse Gas Initiative (RGGI), “Emissions leakage is the concept that there could be a shift of electricity generation from capped sources subject to RGGI to higher-emitting sources not subject to RGGI.” [1]

- Concerns raised by stakeholders in the CPSTF Opportunity Statement: “Without addressing leakage, rising emissions can eliminate the environmental benefits that carbon pricing policies are intended to produce. Similarly, leakage can also harm consumers in areas that have not adopted carbon pricing as more expensive resources push market clearing prices higher.” [2]

Note: Some studies consider emissions from power and non-power sectors, and emissions reduction goals when estimating leakage impacts. PJM study is focused on power sector emissions from simulation of the wholesale electricity market.

[1] Final Report of the RGGI Emissions Leakage Multi-State Staff Working Group to the RGGI Agency Heads. *Potential Emissions Leakage and the Regional Greenhouse Gas Initiative (RGGI)*. 2008. https://mde.maryland.gov/programs/Air/ClimateChange/RGGI/Documents/Leakage_Report_Final_3-08.pdf

[2] CPSTF Opportunity Statement, https://www.pjm.com/-/media/committees-groups/task-forces/cpstf/postings/problem-statement.ashx?la=en

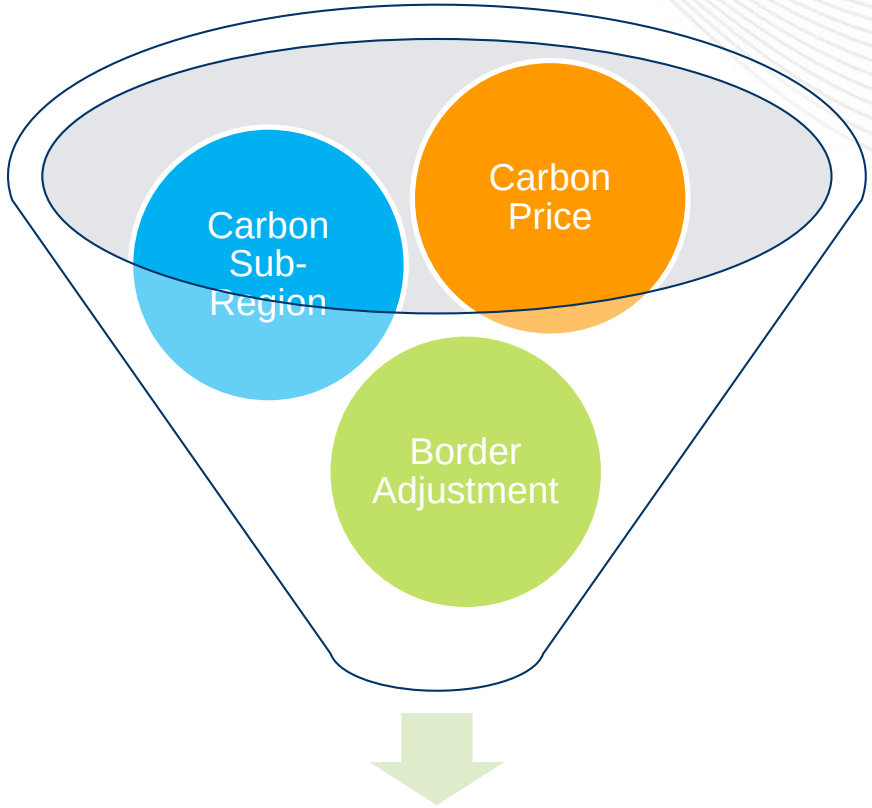
The study does not account for state-specific approaches to leakage mitigation

There are multiple approaches to leakage mitigation:

- *In study:* Border adjustment constraints within wholesale electricity market
  - One-way (transfers into carbon region)
  - Two-way (transfers into and out of carbon region)

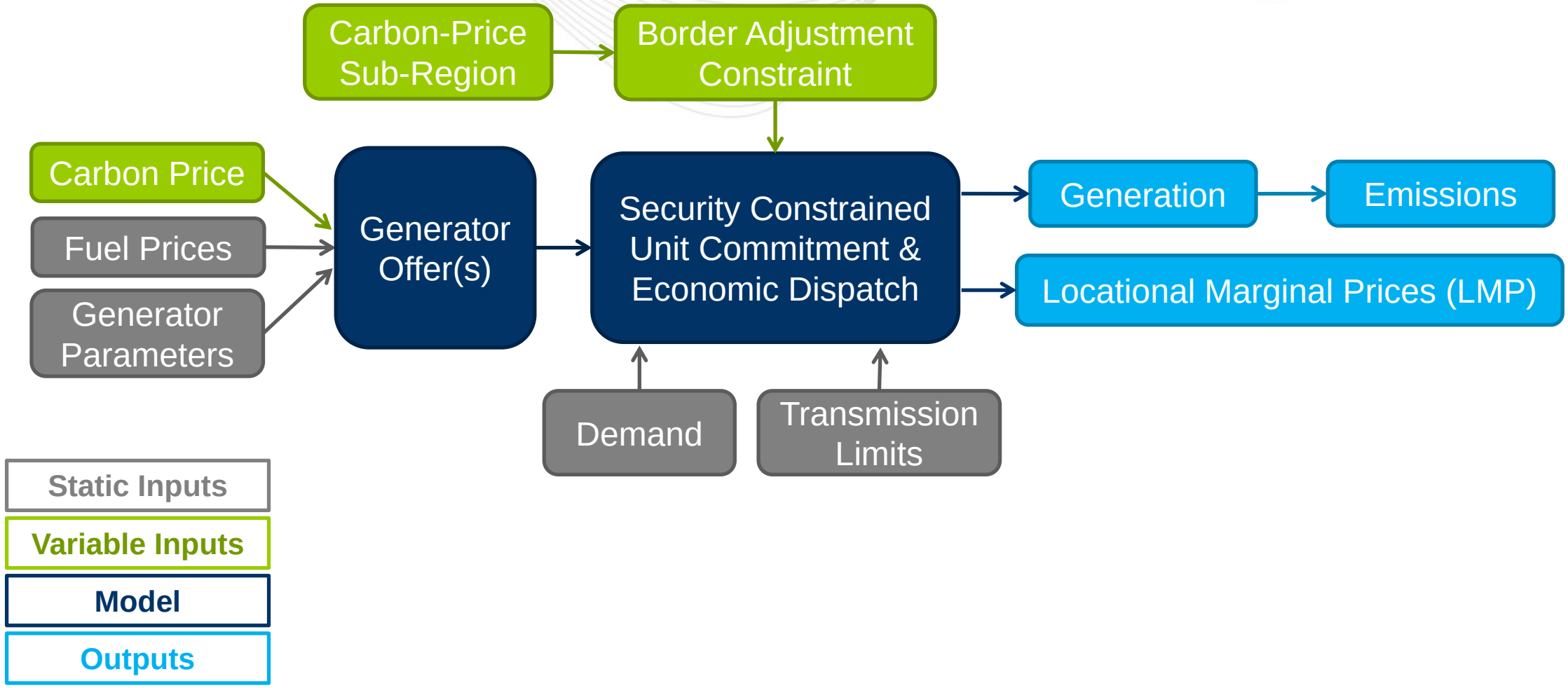
- *Not in study:* State-specific approaches
  - Programs that reduce electricity demand
  - Load-based greenhouse gas compliance obligations
  - Allowance allocation
  - Support for increasing low / zero-emitting in-state generation

Setting up the model included using three key variable inputs



- Year Modeled: **2023** (most recent planning case from Regional Transmission Expansion Plan and Market Efficiency process)
- Variable inputs are used to look at energy market impacts of a carbon price and leakage mitigation approaches
- Utilized PLEXOS to simulate the commitment & dispatch of resources and the resulting market/emissions outcomes
- Potential future analysis: longer-term modeling to evaluate potential changes to resource mix due to a carbon price
  - Out of scope for this phase

Study Methodology: Modeling Overview



RGGI Program helps to determine low and high carbon price values

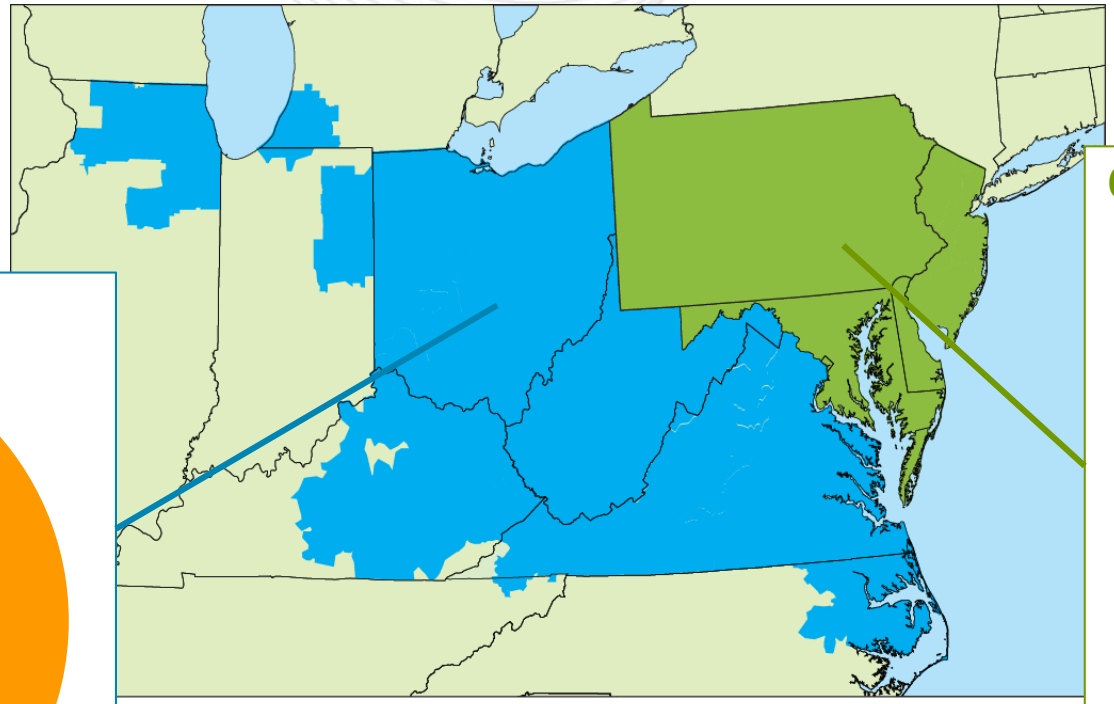
$0 /short ton of CO_2	• Applied in counterfactual case to quantify the impact of adding a carbon price on generation, emissions, and energy prices
$6.87 /short ton of CO_2	• Low-end reference • Trigger price for the RGGI Emissions Containment Reserve (ECR) in 2023
$14.88 /short ton of CO_2	• High-end reference • Trigger price for the RGGI Cost Containment Reserve (CCR) in 2023

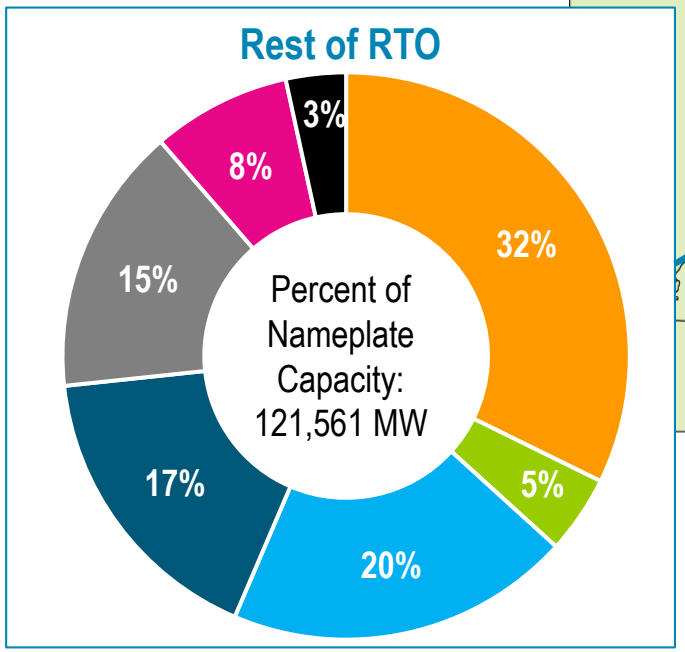
Internal and External resources to PJM are included in the optimization

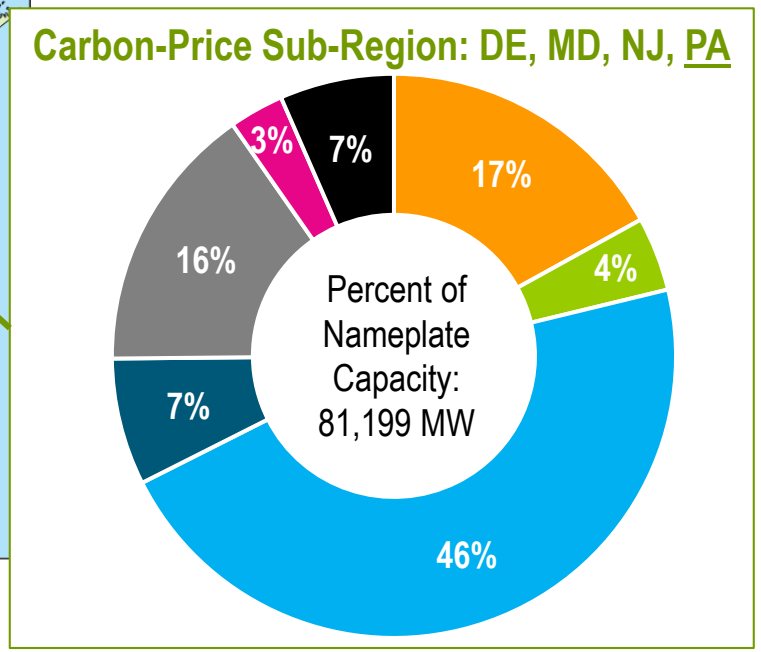
- Current set of results consider PJM states currently participating in RGGI (DE, MD, NJ), with the addition PA only
- New York is modeled with a carbon price, as it is a RGGI state. Study results are focused on the PJM RTO.
- Resources both internal and external to PJM were included in the optimization.

