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

Carbon Pricing Senior Task Force

August 21, 2020

Schedule

July 2019 Meeting:
Reviewed objectives and proposed assumptions for the PJM Carbon Study

January 2020 Meeting:
Reviewed objectives and initial modeling results

March & May 2020
Additional analysis results posted

Today:
Review objectives and additional scenarios taking into account stakeholder feedback

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

✓ Complete

● Future

Modeling Sensitivities

1. Addition of VA to Carbon-Price Sub-Region ✓
2. Addition of VA & PA to Carbon-Price Sub-Region ✓
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)* ✓

Scenario Summary

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

* Applied to offers of resources that meet the RGGI program's "CO2 Budget Source" definition

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.

Review of Leakage Concepts

- Broadly defined, leakage refers to 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]

[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

Context for Leakage Mitigation in Study

There are multiple approaches to leakage mitigation:

- *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

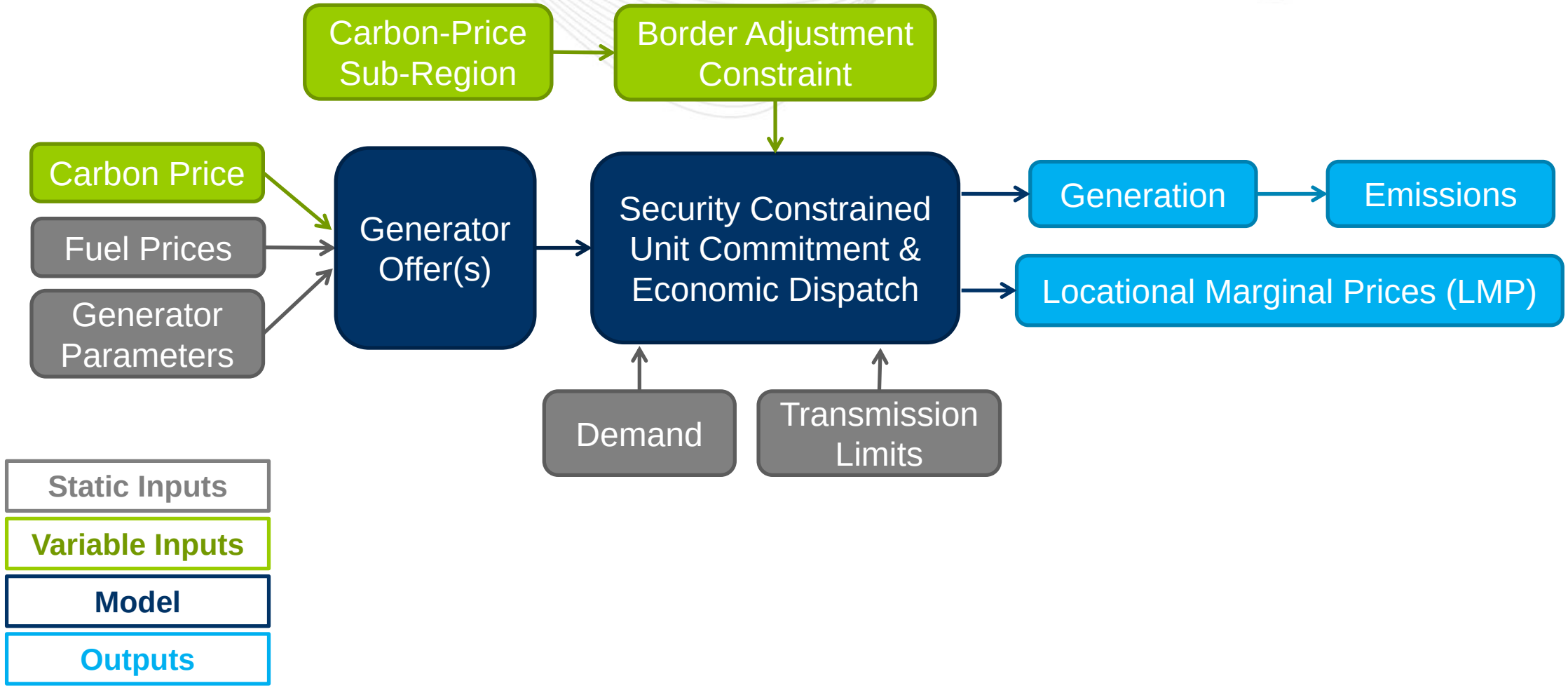
- *In study:* Border adjustment constraints within wholesale electricity market
  - One-way (transfers into carbon region)
  - Two-way (transfers into and out of carbon region)

Study Methodology

- Evaluate the impacts of a carbon price and potential leakage mitigation mechanisms on the PJM energy market by simulating the commitment and dispatch of resources, and the resulting market and emissions outcomes:
  - Utilized PLEXOS, a production cost modeling tool that performs security constrained unit commitment and economic dispatch over a given time horizon & granularity.
    - Provided flexibility needed to model system complexities while developing custom constraints for simulating border adjustments for leakage mitigation.
  - Current phase will model **2023** (most recent planning case from Regional Transmission Expansion Plan and Market Efficiency process)
  - Future analysis may include longer-term modeling to evaluate potential changes to resource mix from application of a carbon price – *out of scope for current phase*.

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

Study Methodology: Modeling Overview



Study Variables

- Carbon Price
- Carbon-Price Sub-Region
- Border Adjustment Approaches

Study Variables: **Carbon Price**

Assumed carbon price in PJM comes from Regional Greenhouse Gas Initiative (RGGI), and was modeled at $6.87/short ton of CO_2 as a low-end reference and $14.88/short ton of CO_2 as a high-end reference.

- $6.87/short ton is the trigger price for the RGGI Emissions Containment Reserve (ECR) in 2023. $14.88/short ton is the trigger price for the RGGI Cost Containment Reserve (CCR) in 2023. [1]

Carbon price is applied to the offers of resources that meet the RGGI program's "CO_2 Budget Source" definition.

- A "CO_2 Budget Source" under RGGI is a fossil-fuel-fired electric power generator with a capacity of 25 MW or greater within a RGGI state. [1]
- 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.

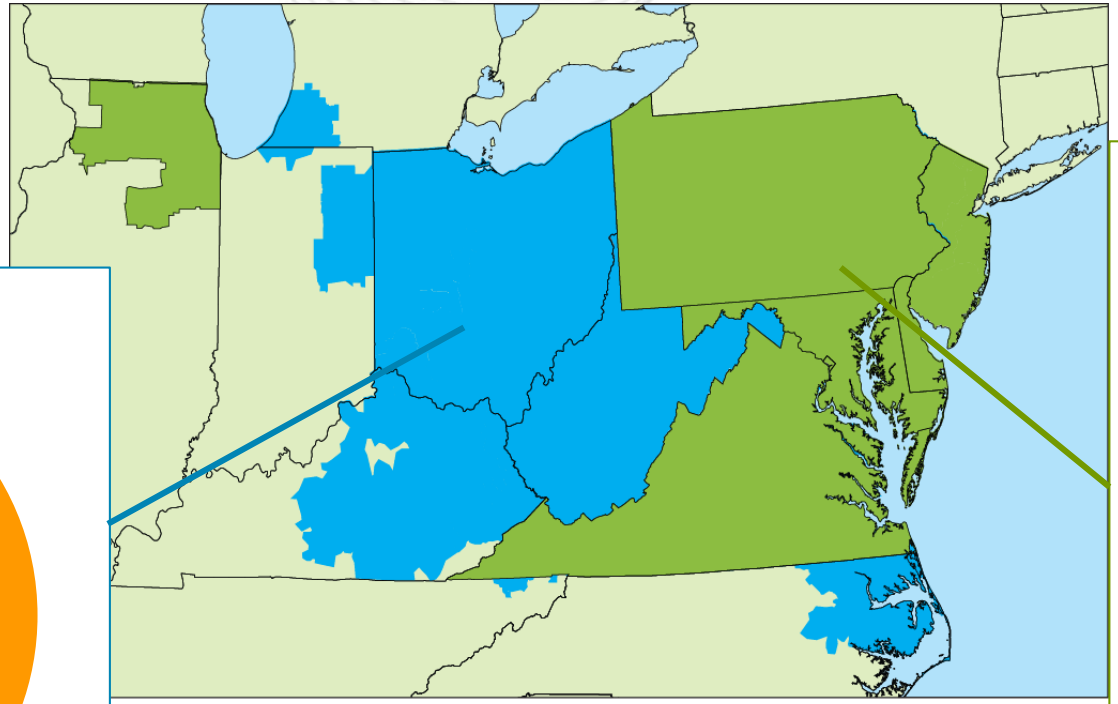
[1] RGGI 2017 Model Rule, https://www.rggi.org/sites/default/files/Uploads/Design-Archive/Model-Rule/2017-Program-Review-Update/2017_Model_Rule_revised.pdf

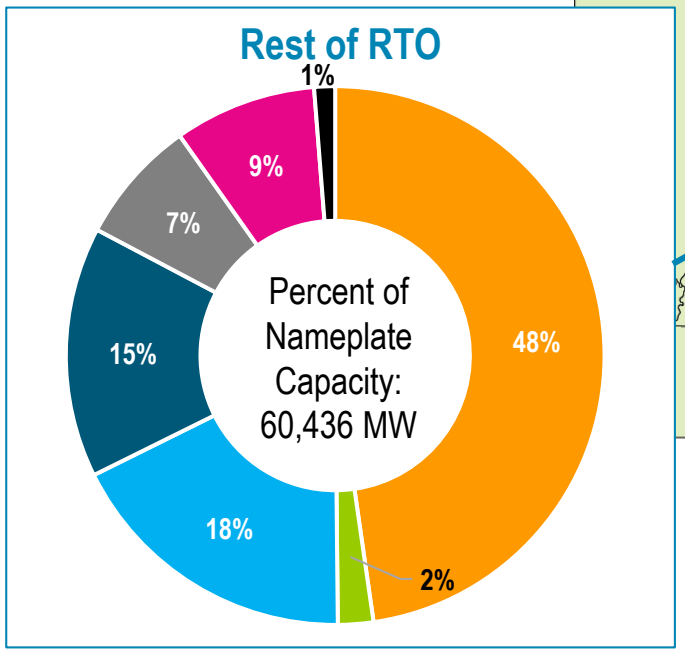
Study Variables: **Carbon-Price Sub-Region Definition**

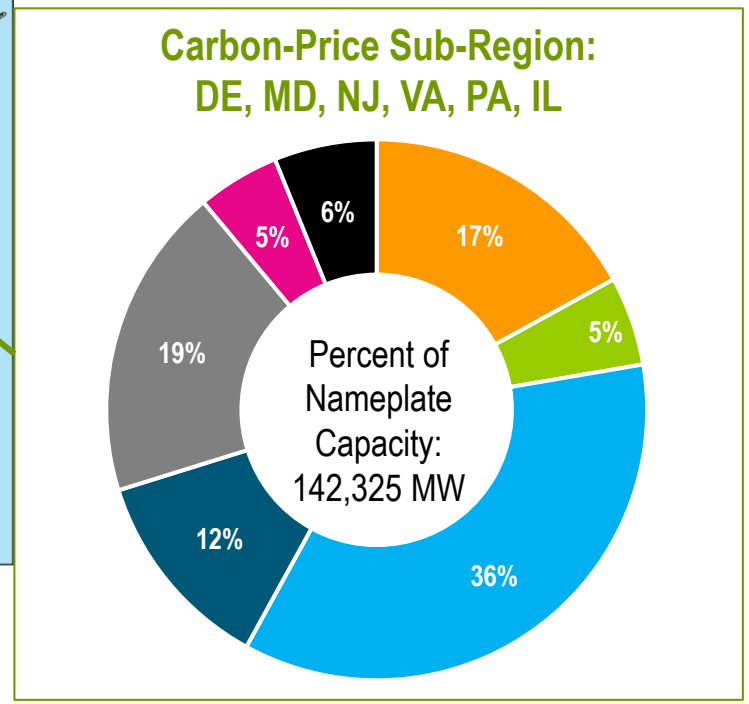
- The current set of results consider PJM states currently participating in RGGI (DE, MD, NJ) in addition to IL, PA and VA as part of the carbon-price sub-region.
  - Note: New York is modeled with a carbon price, as it is a RGGI state. Study results are focused on the PJM RTO.