PA is included in the Carbon Sub-Region

Results depend on the generation mix, and emissions intensities, of each sub-region.







Coal
Natural Gas CT
Hydro
Other
Natural Gas CC / Steam
Nuclear
Wind & Solar

Three variations of Border Adjustment approaches are modeled

No Border Adjustment

- Determine baseline for economic and environmental leakage between regions

One-Way Border Adjustment

- Accounts for impacts of carbon price on transfers into the carbon-pricing region

Two-Way Border Adjustment

- Accounts for impacts of carbon price on transfers into carbon-pricing region and transfers from the carbon-pricing region

RGGI Revenue will coexist with a Carbon Price

- Each state will continue to collect RGGI revenue from each RGGI Regulated Source located in its state as it does today.

- These financial transactions take place **outside** of the market and the grid operator's settlement process.

Residual funds allocation will be determined by the States

- The analysis will include the value of the carbon residual funds resulting from **border adjustments**. States, not PJM, will determine how these funds are allocated, **if any**.
  - **Surplus** possible when there are net transfers into the carbon-pricing region.
  - **Deficit** possible when there are net transfers from the carbon-pricing region.
- Based on the states that make up the carbon-price sub-region, there may not be any carbon residual funds.

Overview

Review of Context and Study Assumptions

Part 1: Impacts of a RGGI Carbon Price in the PJM Energy Market; Addition of PA to carbon-price sub-region

Part 2: Impacts of Potential Border Adjustments for Leakage Mitigation; **Addition of PA** to carbon-price sub-region

Part 1 Scenario Summary

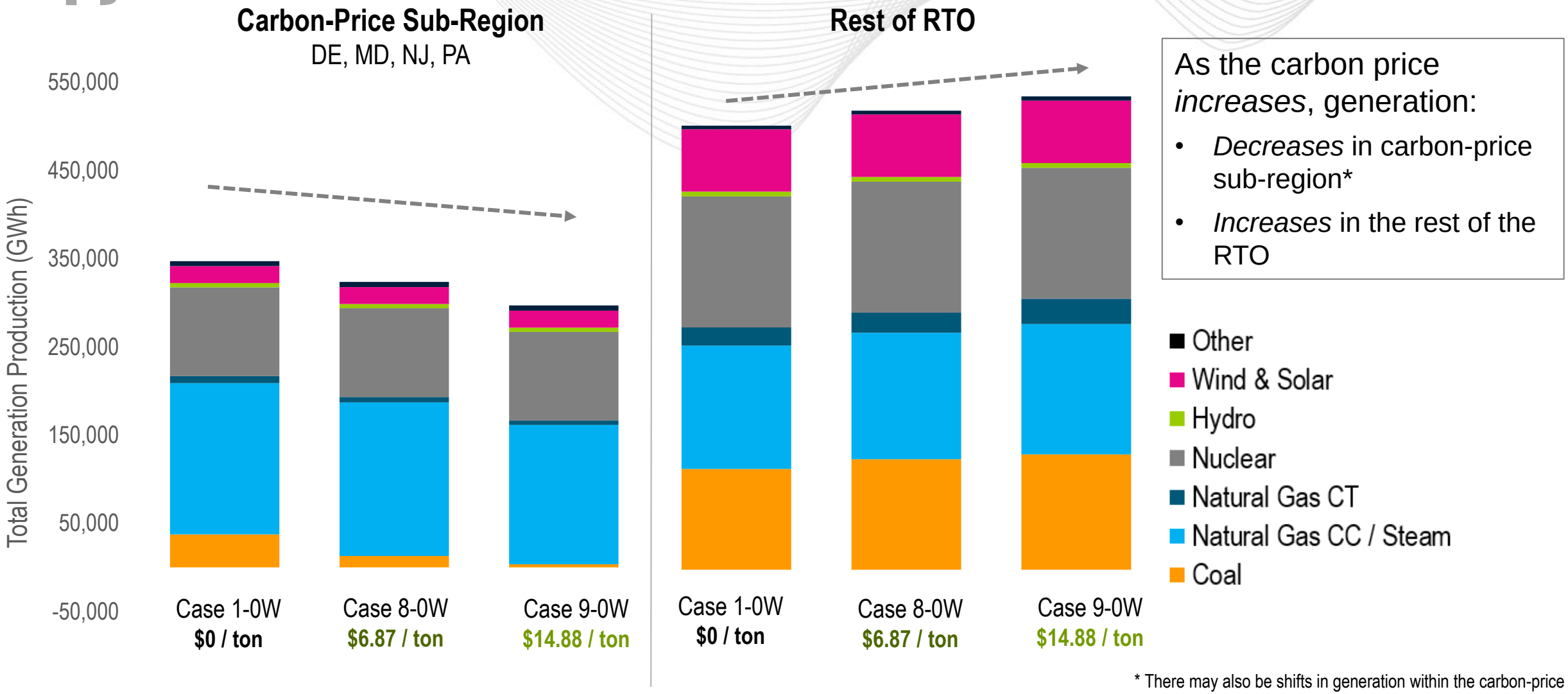
Impacts Associated with a RGGI Carbon Price in the PJM Energy Market

- Scenarios with RGGI price at $6.87/short ton and $14.88/short ton compared to a counterfactual scenario with RGGI price at $0/short ton ("No RGGI") to quantify differences in:
  - Generation
  - Emissions
  - Prices
- The year 2023 was simulated for the following cases:

Case	RGGI Price	Border Adjustment
Case 1-0W	$0/short ton (i.e. "No RGGI Price")	None
Case 8-0W	$6.87/short ton	None
Case 9-0W	$14.88/short ton	None

- Results are broken out by the following regions:
  - Carbon-Price Sub-Region – includes DE, MD, NJ **and PA**
  - Rest of RTO – all other states in PJM

2023 Generation Production by Sub-Region

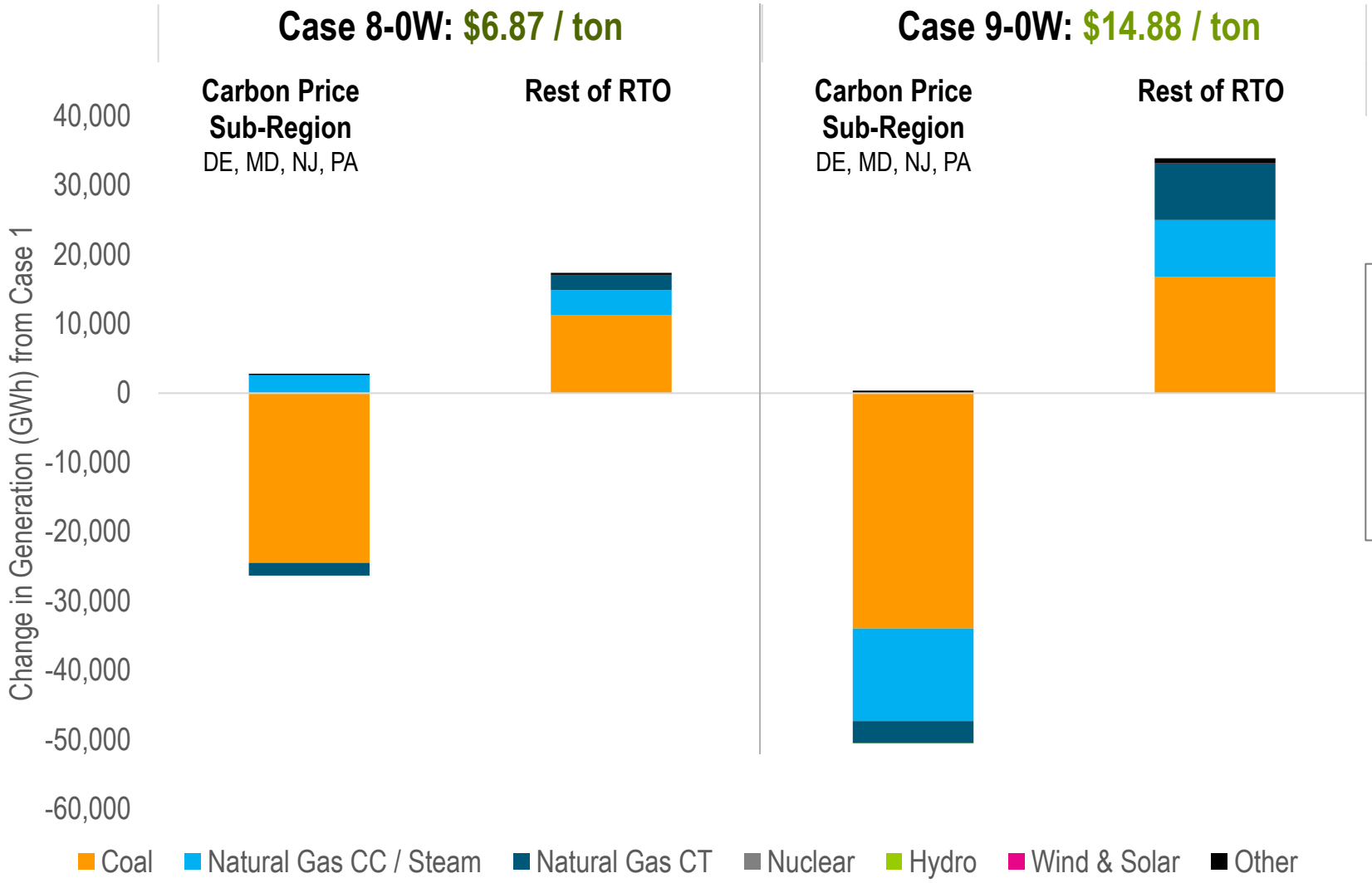


As the carbon price *increases*, generation:

- *Decreases* in carbon-price sub-region*
- *Increases* in the rest of the RTO

* There may also be shifts in generation within the carbon-price sub-region, as the carbon price is only applied to RGGI generators.