States included in Carbon-Pricing 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

Carbon Revenue – RGGI Revenue

- 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.

Carbon Revenue – Residual Funds

- 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.

Results Overview for 8/21/2020 CPSTF

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

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

Part 1 Scenario Summary

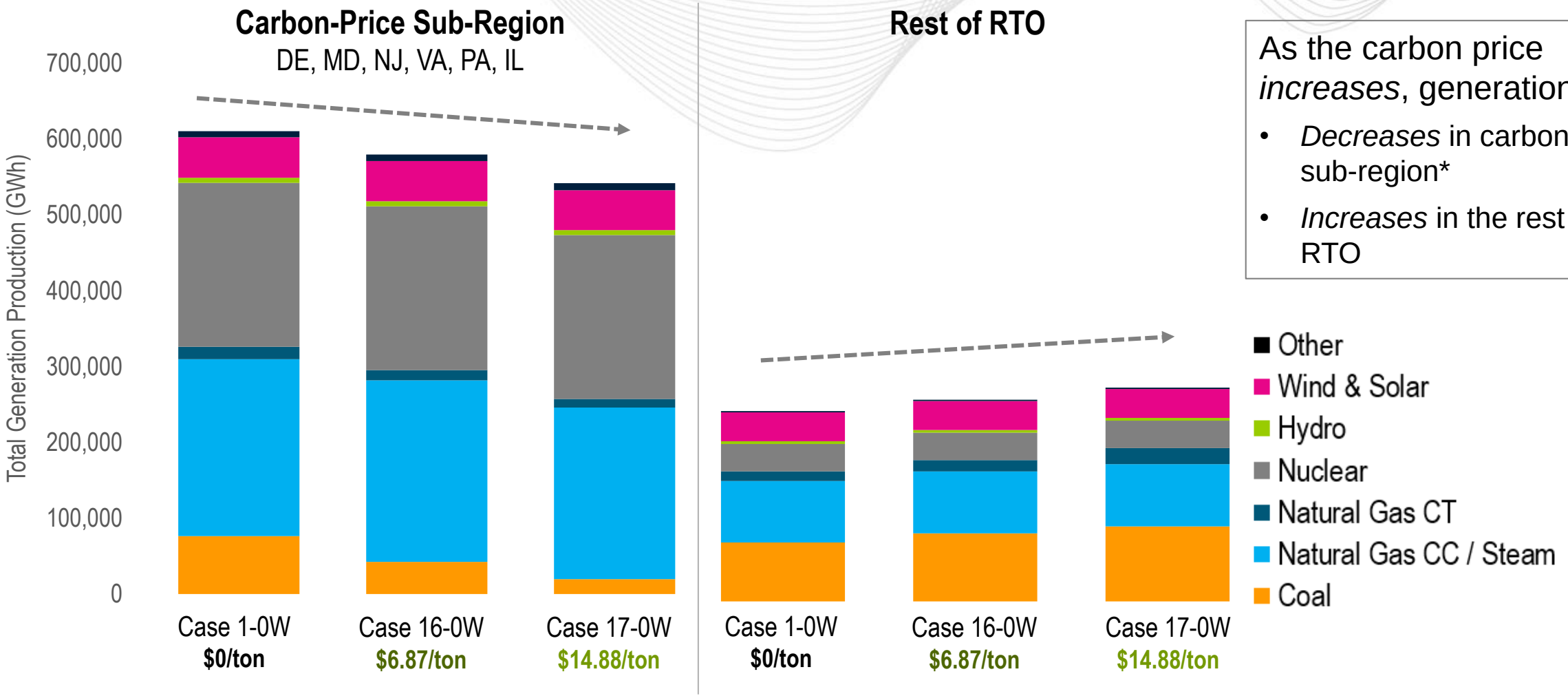
Impacts Associated with a RGGI Carbon Price in the PJM Energy Market

- 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	Carbon Price	Border Adjustment
Case 1-0W	$0/short ton (i.e. "No RGGI Price")	None
Case 16-0W	$6.87/short ton	None
Case 17-0W	$14.88/short ton	None

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

2023 Generation Production by Sub-Region

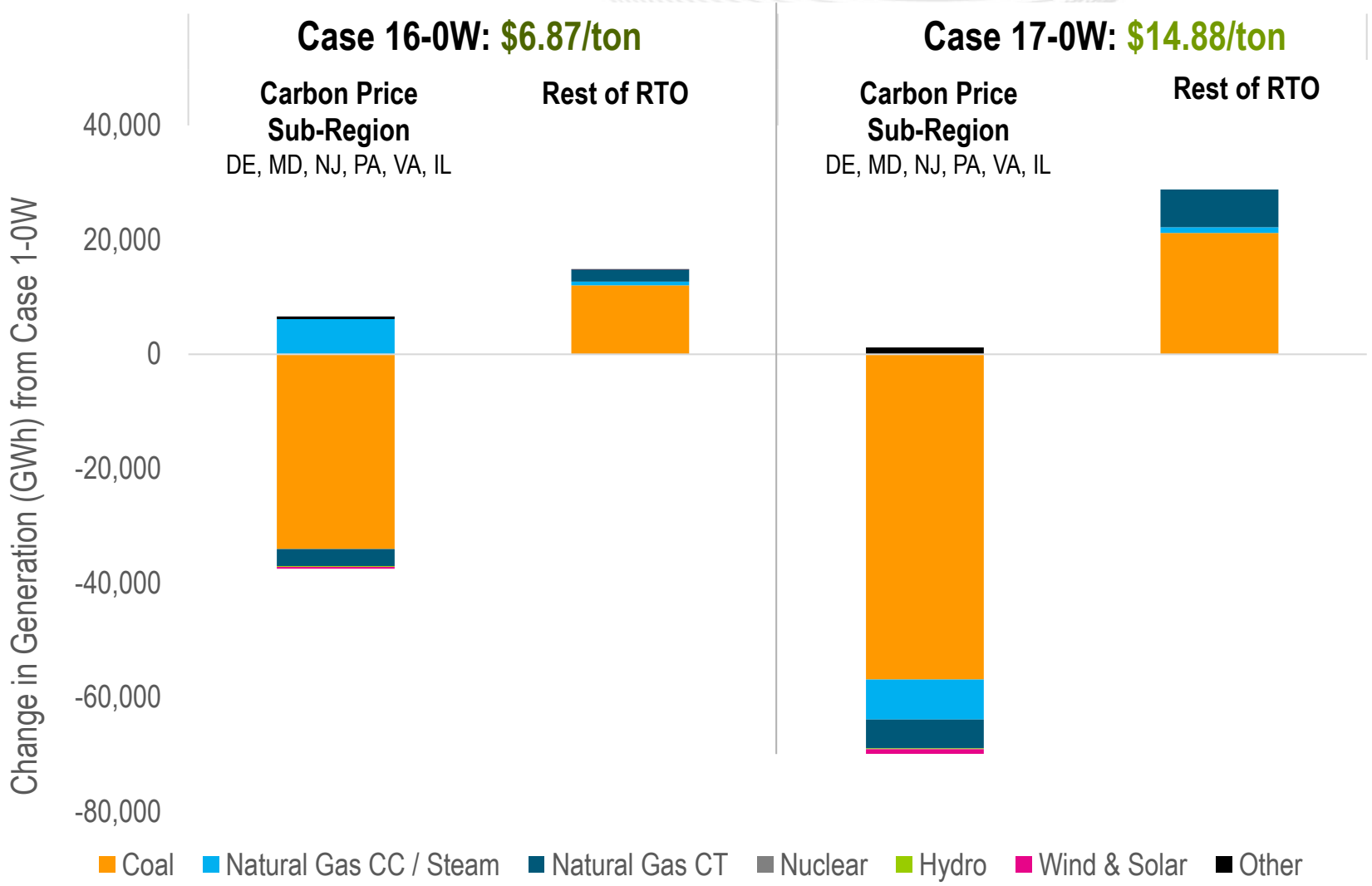


As the carbon price *increases*, generation:

- *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.

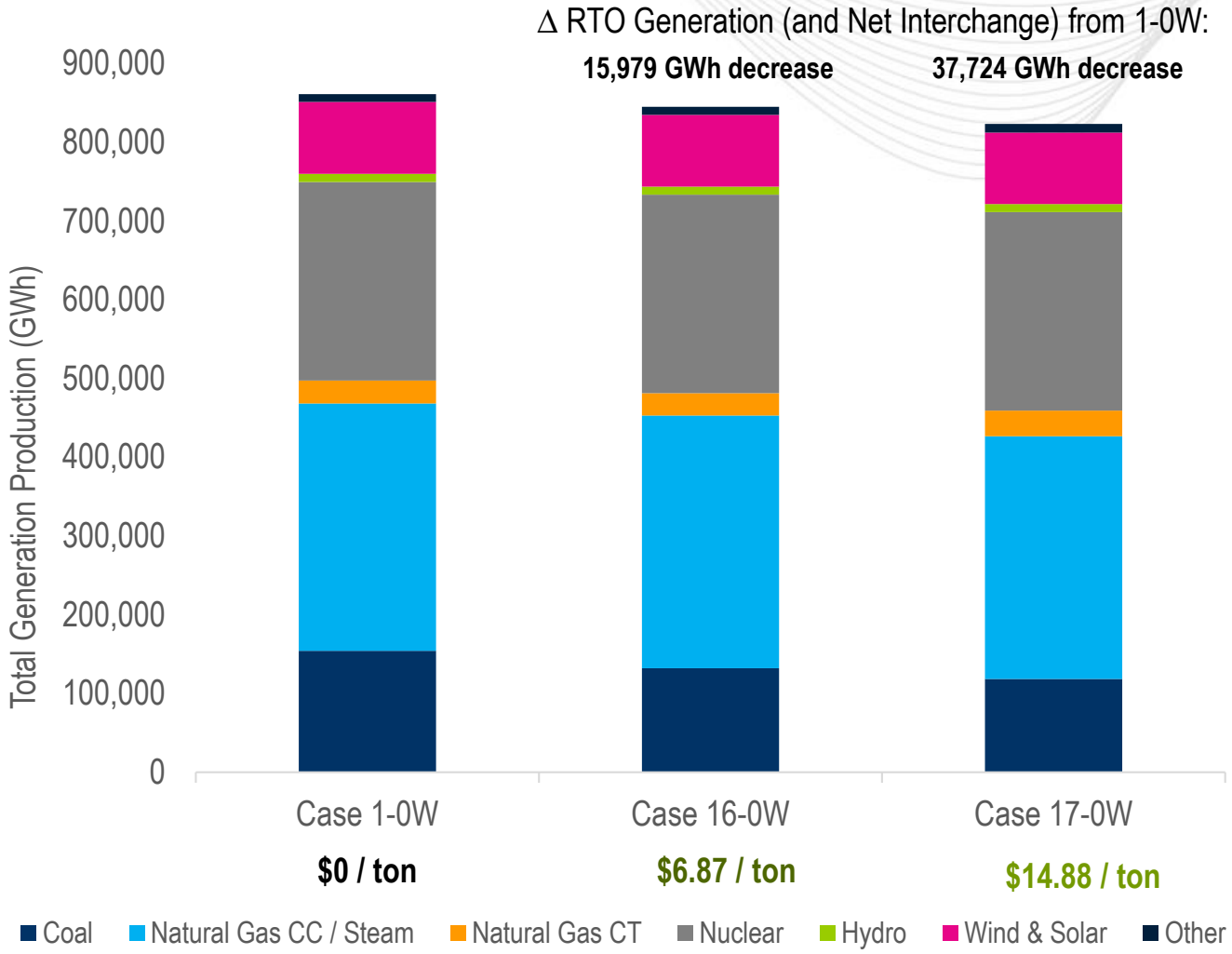
2023 Shifts in Generation Production from Case 1-0W ($0/ton CO_2) by Sub-Region