2023 Shifts in Generation Production from Case 1-0W ($0 / ton CO_2) by Sub-Region

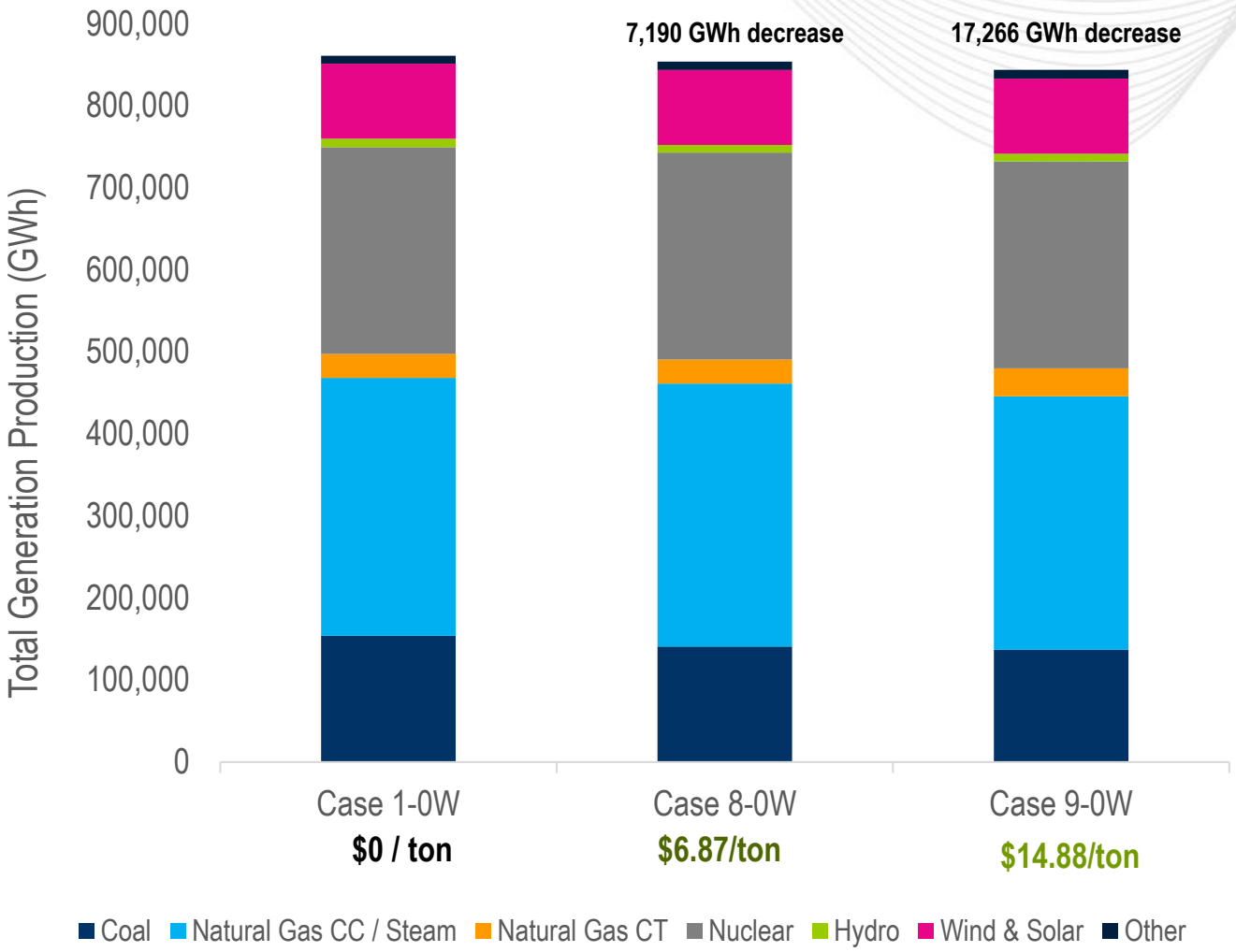


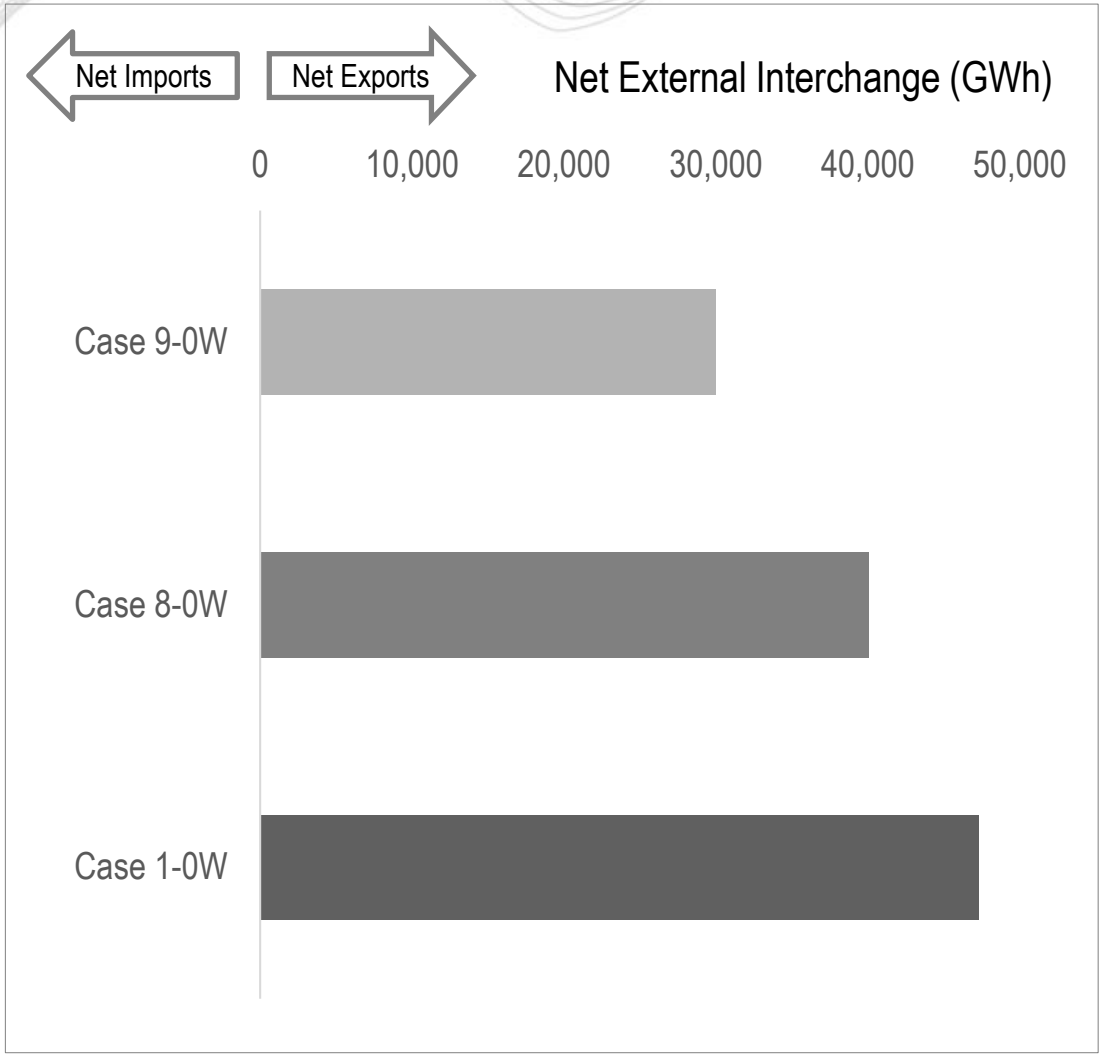
Generation displaced in carbon-price sub-region is relatively higher in emissions intensity than the increased generation in rest of RTO.

- Driven by generation mixes in each sub-region.

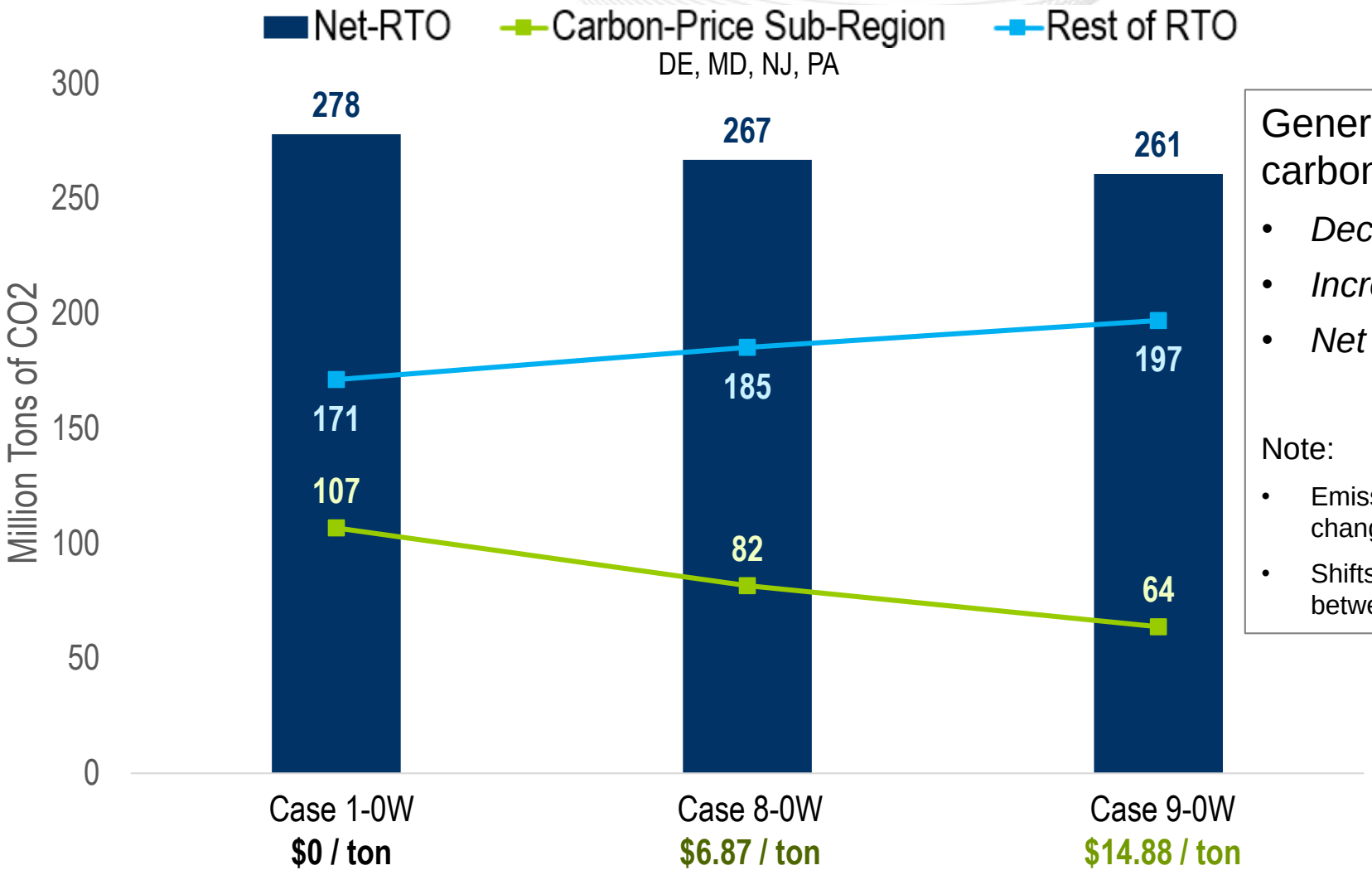
2023 Total RTO Generation Production and Net External Interchange

Δ RTO Generation (and Net Interchange) from 1-0W:





2023 Total CO_2 Emissions



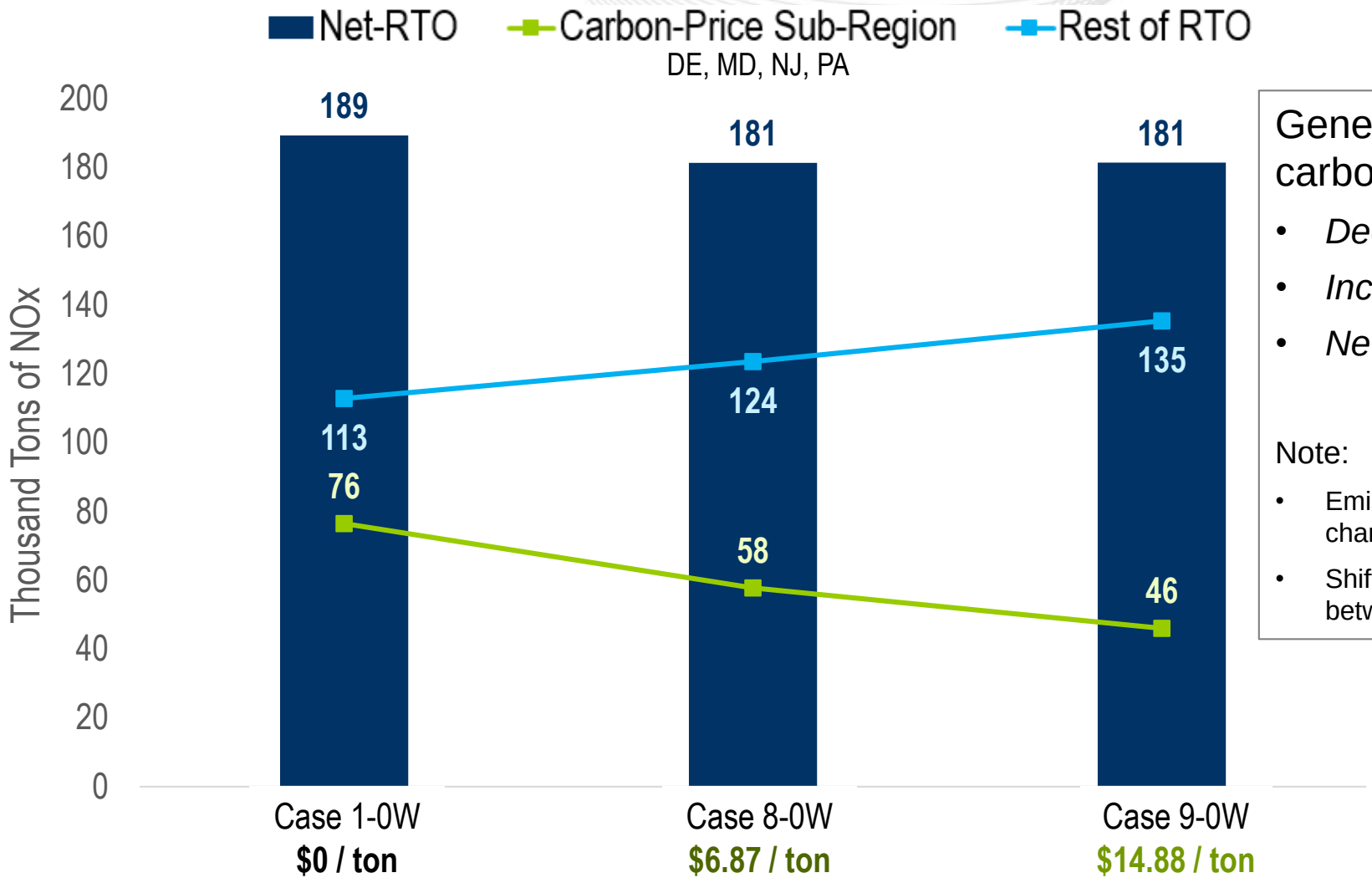
Generation shift from increasing carbon price results in CO_2:

- *Decrease* in carbon-price sub-region
- *Increase* in rest of RTO (no carbon price)
- *Net decrease* across the RTO

Note:

- Emissions are for PJM only and do not account for changes in external regions
- Shifts in RTO generation and external interchange between cases are driving changes in emissions

2023 Total NO_X Emissions



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Note:

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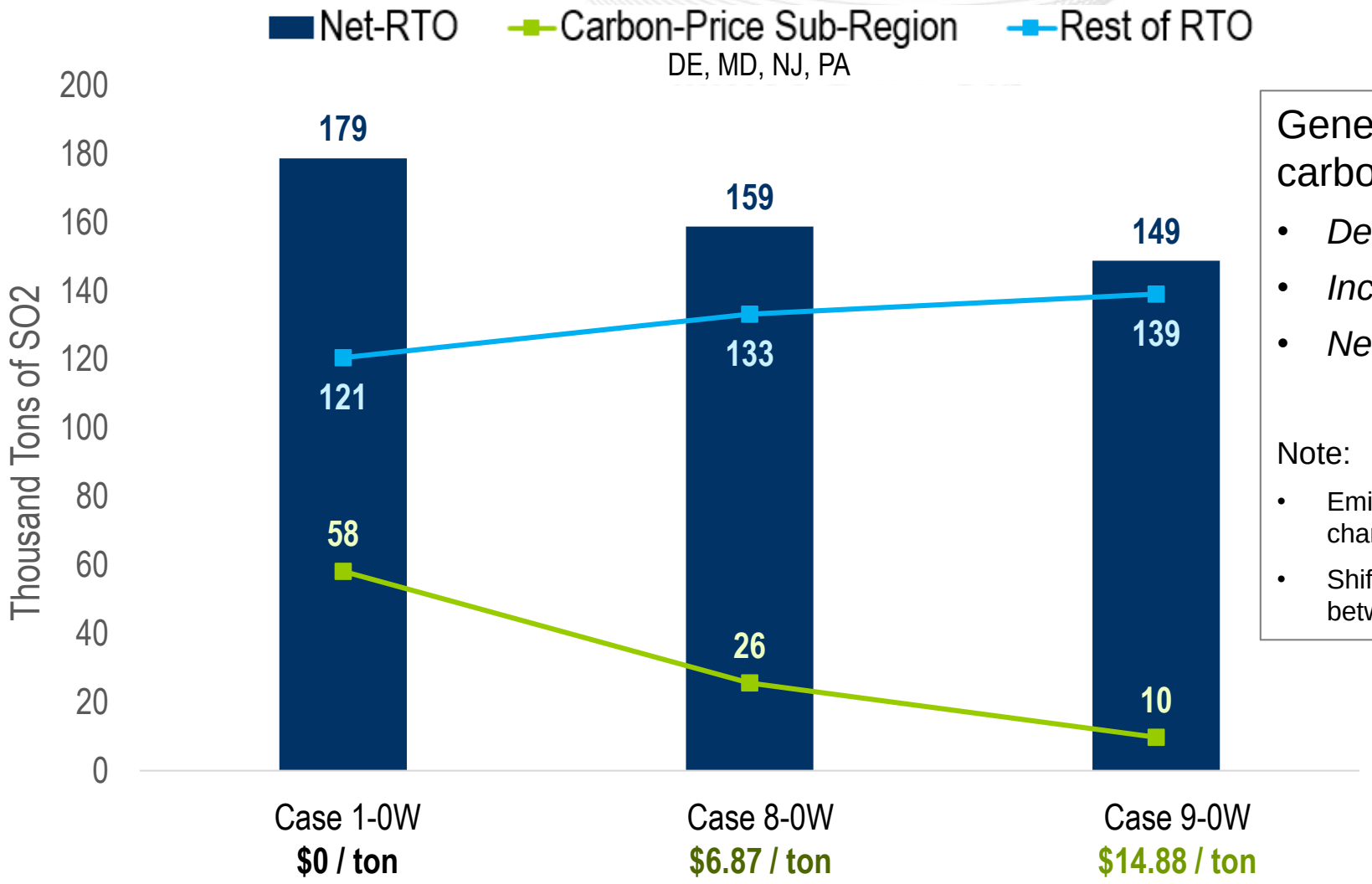
2023 Total SO_2 Emissions



Generation shift from increasing carbon price results in CO_2:

- *Decrease* in carbon-price sub-region
- *Increase* in rest of RTO (no carbon price)
- *Net decrease* across the RTO

Note:

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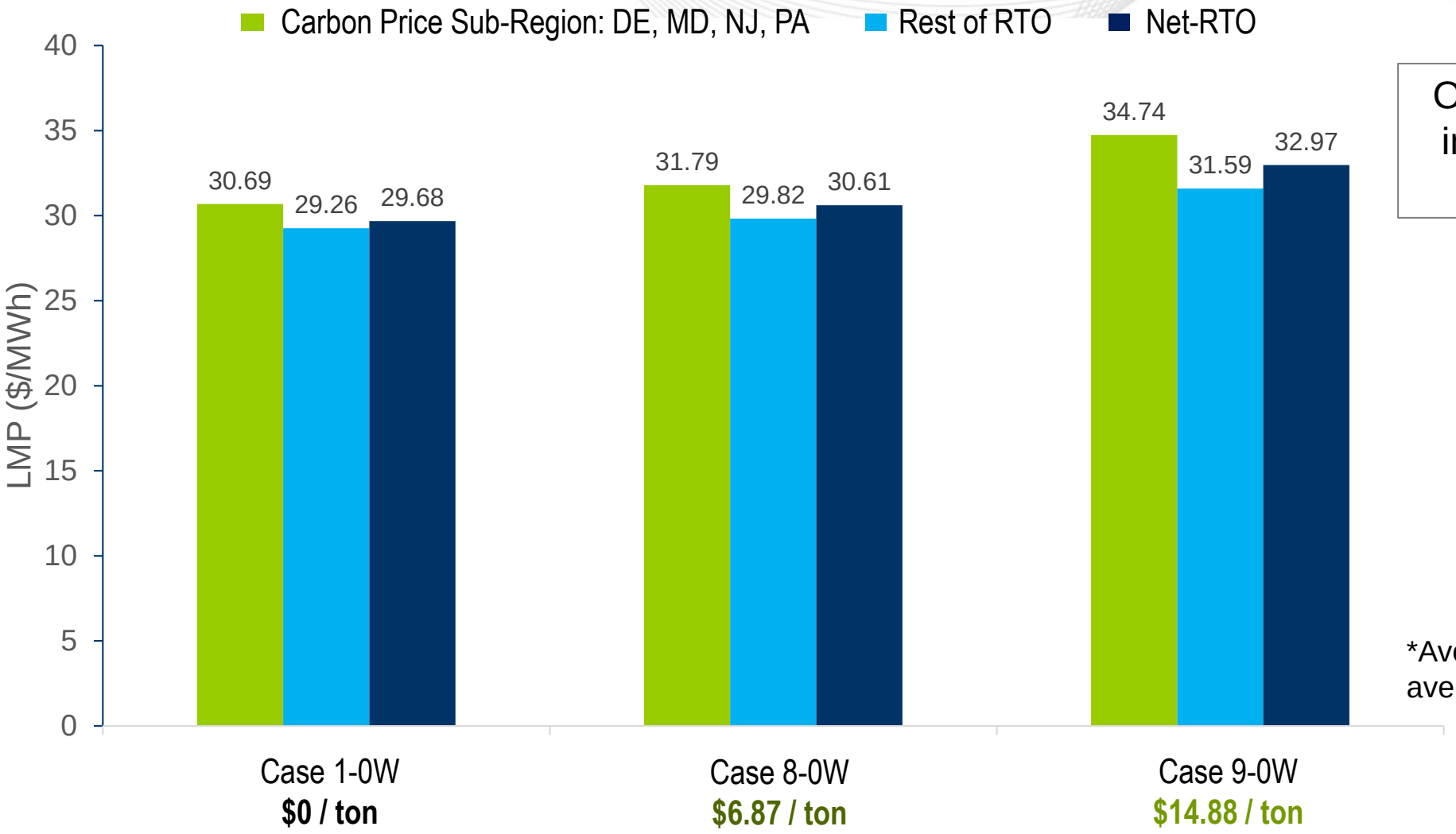
- Shifts in RTO generation and external interchange between cases are driving changes in emissions

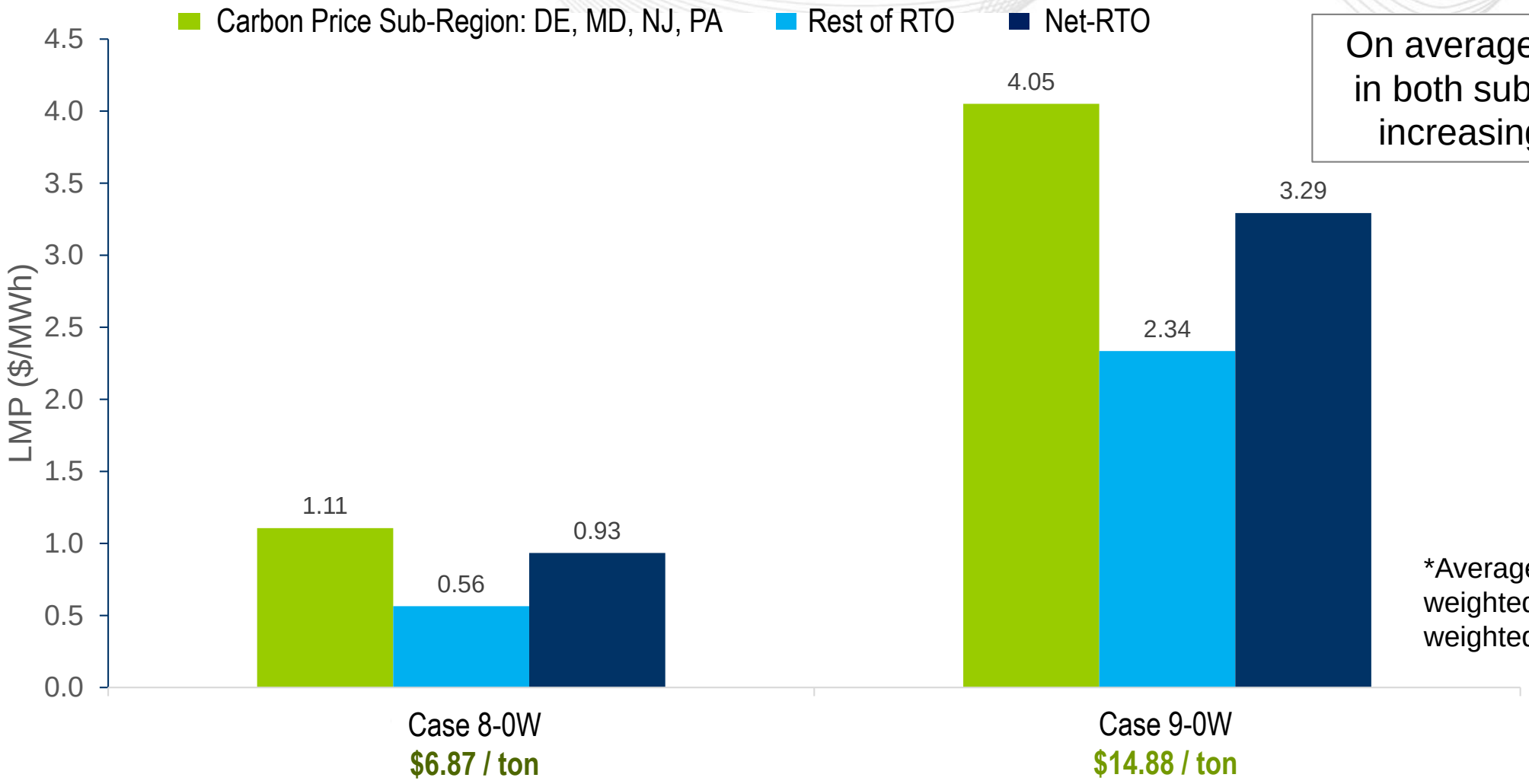
2023 PJM Average Yearly LMPs* by Sub-Region & Carbon Price



On average, LMPs increase in both sub-regions with an increasing carbon price.

*Average yearly LMPs are time-weighted averages of load-weighted hourly LMPs.

2023 Difference in Average Yearly LMPs* from Case 1-0W by Sub-Region & Carbon Price

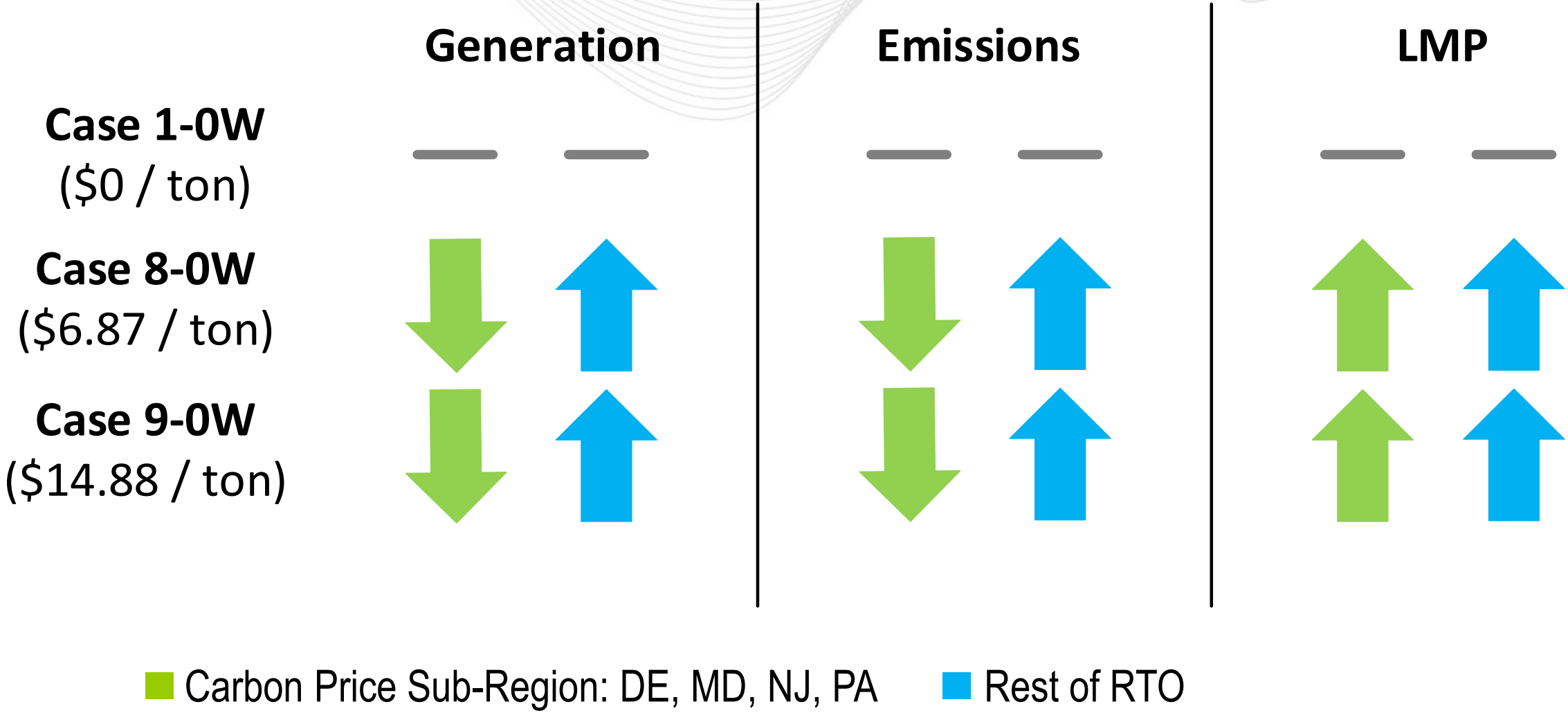


On average, LMPs increase in both sub-regions with an increasing carbon price.