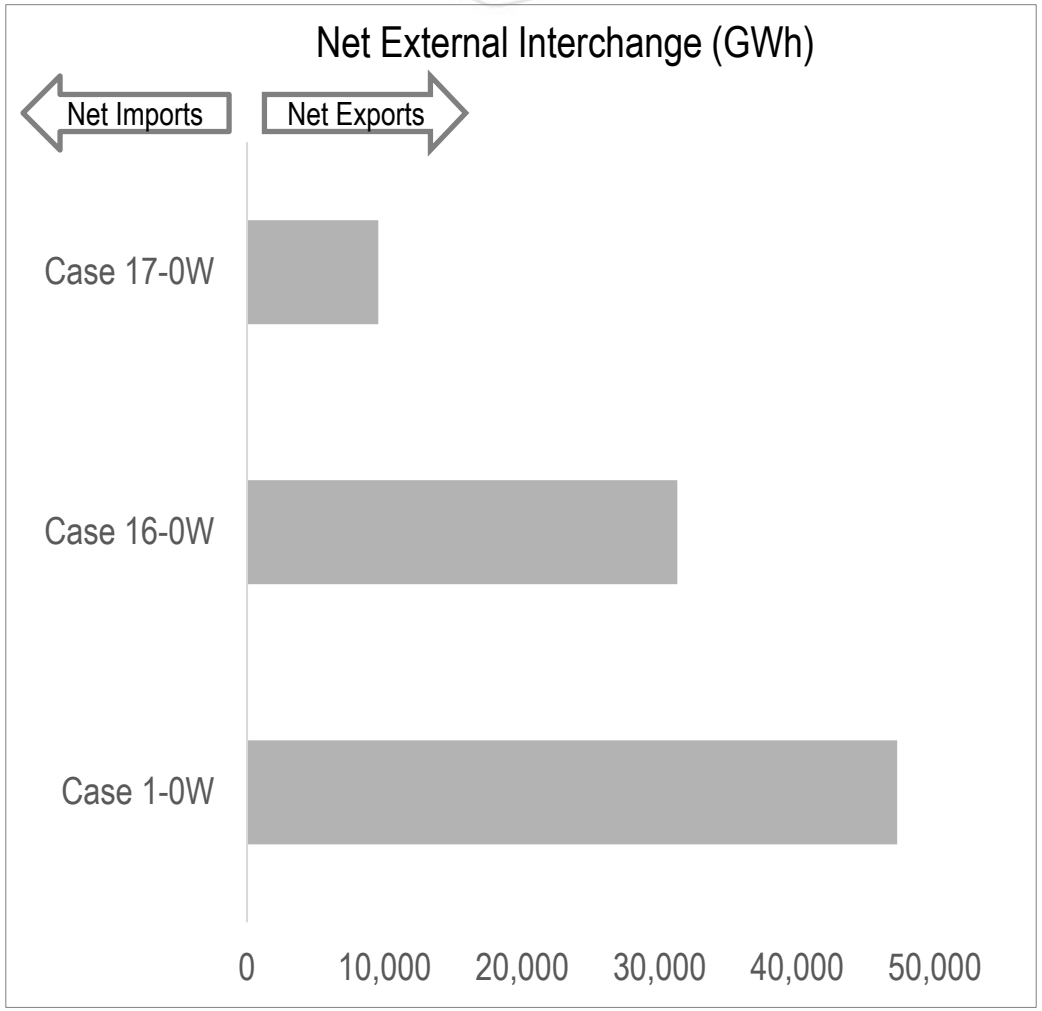


Generation displaced in carbon-price sub-region is relatively equivalent in emissions intensity to the increased generation in rest of RTO.

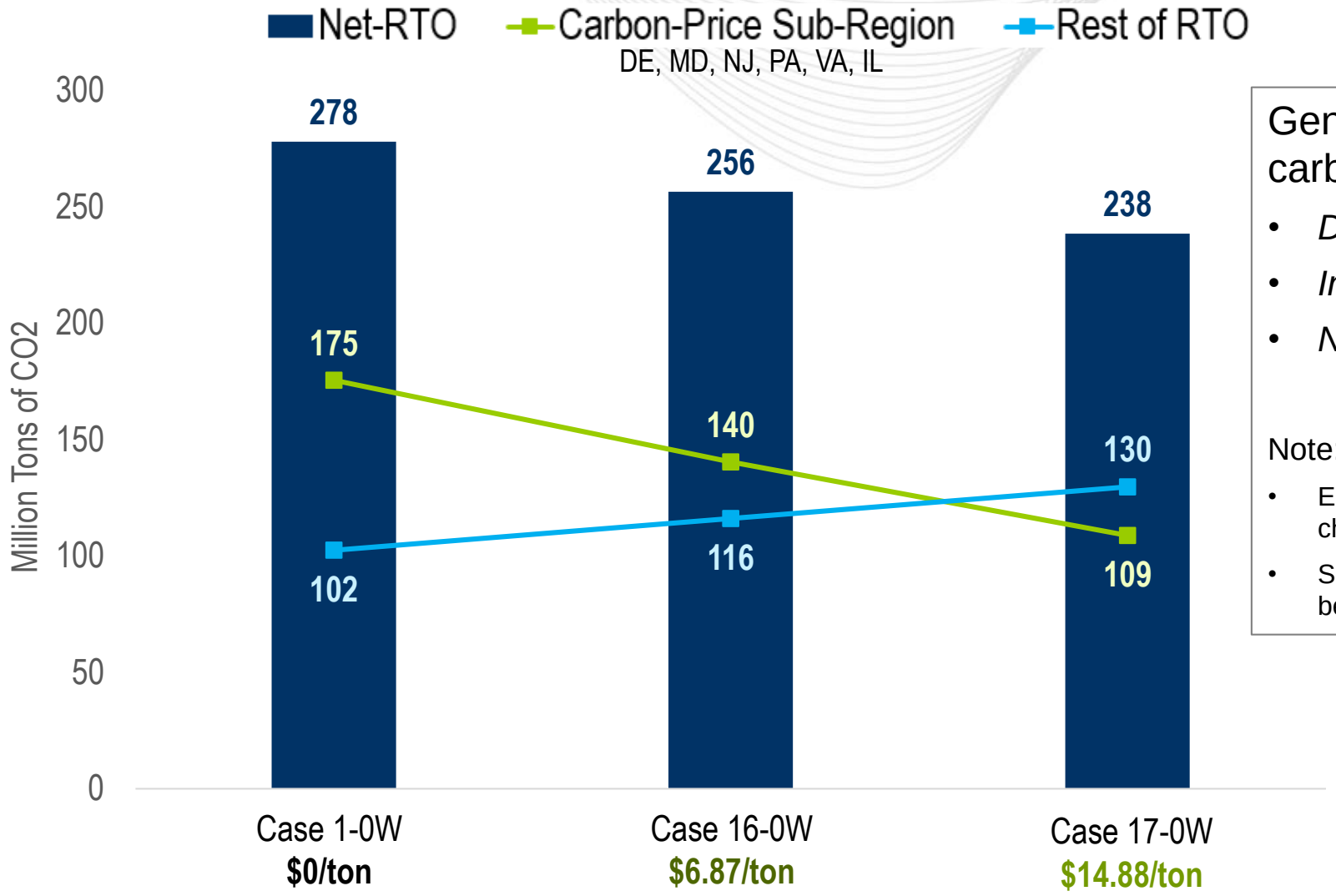
- Driven by generation mixes in each sub-region.

Interchange between PJM and External Regions





2023 Total CO_2 Emissions



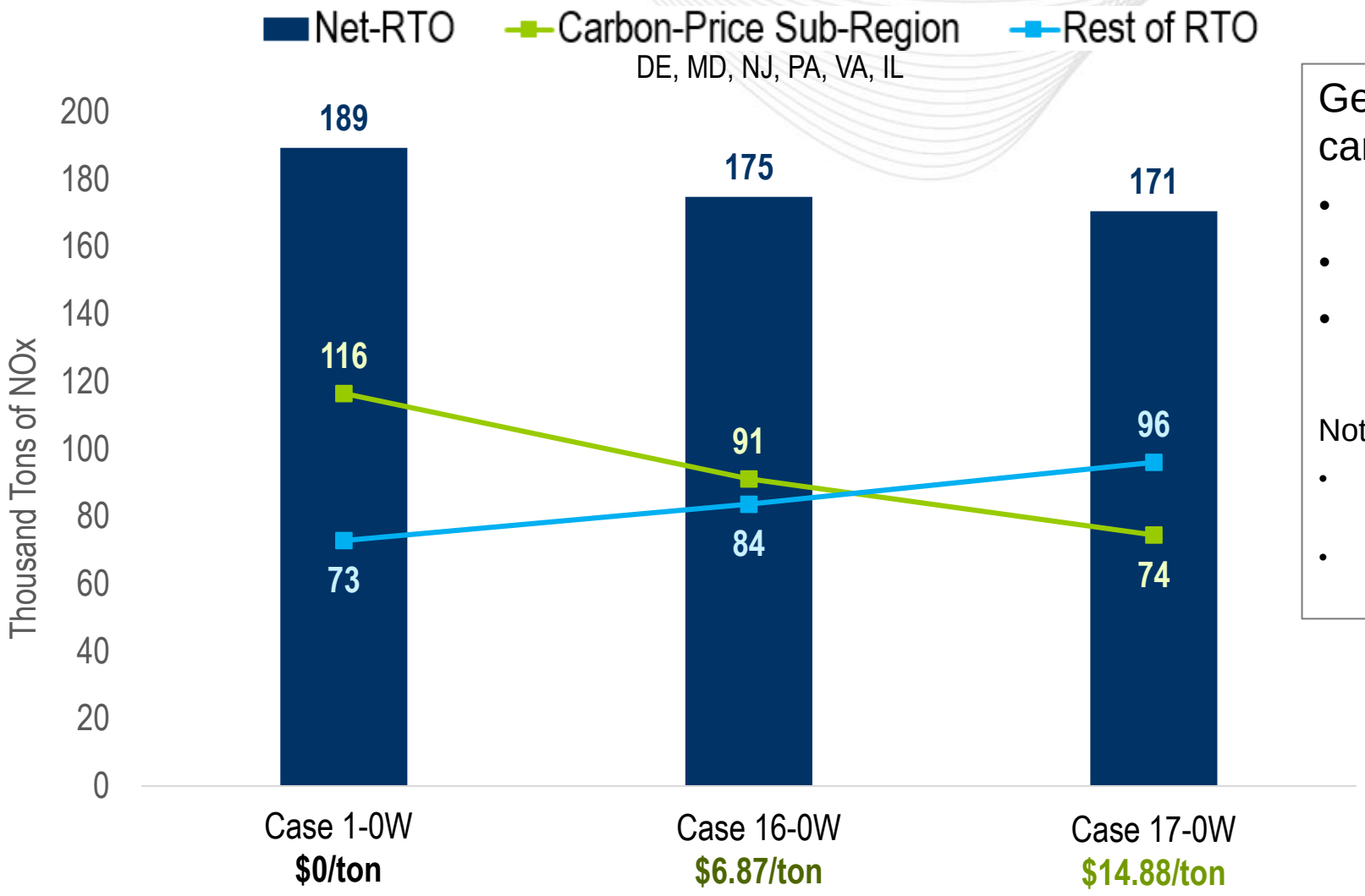
Generation shift from increasing carbon price results in CO_2:

- *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



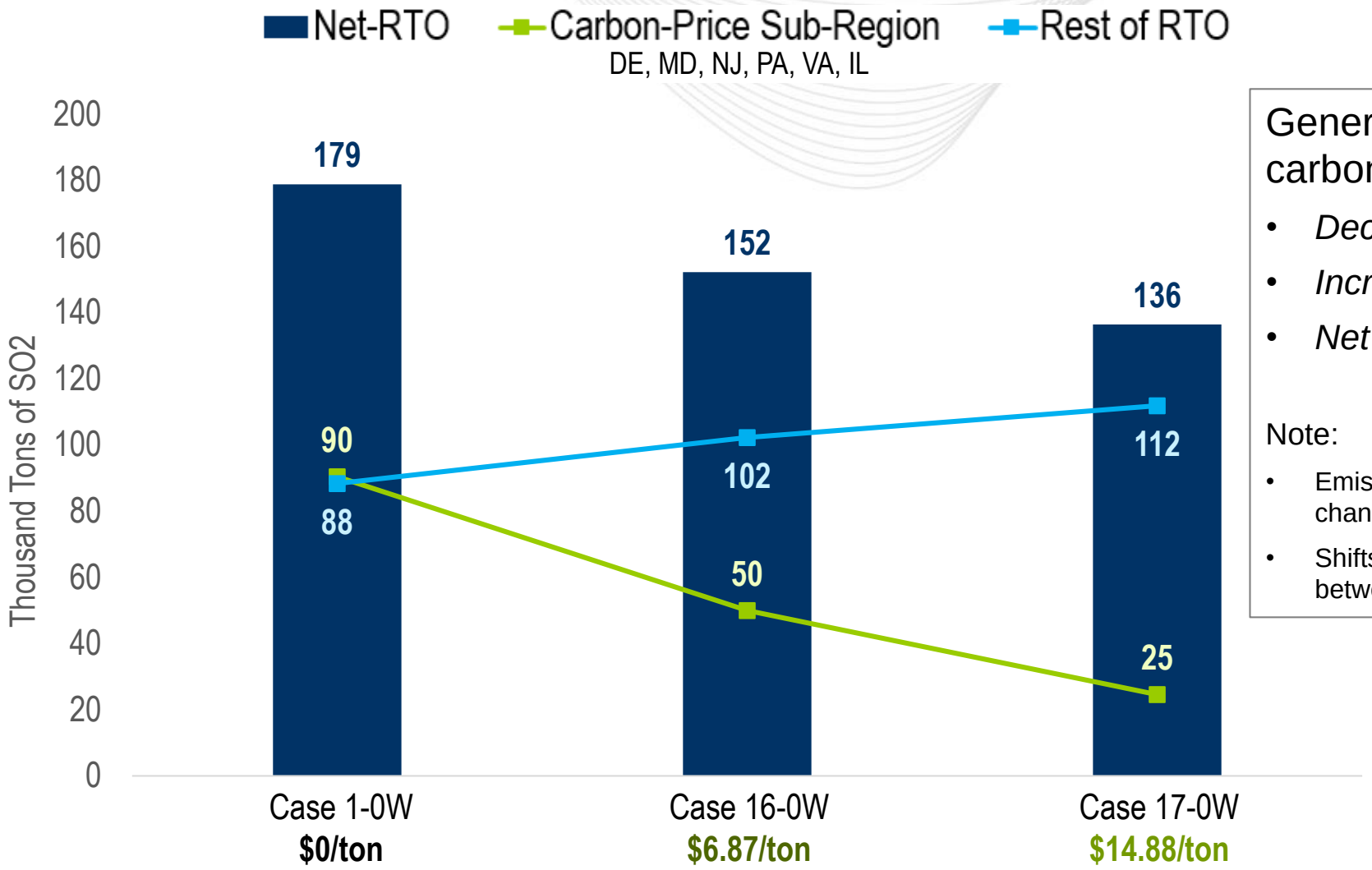
Generation shift from increasing carbon price results in NO_x:

- *Decrease* in carbon-price sub-region
- *Increase* in rest of RTO
- *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 SO_2 Emissions



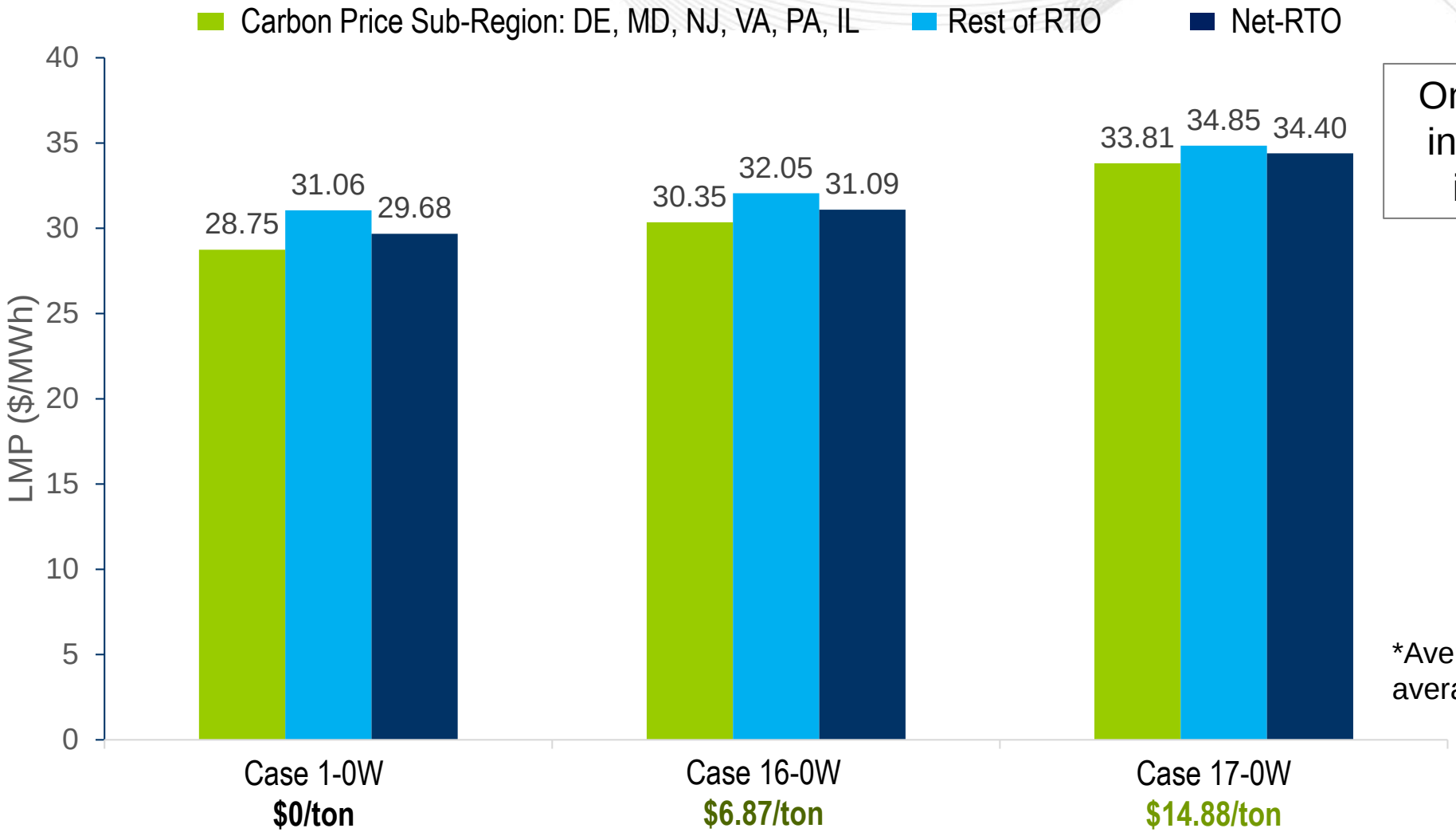
Generation shift from increasing carbon price results in SO_2:

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

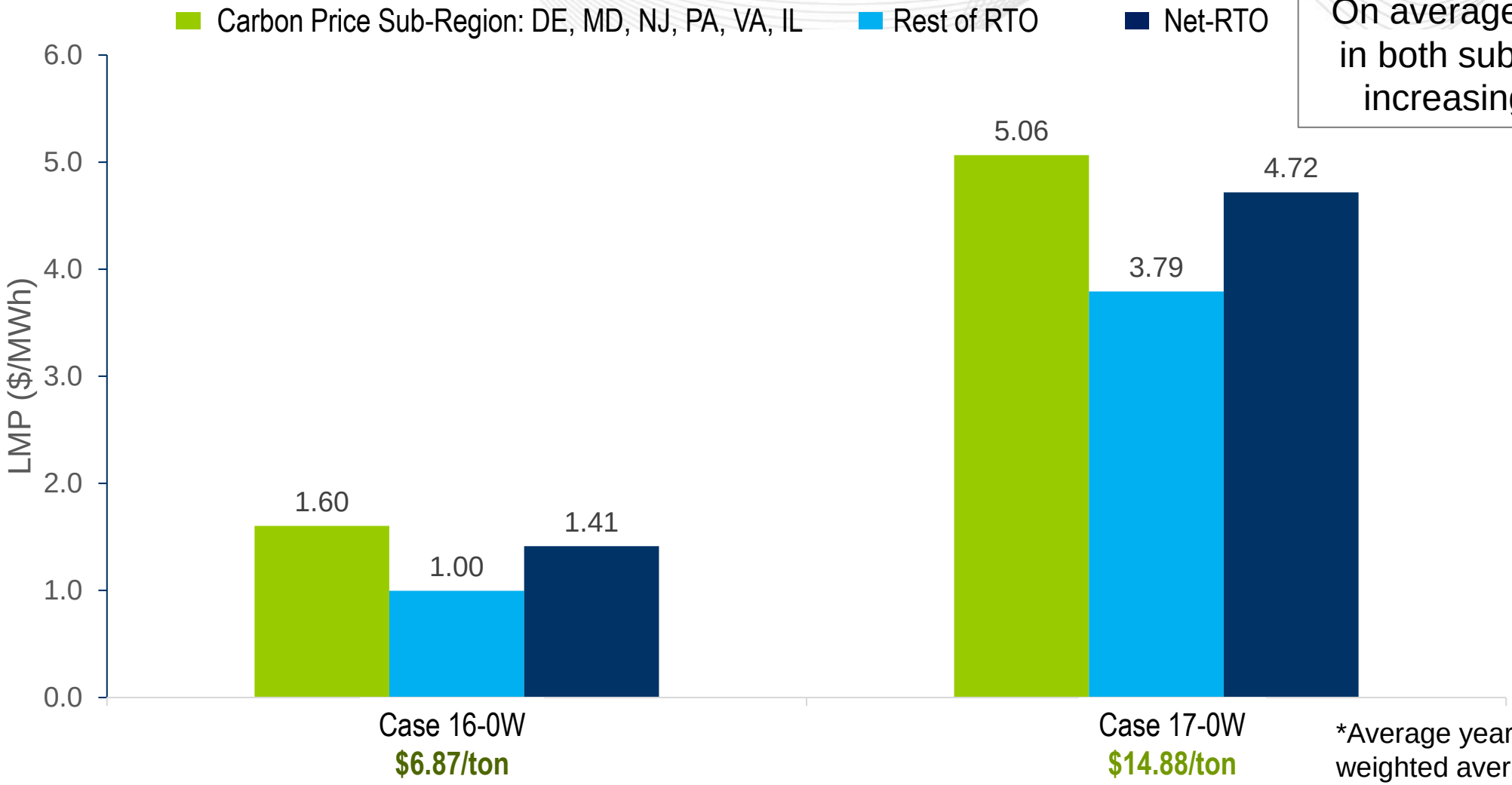


On average, LMPs increase in both sub-regions with an increasing carbon price.