*Average yearly LMPs are time-weighted averages of load-weighted hourly LMPs.

Results Summary

Part 1: Impacts Associated with a RGGI Carbon Price in the PJM Energy Market



- **Generation:**
  - Compared to the no carbon price scenario, the carbon price scenarios result in shifts in generation production from the Carbon-Price Sub-Region to the Rest of RTO.
  - The generation displaced in the Carbon-Price Sub-Region has relatively higher emissions intensity than the increased generation in the Rest of RTO. This is driven by the generation mixes between of each sub-region.

Results Summary (cont.)

Part 1: Impacts Associated with a RGGI Carbon Price in the PJM Energy Market
Carbon-Price Sub-Region: DE, MD, NJ, PA

- **Emissions:**
  - The shift in generation production results in a decrease in emissions in the Carbon-Price Sub-Region, an increase in emissions in the Rest of RTO, and a net decrease in emissions across the RTO.

- **Energy Prices:**
  - Compared to the scenario with no carbon price, on average, LMPs increase in both sub-regions as the carbon price increases.

Overview

Review of Context and Study Assumptions

Part 1: Impacts of a RGGI Carbon Price in the PJM Energy Market; **Addition of PA** to carbon-price sub-region

Part 2: Impacts of Potential Border Adjustments for Leakage Mitigation; **Addition of PA** to carbon-price sub-region

Leakage Mitigation Mechanism: Border Adjustments

- Two leakage mitigation mechanisms were studied and were compared against the case with no leakage mitigation
  1) No Border Adjustment (no leakage mitigation)
  2) One-Way Border Adjustment
  3) Two-Way Border Adjustment

- Each leakage mitigation mechanism was studied using the RGGI ECR price of $6.87/short ton and the RGGI CCR price of $14.88/short ton.

Part 2 Scenario Summary

Impacts of Potential Border Adjustments for Leakage Mitigation

- The year 2023 was simulated for the following cases for the carbon-price sub-region that included DE, MD, NJ and PA:

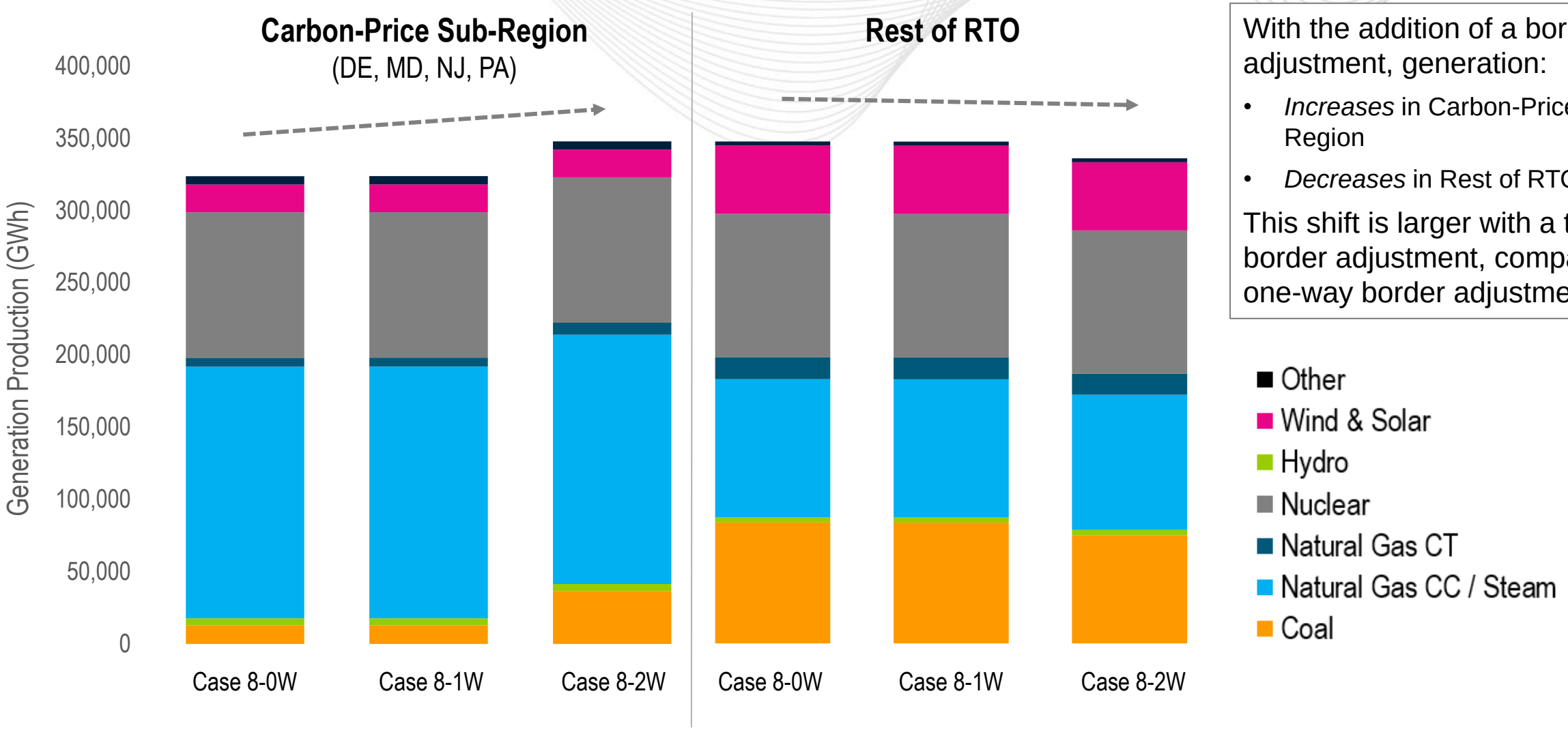
Case	RGGI Price	Border Adjustment
Case 8-0W	$6.87/short ton	None
Case 8-1W	$6.87/short ton	One-Way
Case 8-2W	$6.87/short ton	Two-Way
Case 9-0W	$14.88/short ton	None
Case 9-1W	$14.88/short ton	One-Way
Case 9-2W	$14.88/short ton	Two-Way

Results Metrics

- The following metrics are compared for each simulation case:
  - Generation
  - Emissions
  - Prices
  - Carbon Revenue (Residual Funds)

- Results are broken out by the following regions:
  - Carbon-Price Sub-Region – includes **DE, MD, NJ and PA**
  - Rest of RTO – all other states in PJM

2023 Generation Production by Sub-Region: **$6.87 / ton CO_2**

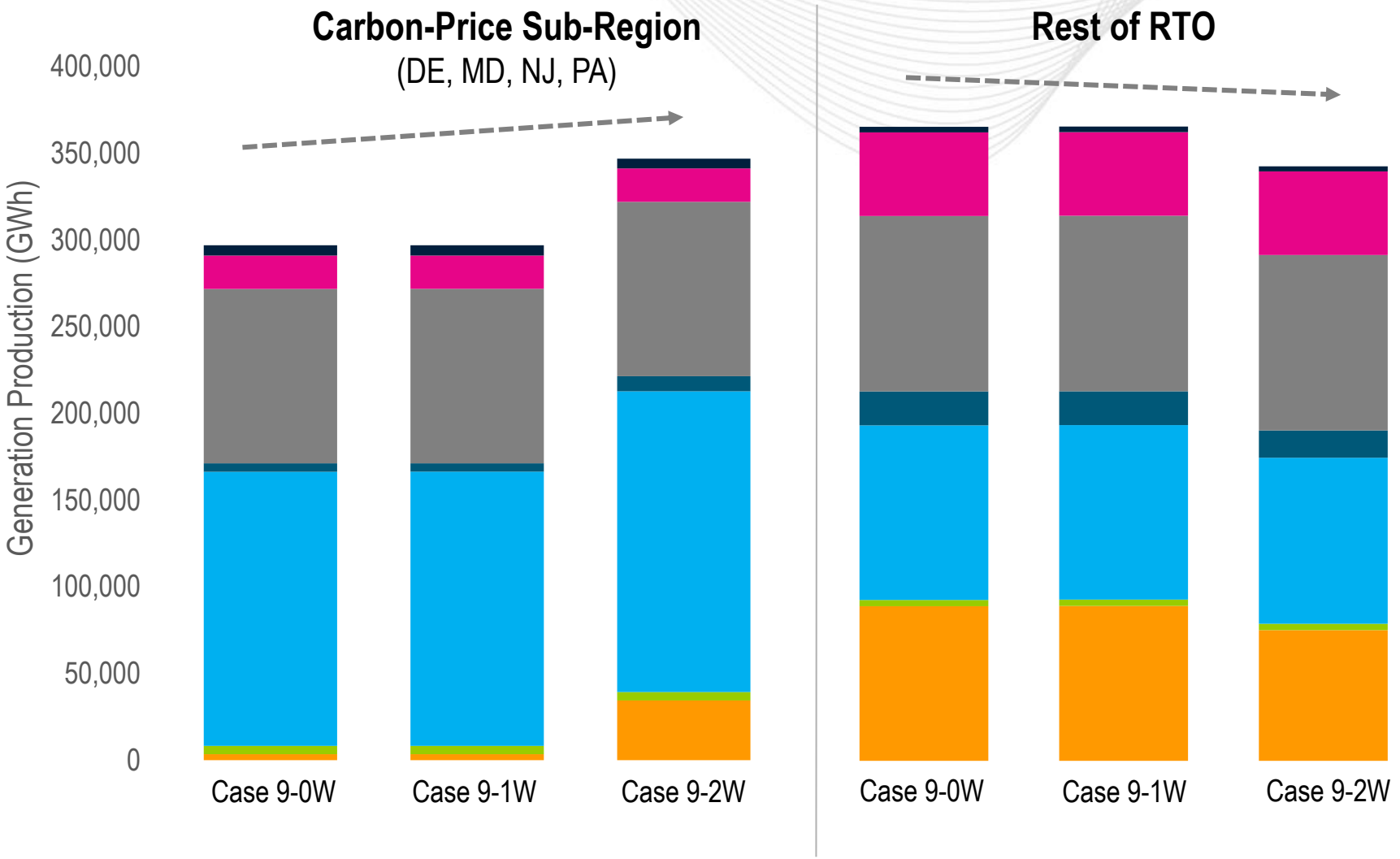


With the addition of a border adjustment, generation:

- *Increases* in Carbon-Price Sub-Region
- *Decreases* in Rest of RTO

This shift is larger with a two-way border adjustment, compared to a one-way border adjustment.

2023 Generation Production by Sub-Region: **$14.88 / ton CO_2**



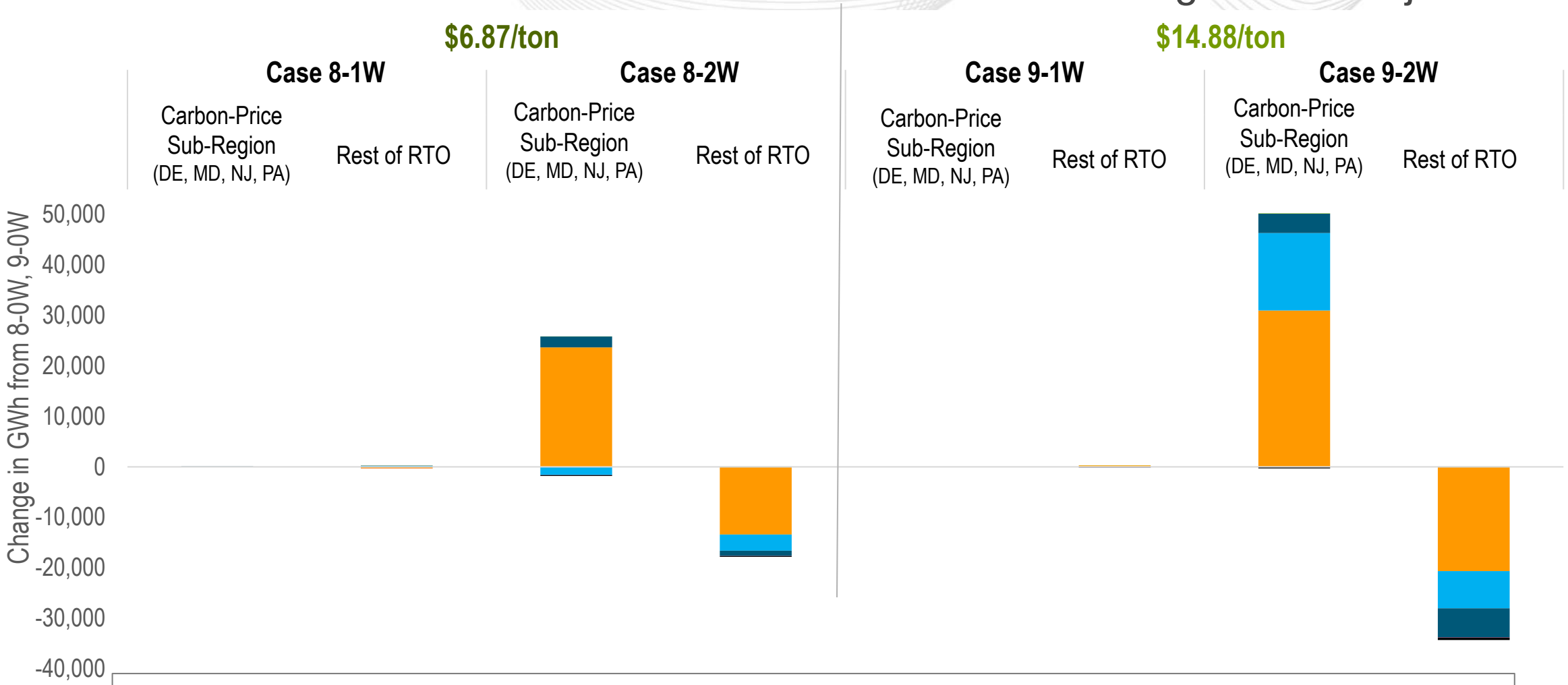
With the addition of a border adjustment, generation:

- *Increases* in Carbon-Price Sub-Region
- *Decreases* in Rest of RTO

This shift is larger with a two-way border adjustment, compared to a one-way border adjustment.

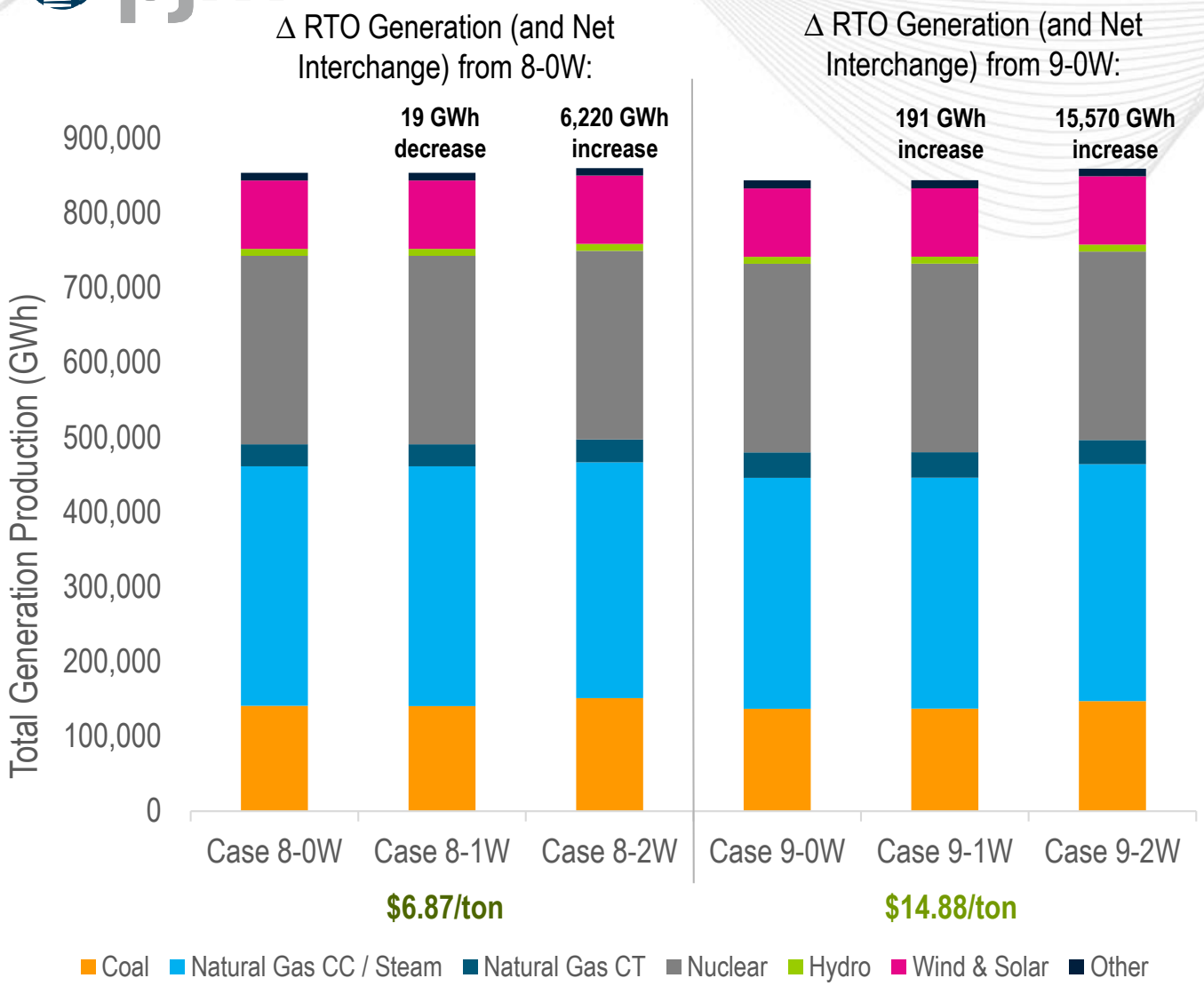
- Other
- Wind & Solar
- Hydro
- Nuclear
- Natural Gas CT
- Natural Gas CC / Steam
- Coal

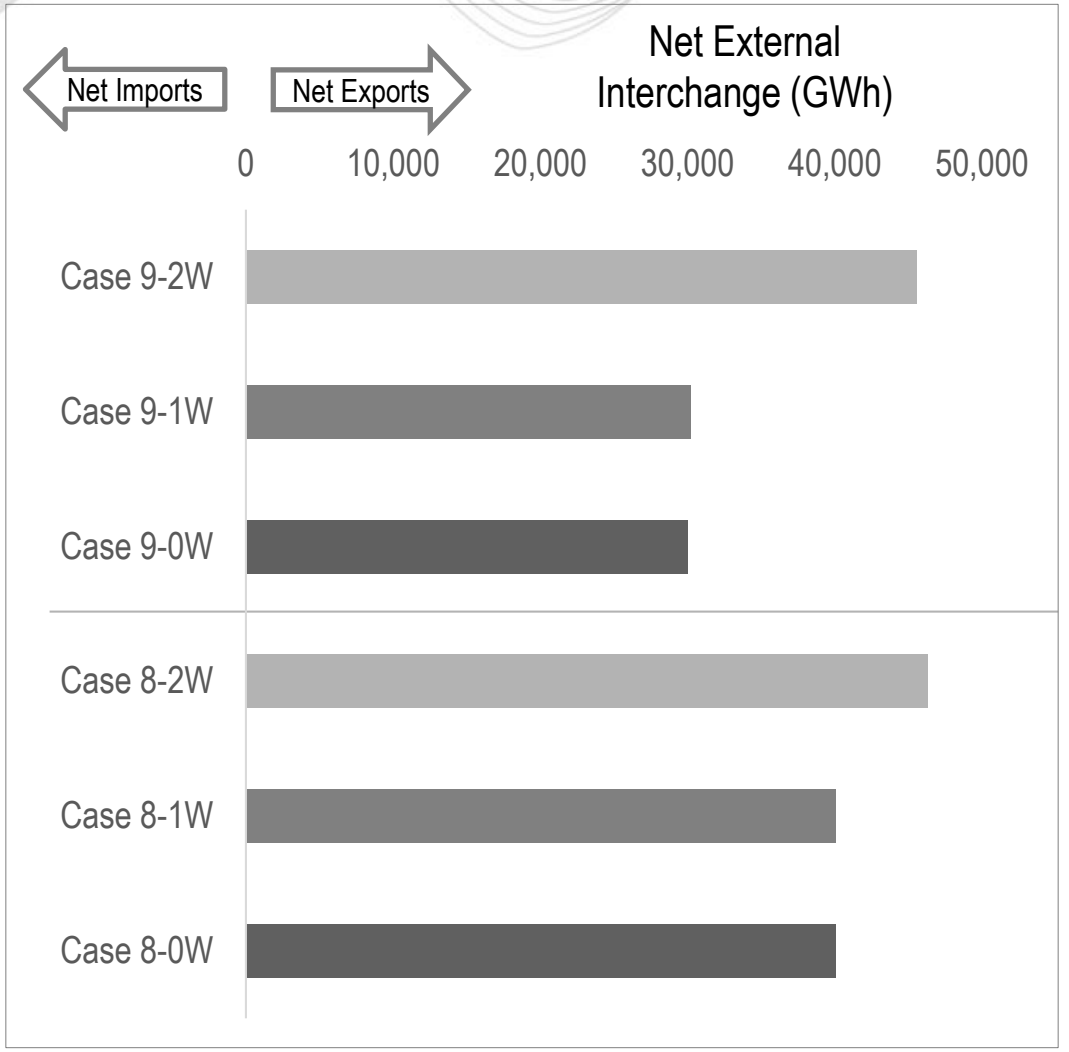
Shift in Generation Production by Sub-Region from adding Border Adjustment



Larger generation shift with a two-way border adjustment, compared to a one-way border adjustment. Increased generation in Carbon-Price Sub-Region has relatively equivalent emissions intensity to the displaced generation in rest of RTO.

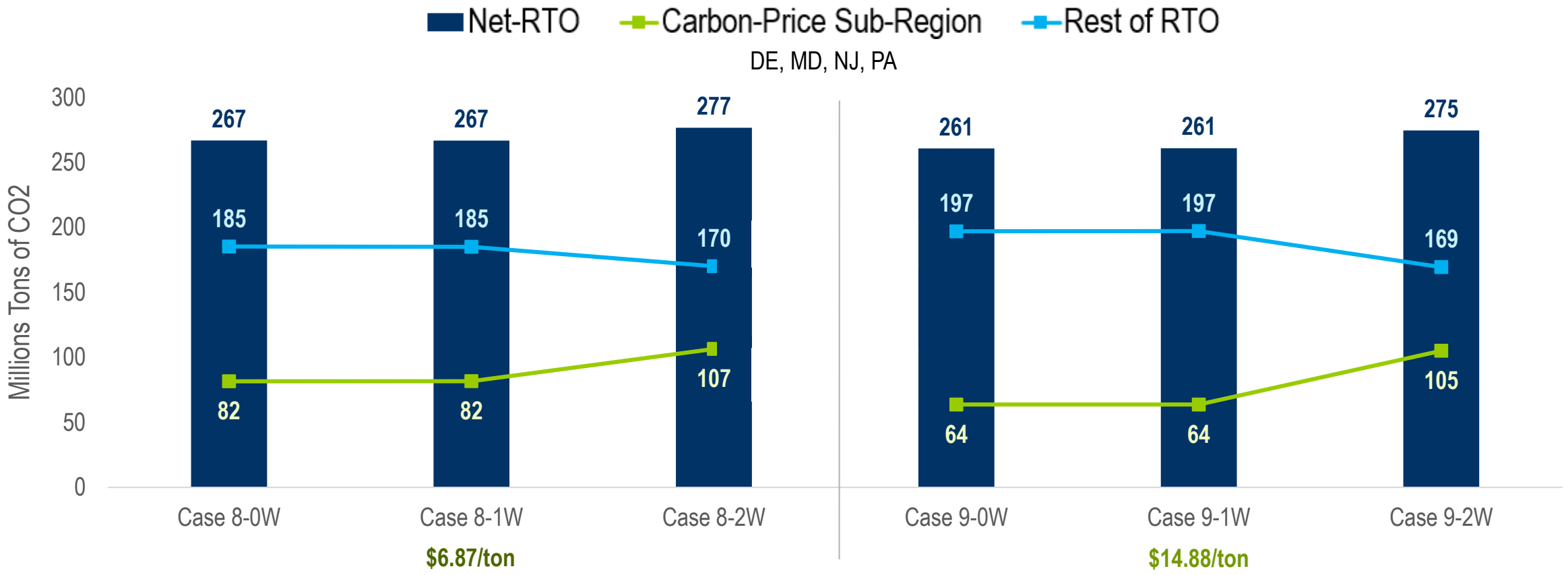
2023 Total RTO Generation Production and Net External Interchange





Impact of Border Adjustment on CO_2 Emissions

Generation shift from one-way border adjustment results in small emissions shifts between sub-regions, and small *net decrease* across Net-RTO. Two-way border adjustment results in emissions *increase* in Carbon-Price Sub-Region, *decrease* in Rest of RTO and *net increase* across Net-RTO.