*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

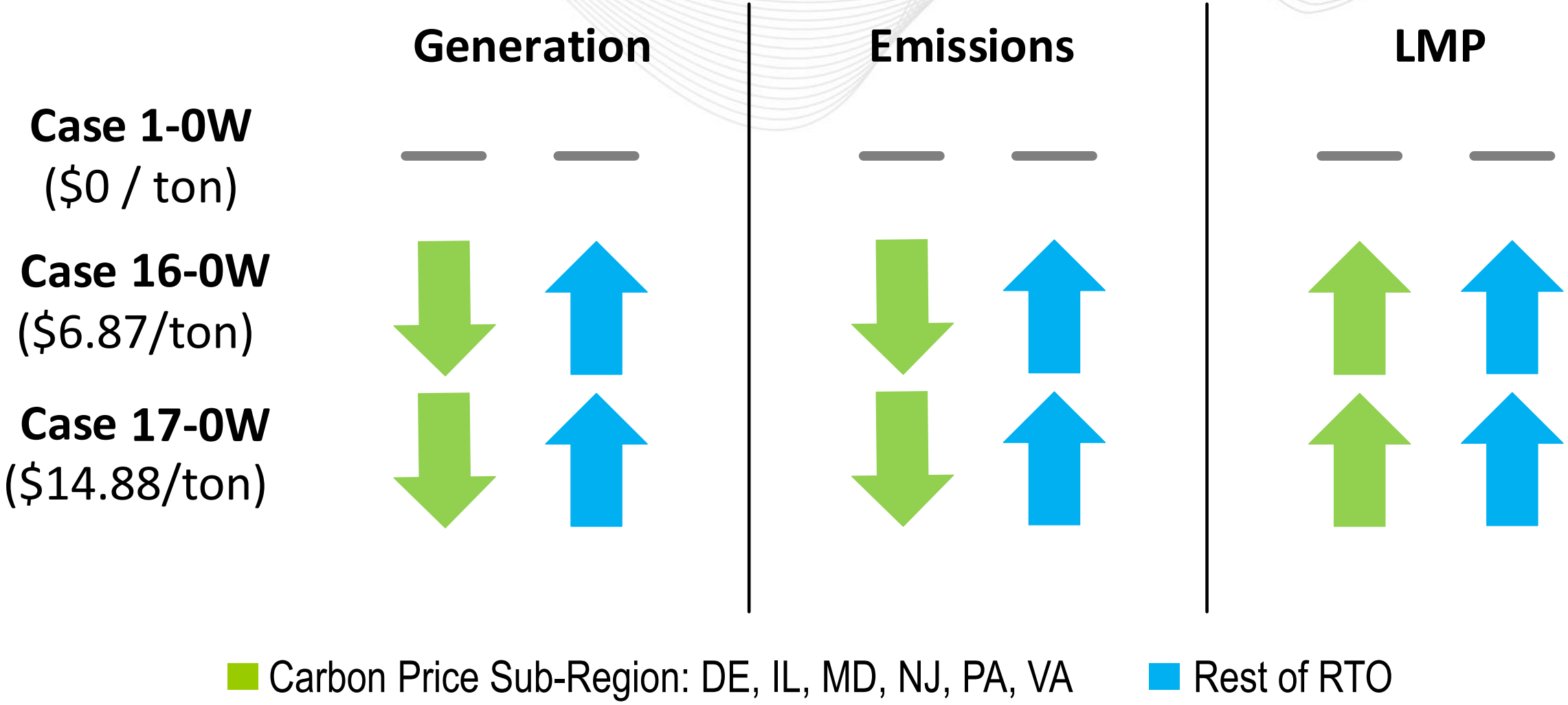
On average, LMPs increase in both sub-regions with an increasing carbon price.



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

Results Summary

Part 1: Impacts of Higher Carbon Prices in a Sub-Region of PJM (DE, MD, NJ, VA, PA, IL)



- **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 types of resources being impacted are driven by the generation mixes of each sub-region.

Results Summary (cont.)

Part 1: Impacts of Higher Carbon Prices in a Sub-Region of PJM (DE, MD, NJ, VA, PA, IL)

- **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 Net-RTO emissions.

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

Results Overview for 8/21/2020 CPSTF

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

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

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, IL, MD, NJ, PA and VA:

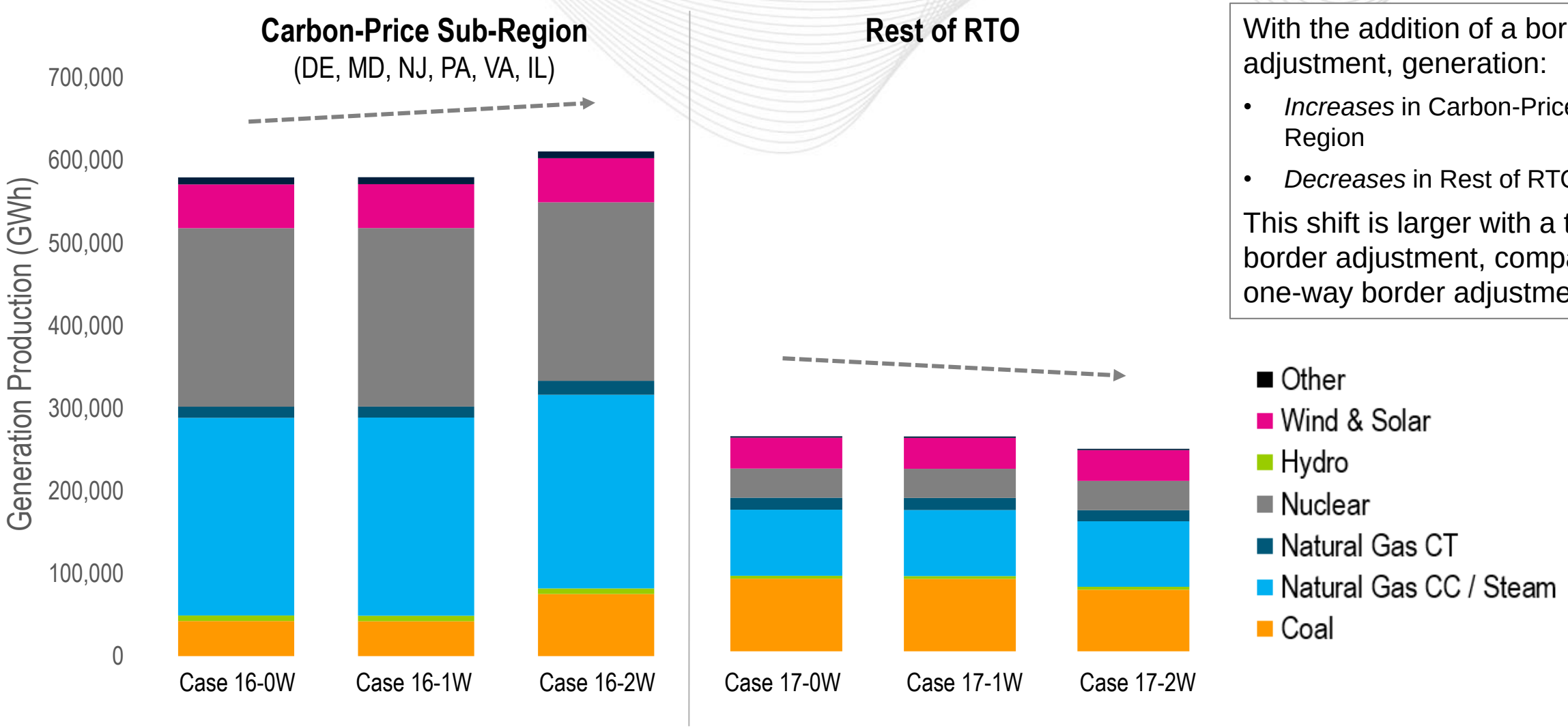
Case	RGGI Price	Border Adjustment
Case 16-0W	$6.87/short ton	None
Case 16-1W		One-Way
Case 16-2W		Two-Way
Case 17-0W	$14.88/short ton	None
Case 17-1W		One-Way
Case 17-2W		Two-Way

Results Metrics

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

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

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

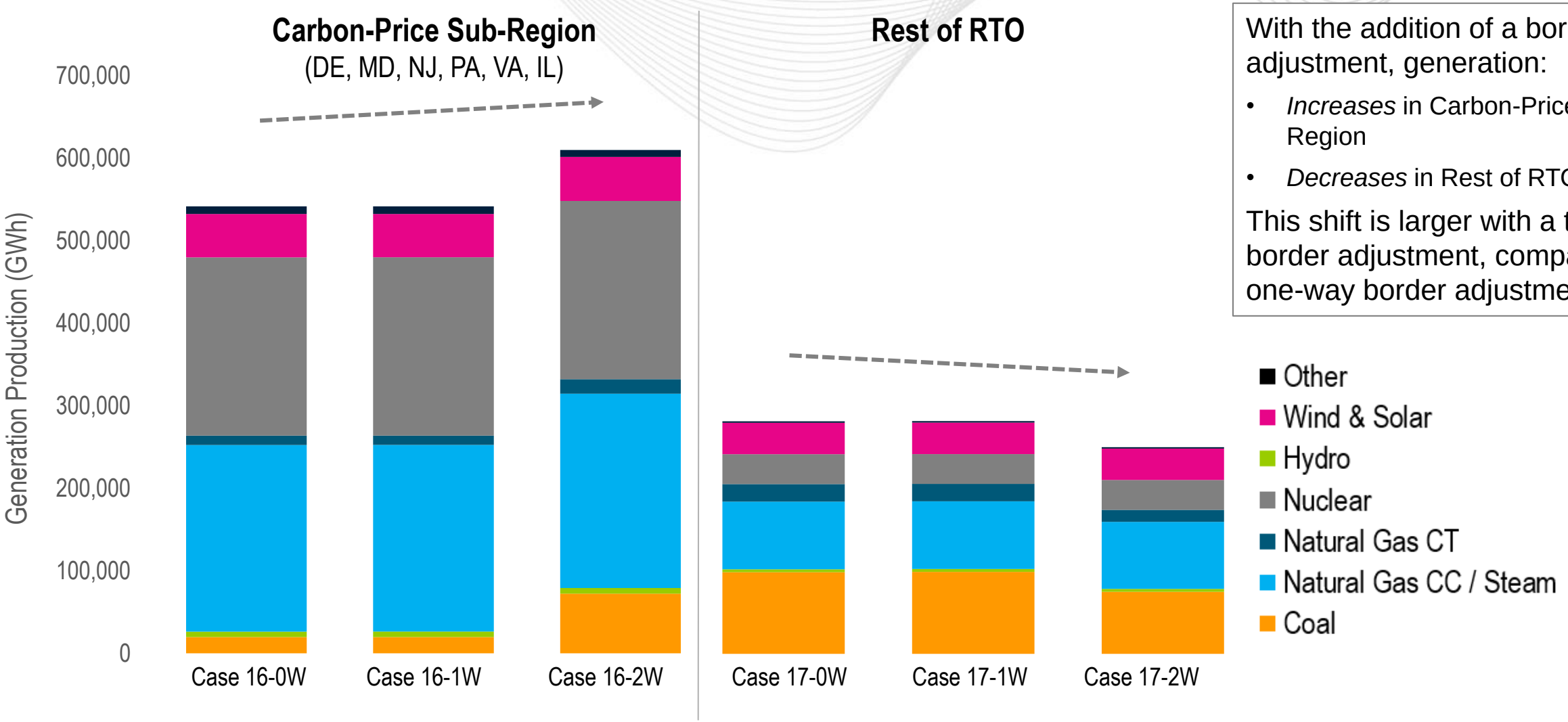


With the addition of a border adjustment, generation:

- *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**

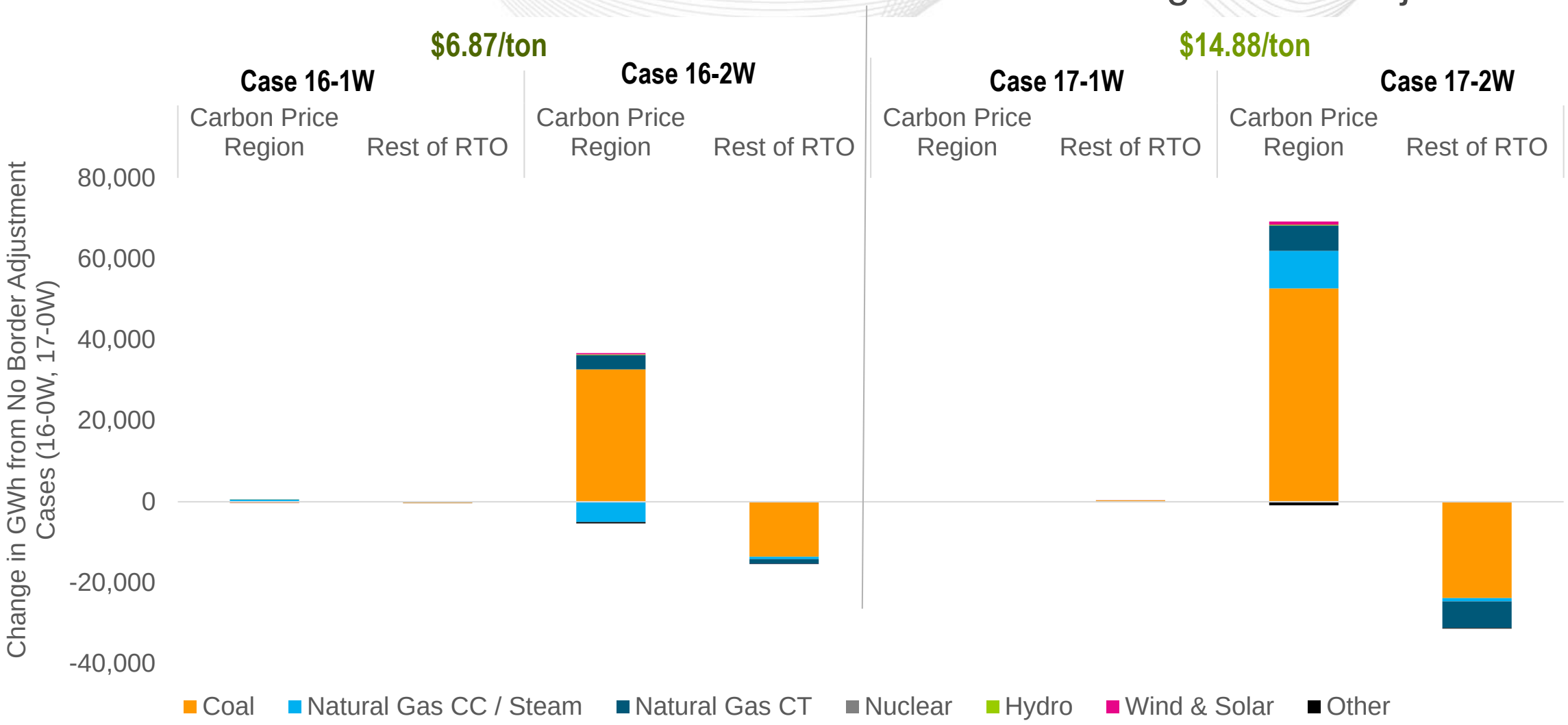


With the addition of a border adjustment, generation:

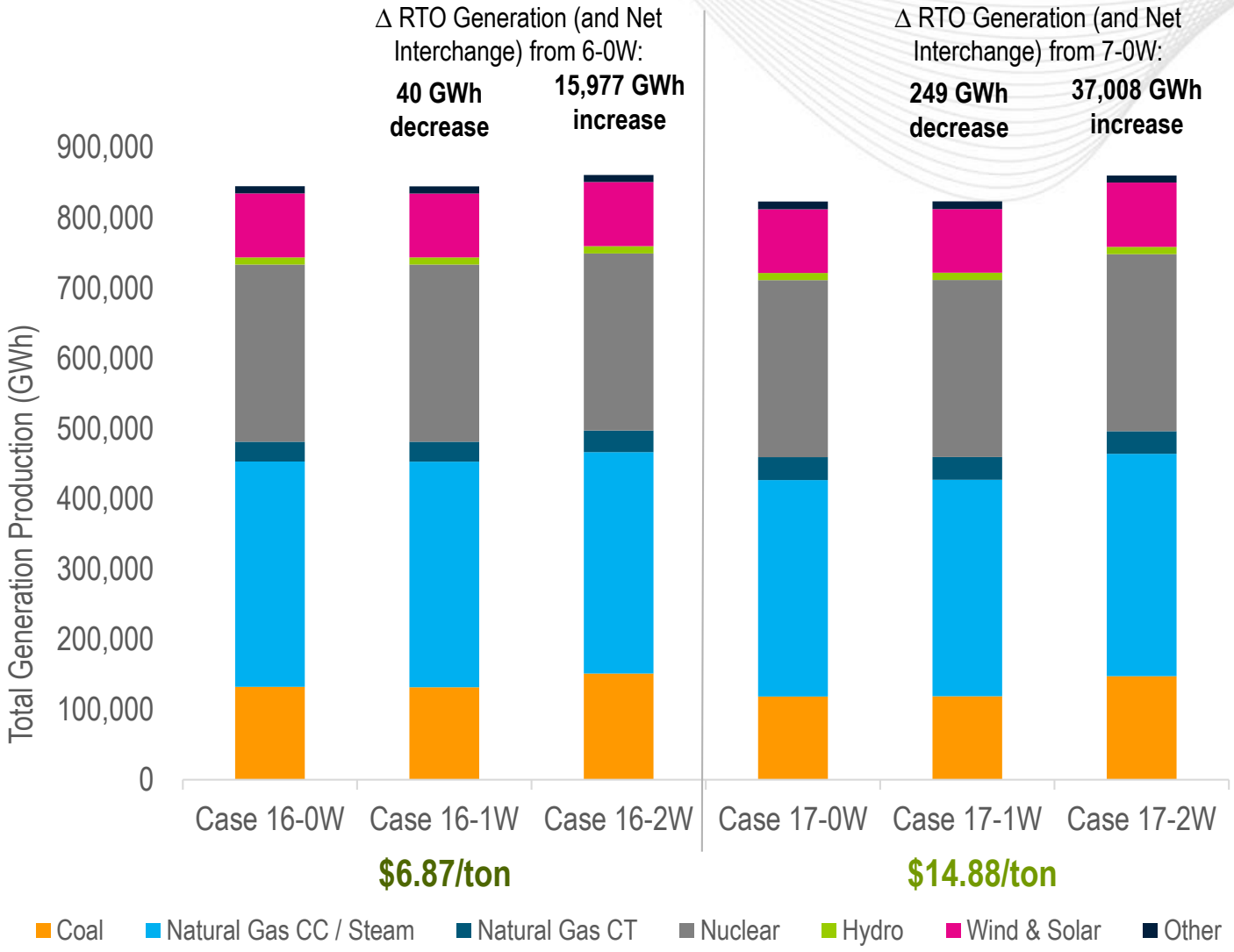
- *Increases* in Carbon-Price Sub-Region
- *Decreases* in Rest of RTO

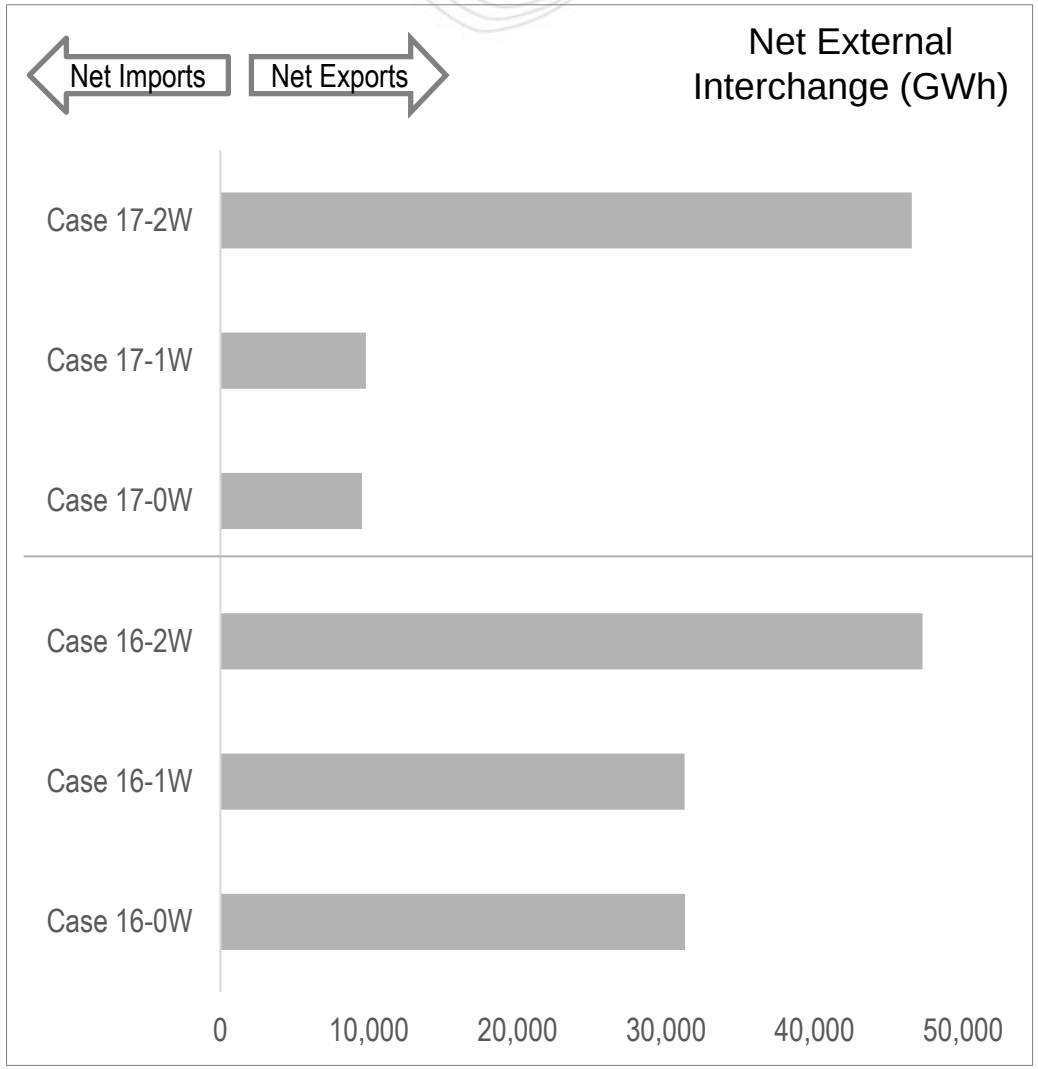
This shift is larger with a two-way border adjustment, compared to a one-way border adjustment.