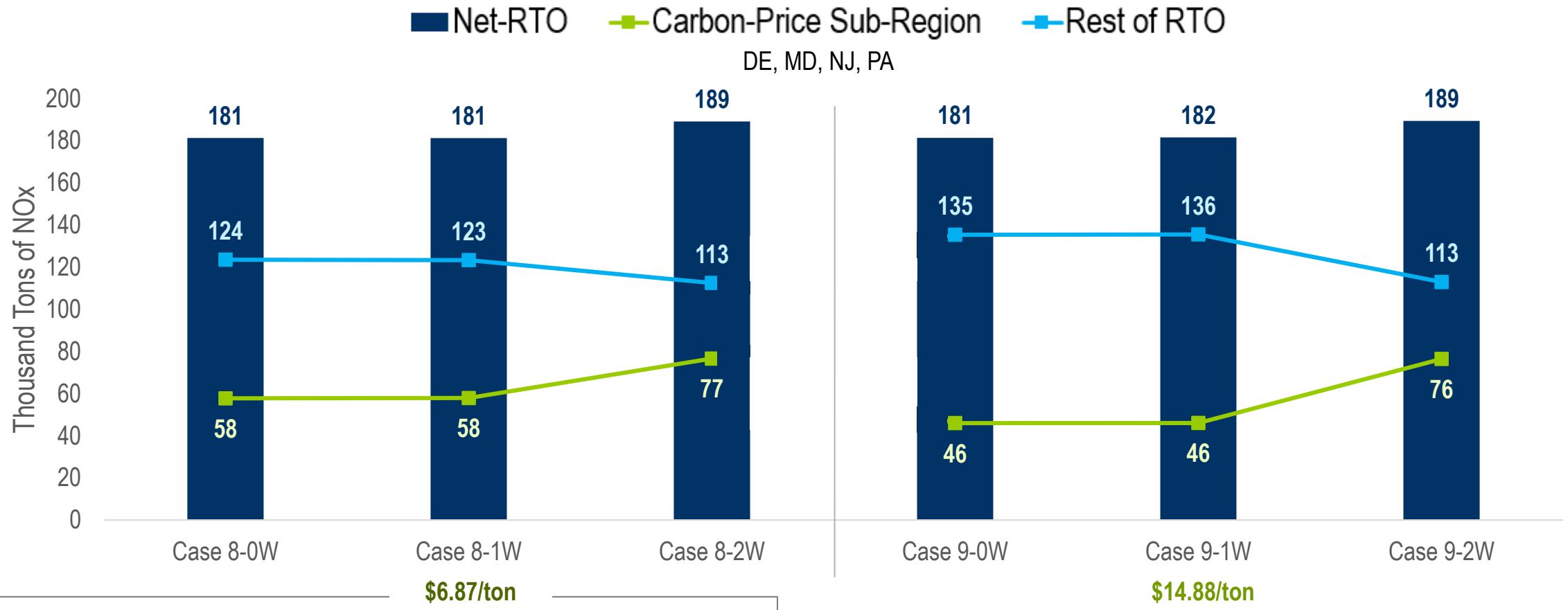


Note:

- Emissions are for PJM only and do not account for changes in external regions
- Shifts in RTO generation and external interchange between cases are driving changes in emissions

Impact of Border Adjustment on NO_X Emissions

Generation shift from one-way border adjustment results in small emissions shifts between sub-regions, and small *net decrease* across Net-RTO. Two-way border adjustment results in emissions *increase* in Carbon-Price Sub-Region, *decrease* in Rest of RTO and *net increase* across Net-RTO.



Note:

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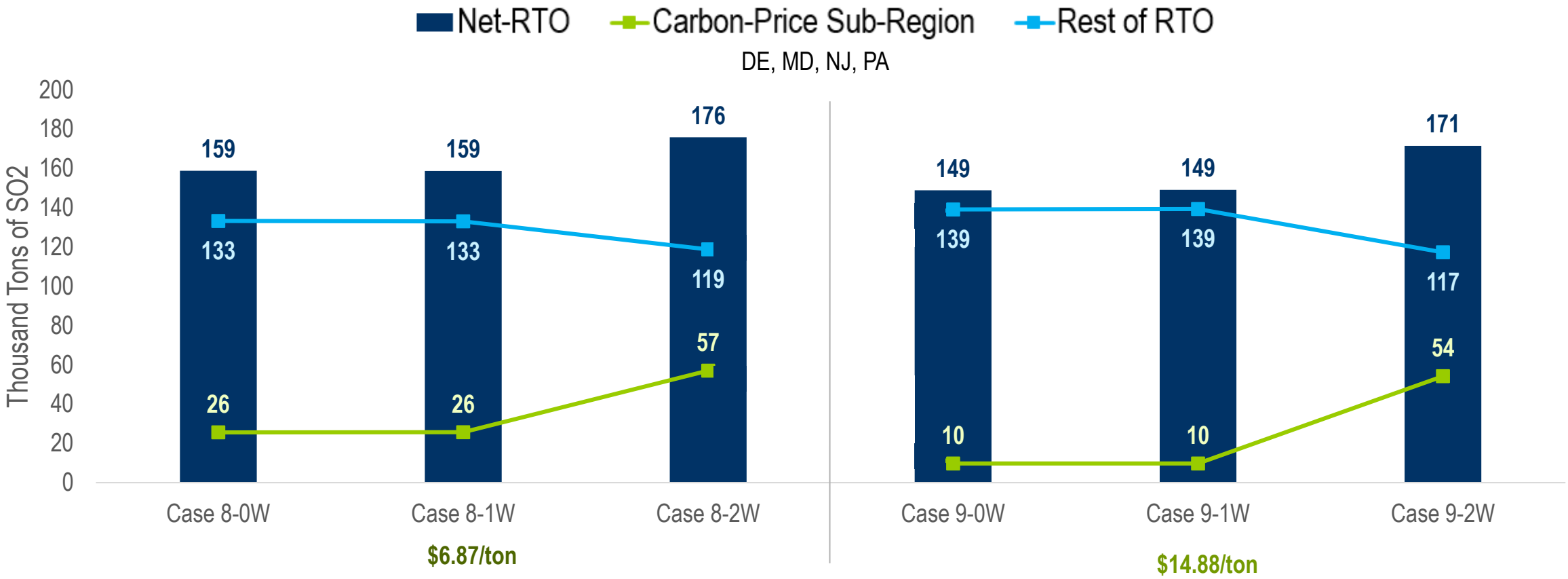
Impact of Border Adjustment on SO_2 Emissions

Generation shift from one-way border adjustment results in small emissions shifts between sub-regions, and small *net decrease* across Net-RTO. Two-way border adjustment results in emissions *increase* in Carbon-Price Sub-Region, *decrease* in Rest of RTO and *net increase* across Net-RTO.



Note:

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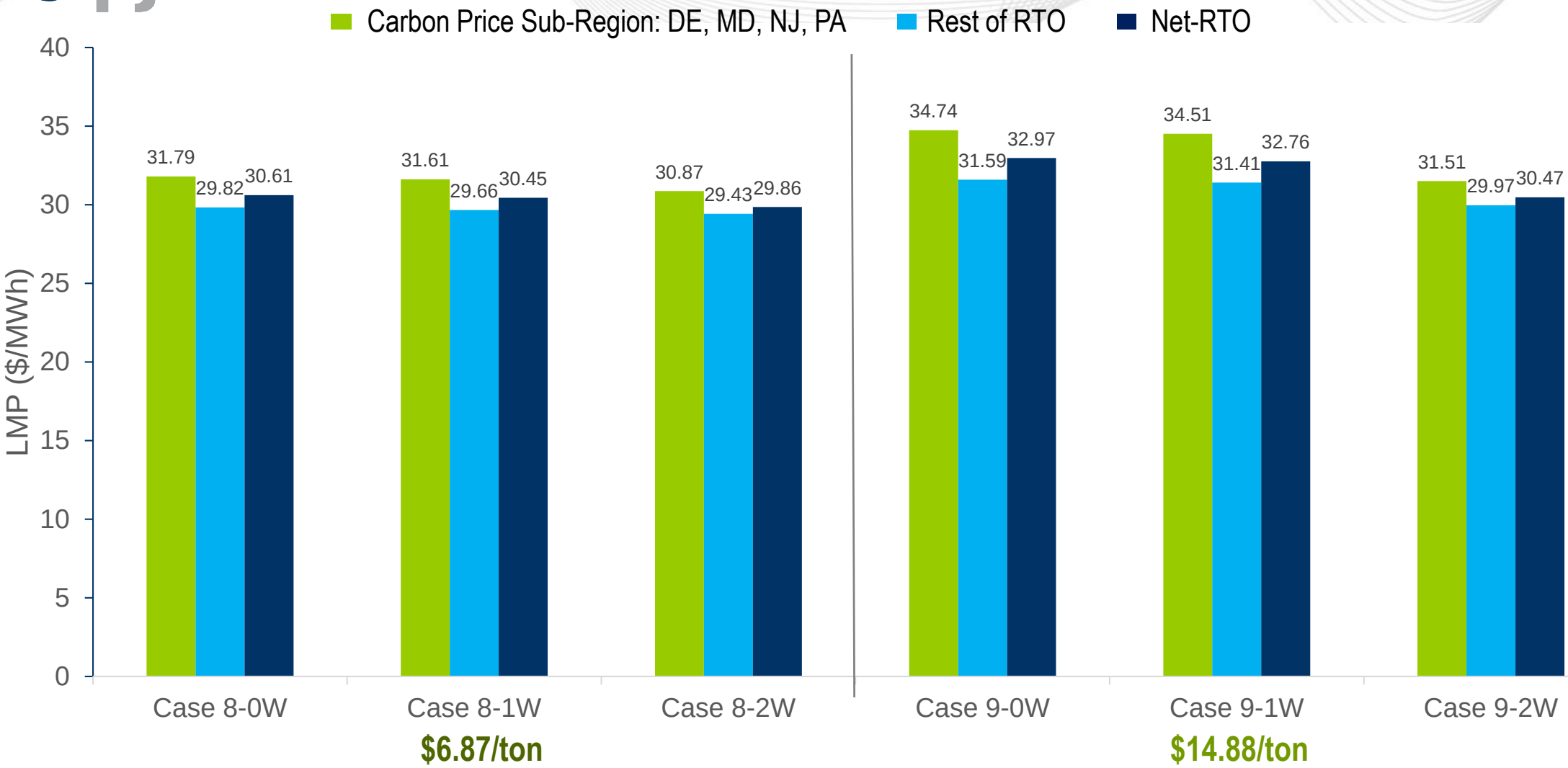
- Shifts in RTO generation and external interchange between cases are driving changes in emissions

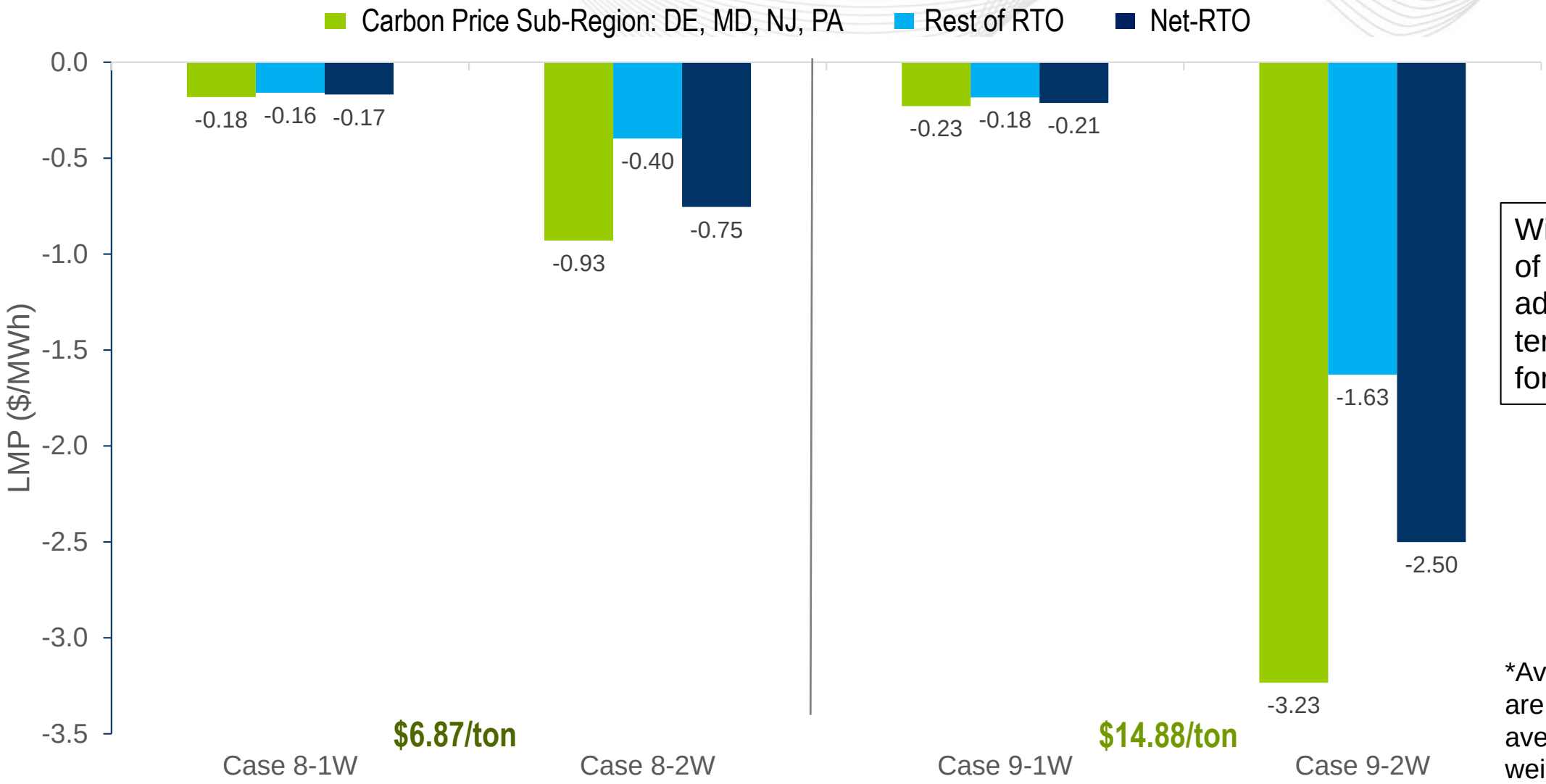
2023 PJM Average Yearly LMPs* by Sub-Region



With the addition of a border adjustment, LMPs tend to decrease for both regions.

*Average yearly LMPs are time-weighted averages of load-weighted hourly LMPs.