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



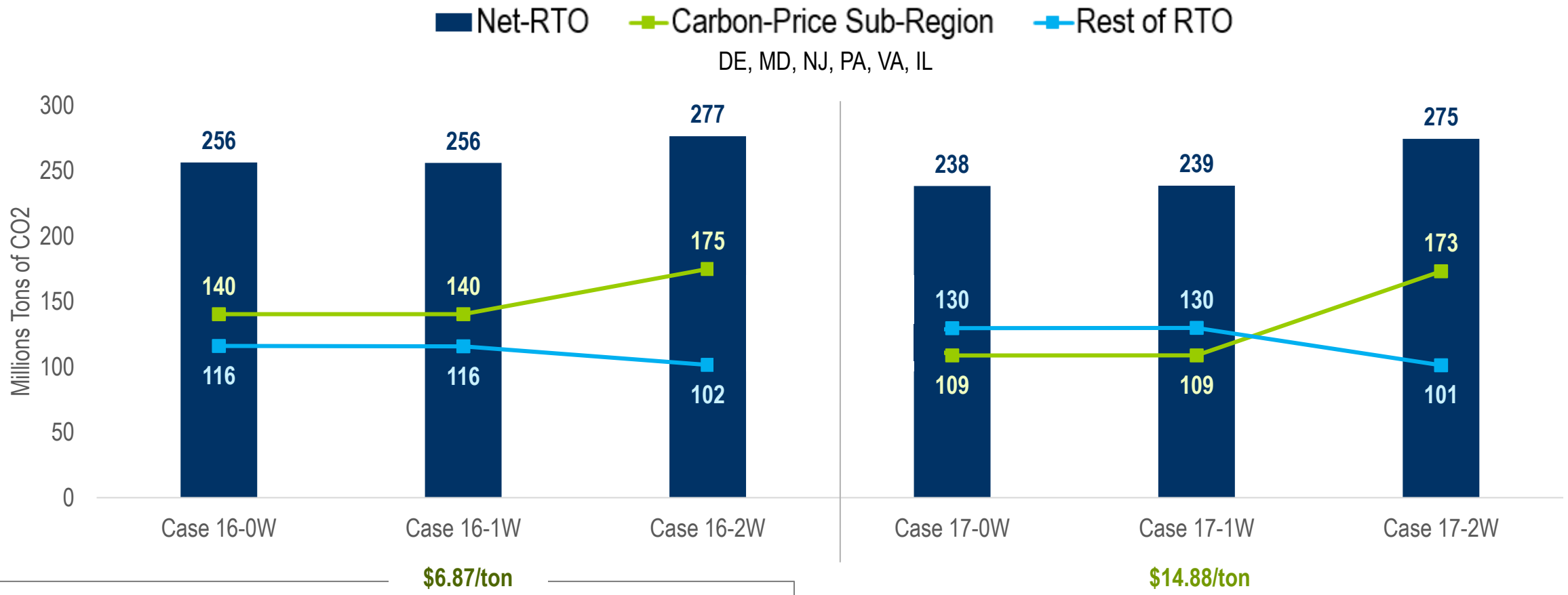
Interchange between PJM and External Regions





Impact of Border Adjustment on CO_2 Emissions

Generation shift from one-way border adjustment results in a small emissions shift between sub-regions and 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.

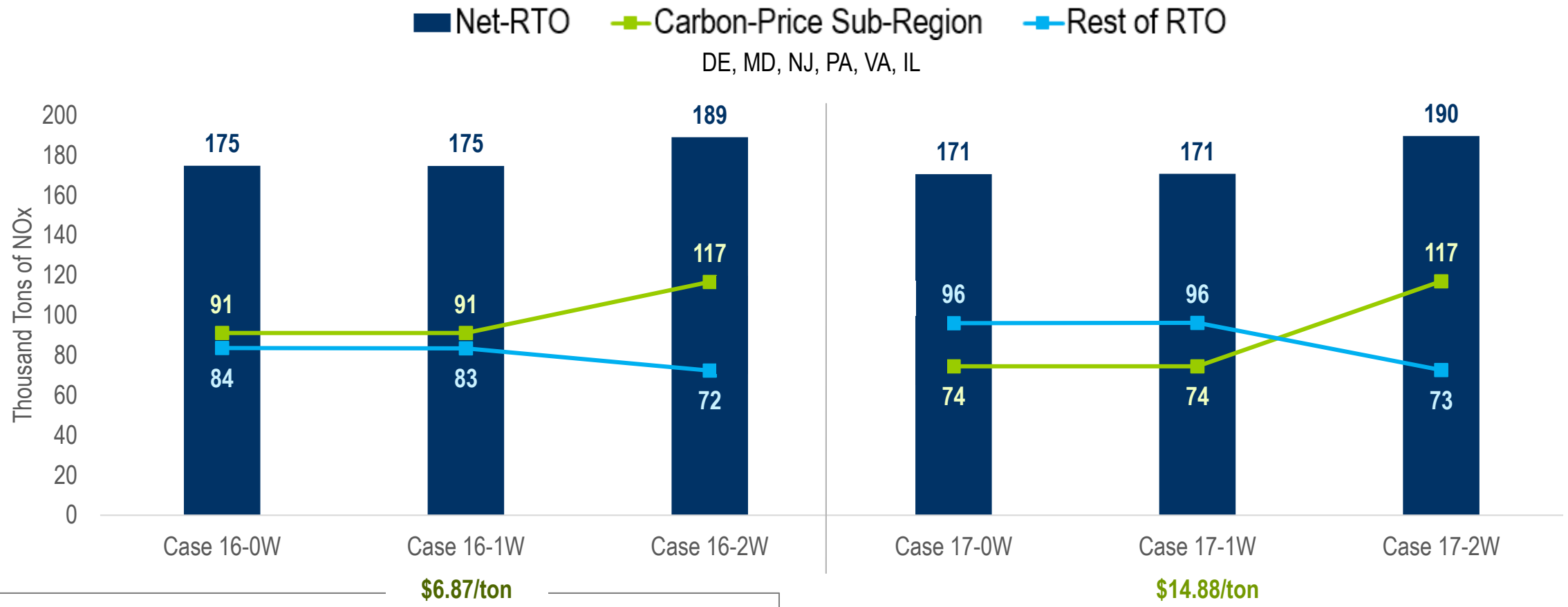


Note:

- 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 a small emissions shift between sub-regions and 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.

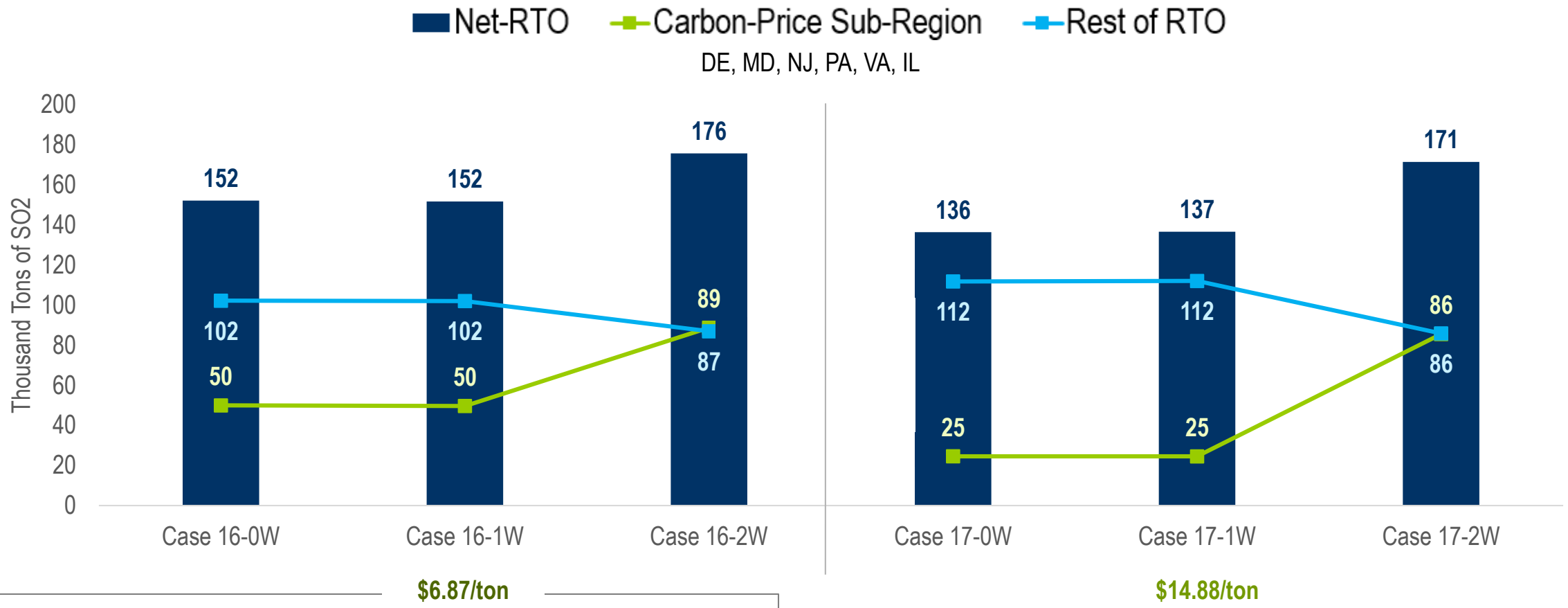


Note:

- 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 SO_2 Emissions

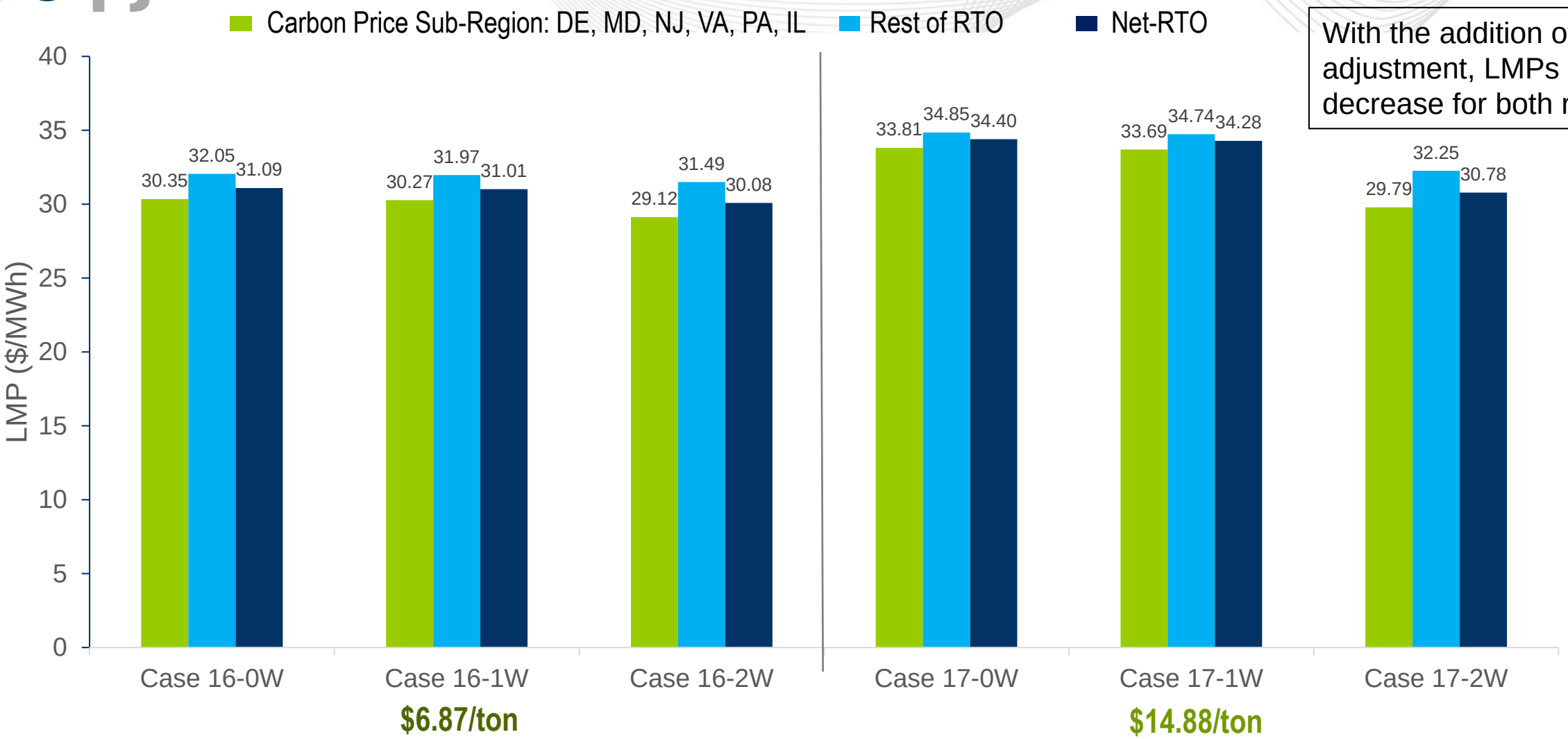
Generation shift from one-way border adjustment results in a small emissions shift between sub-regions and across Net-RTO.
Two-way border adjustment results in emissions *increase* in Carbon-Price Sub-Region, *decrease* in Rest of RTO and *net increase* across Net-RTO.