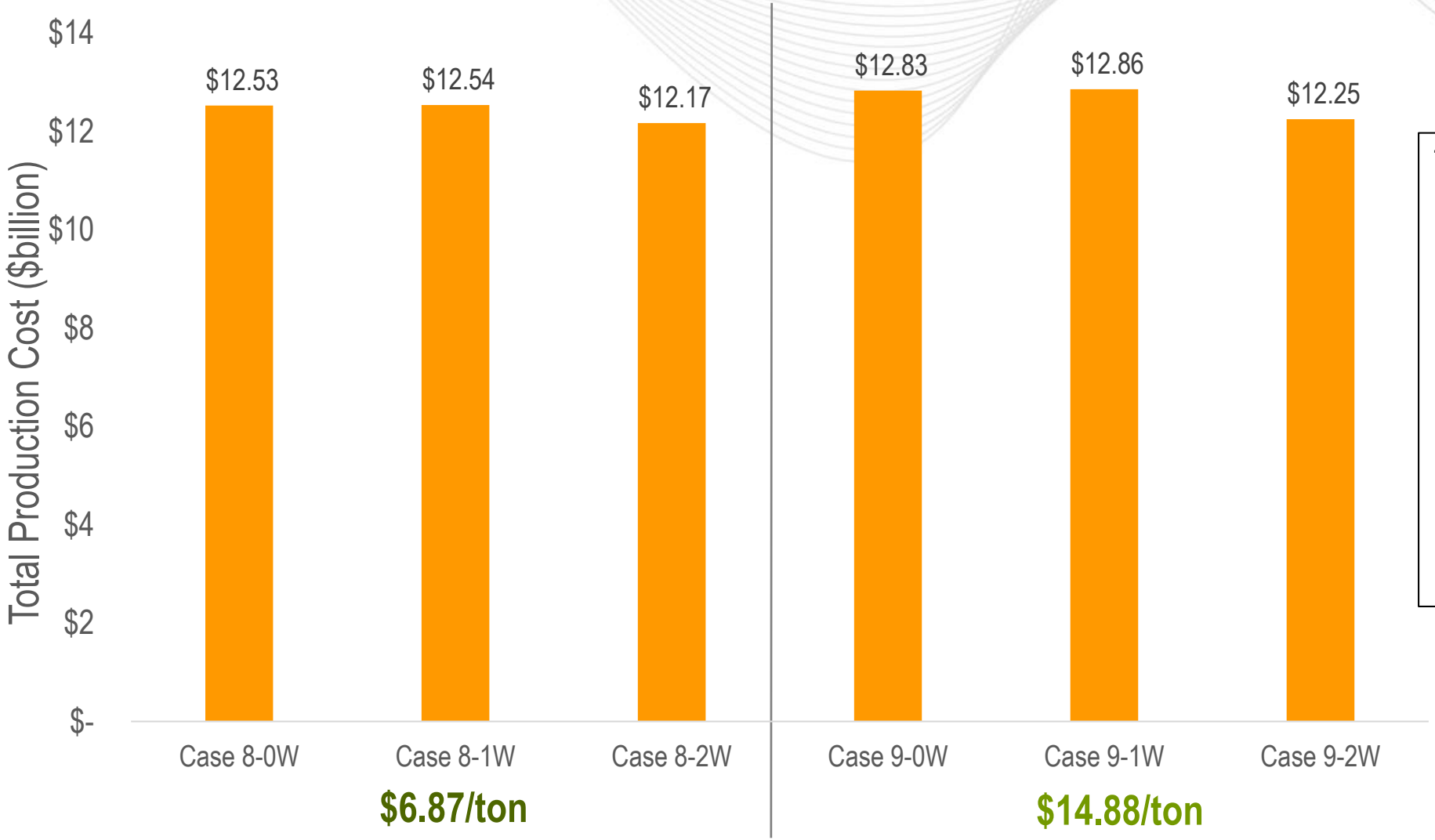
2023 Difference in Average Yearly LMPs* from Case 0W by Sub-Region and RGGI Price



With the addition of a border adjustment, LMPs tend to decrease for both regions.

*Average yearly LMPs are time-weighted averages of load-weighted hourly LMPs.

Impact of Border Adjustments on 2023 RTO Total Production Cost



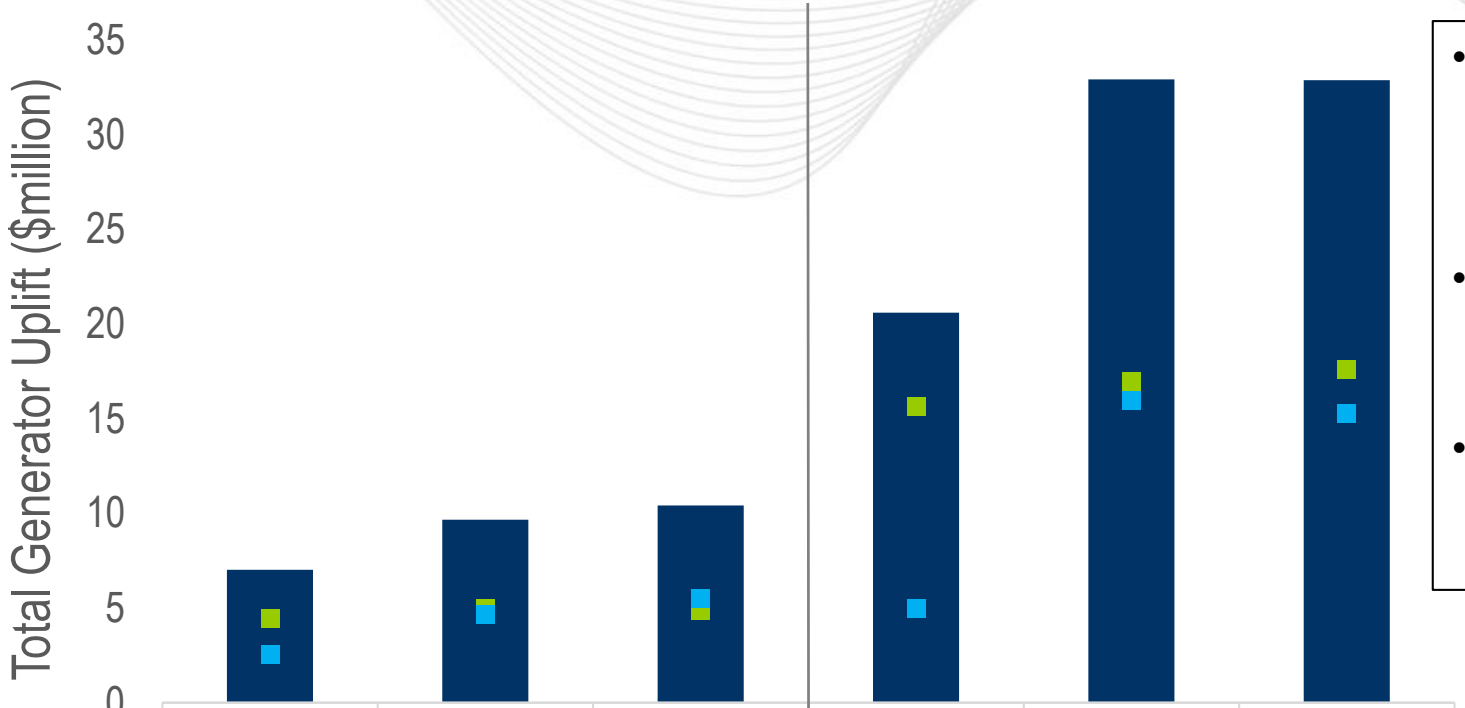
Total System Production Cost:

- *Increases* with a one-way border adjustment
- *Decreases* with a two-way border adjustment

Note:

- Total System Production Cost does not account for changes in generation in external regions

Impact of Border Adjustments on 2023 RTO Uplift*



	Case 8-0W	Case 8-1W	Case 8-2W	Case 9-0W	Case 9-1W	Case 9-2W
Net-RTO	$7.02	$9.66	$10.42	$20.61	$32.93	$32.89
Carbon-Price Sub-Region (DE, MD, NJ, PA)	$4.45	$4.99	$4.89	$15.63	$16.96	$17.62
Rest of RTO	$2.57	$4.67	$5.54	$4.98	$15.97	$15.27

$6.87/ton **$14.88/ton**

- Uplift is **approximated** as the revenue needed to make a unit whole to its costs for each day.
- Total uplift *increases* with either a one-way or two-way border adjustment
- This change in uplift may *increase* as the carbon price increases

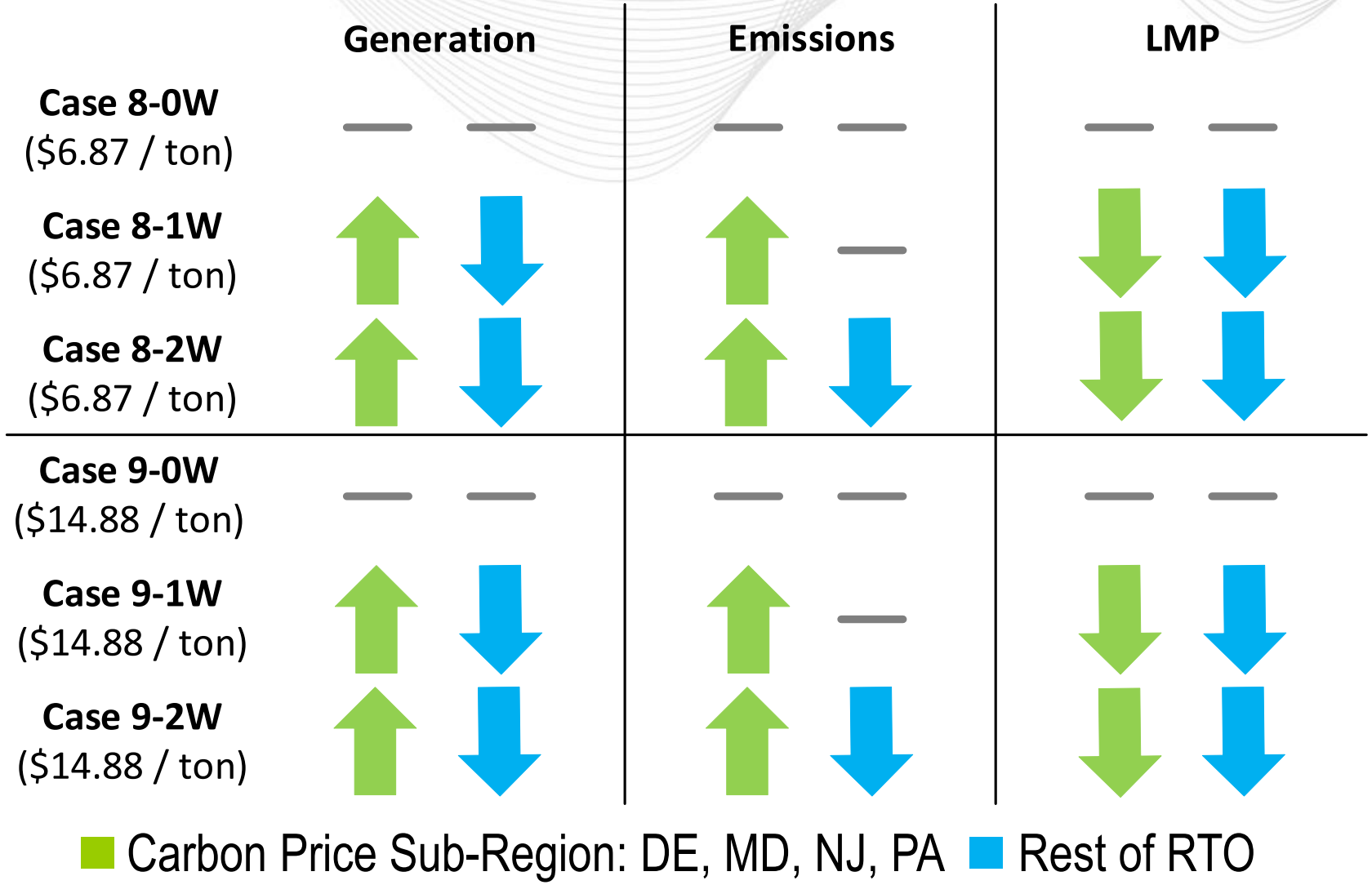
Impact of Border Adjustment on CO_2 Emission Costs to Generators

- As previously noted, compared to scenarios with no leakage mitigation, the border adjustment scenarios result in shifts in generation production from the Rest of RTO to the Carbon-Price Sub-Region.
- This could be assumed to increase the funds from CO_2 allowance sales that states would collect if the CO_2 compliance obligation continues to be placed on the emitting generators in their states.
- However, it is possible in the **two-way** border adjustment case, that generators will not receive enough revenue through the market to cover their RGGI compliance obligations (which are paid outside the market) and generation costs.

- In all simulation cases, there are no carbon residual funds at any time.
- This is because the carbon component of the LMP is $0/MWh at all times in all cases.
- In other words, the carbon cost of the marginal unit being transferred from the Rest of RTO Sub-Region to the Carbon-Price Sub-Region is zero in all the simulation cases.

Results Summary

Part 2: Impacts of Potential Border Adjustments for Leakage Mitigation



- **Generation:**
  - Compared to scenarios with no leakage mitigation, the border adjustment scenarios result in shifts in generation production from the Rest of RTO to the Carbon-Price Sub-Region.
  - This generation shift increases as the price of carbon increases, and is greater with a two-way border adjustment, compared to a one-way border adjustment.
  - The generation displaced in the Rest of RTO is of relatively equivalent emissions intensity to the increased generation in the Carbon-Price Sub-Region. This is reflective of the in generation mixes in each sub-regions.

- **Emissions:**
  - Use of a one-way border adjustment mechanism resulted in an increase in emissions in the Carbon-Price Sub-Region, a decrease in emissions in the Rest of RTO, and a *net decrease* in total Net-RTO emissions.
  - Use of a two-way border adjustment mechanism resulted in an increase in emissions in the Carbon-Price Sub-Region, a decrease in emissions in the Rest of RTO, and a *net increase* in total Net-RTO emissions.
  - The change in emissions is greater as the carbon price increases.

- **Energy Prices:**
  - Use of a border adjustment mechanism may mitigate the impact of a carbon price on the LMP.
  - Compared to scenarios with no leakage mitigation, on average, as the carbon price increases, a two-way border adjustment results in greater price decreases than a one-way border adjustment.