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

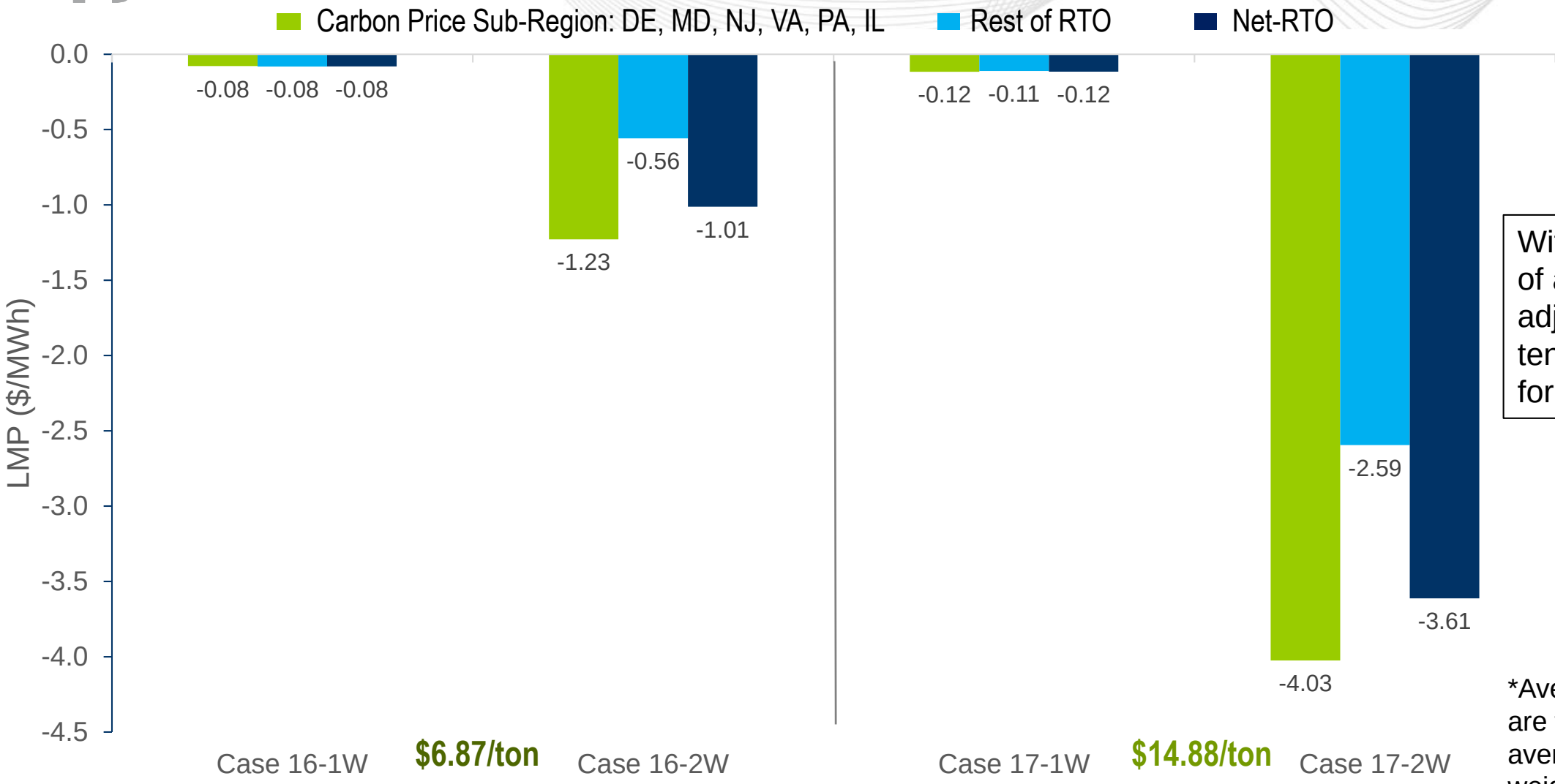
2023 PJM Average Yearly LMPs* by Sub-Region



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.

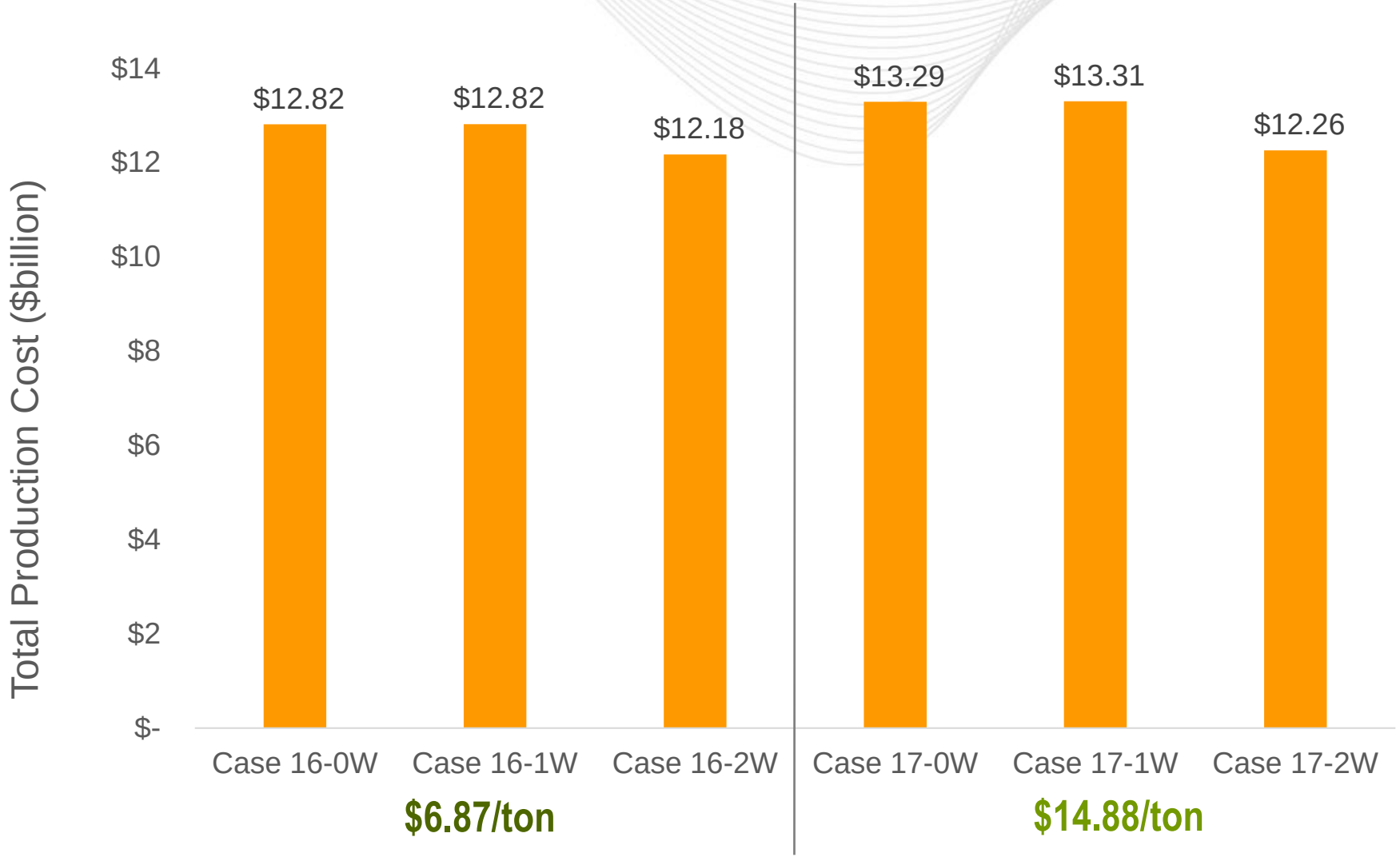
2023 Difference in Average Yearly LMPs* from Case 0W by Sub-Region and RGGI Price



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



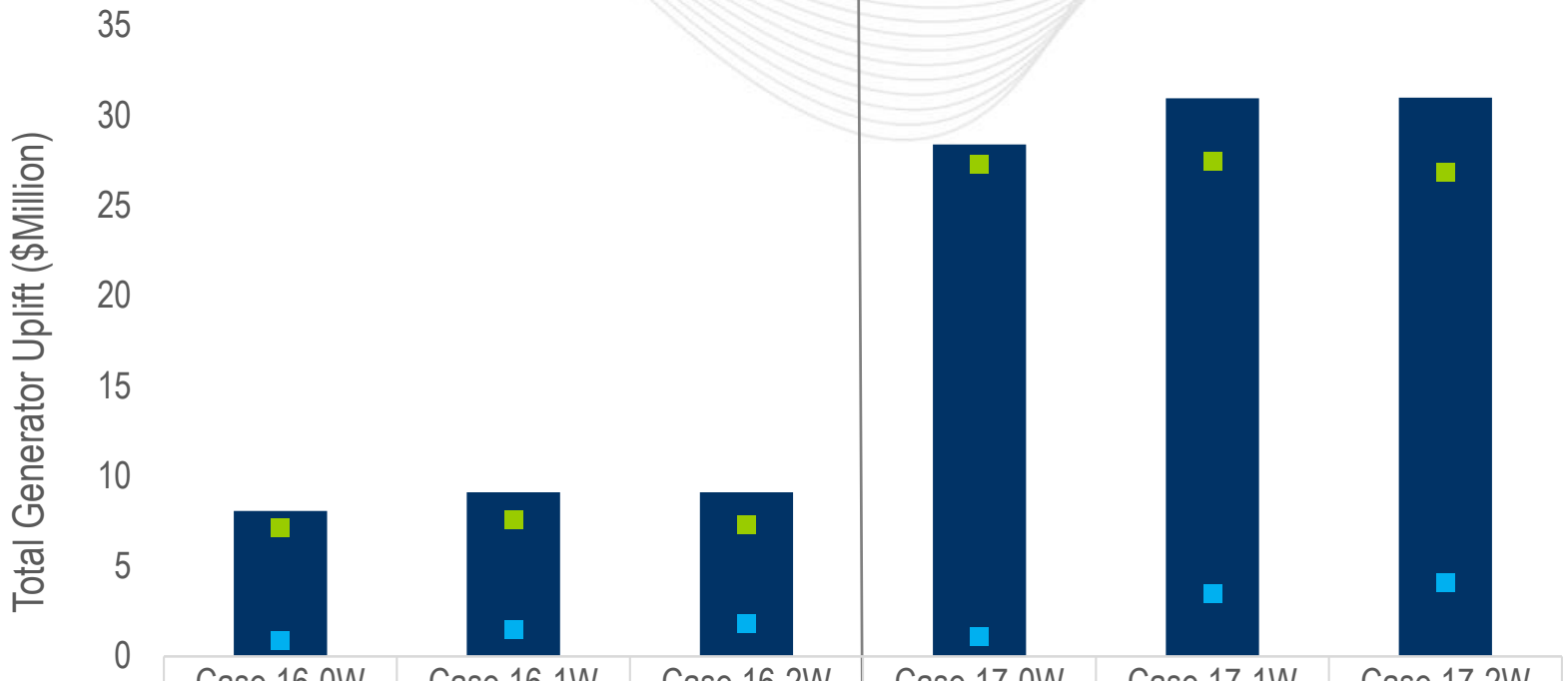
Total System Production Cost:

- *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 16-0W	Case 16-1W	Case 16-2W	Case 17-0W	Case 17-1W	Case 17-2W
Net-RTO	$8.06	$9.10	$9.10	$28.38	$30.94	$30.99
Carbon-Price Sub-Region (DE, MD, NJ, VA, PA, IL)	$7.16	$7.58	$7.29	$27.30	$27.48	$26.87
Rest of RTO	$0.90	$1.51	$1.82	$1.08	$3.47	$4.12

$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

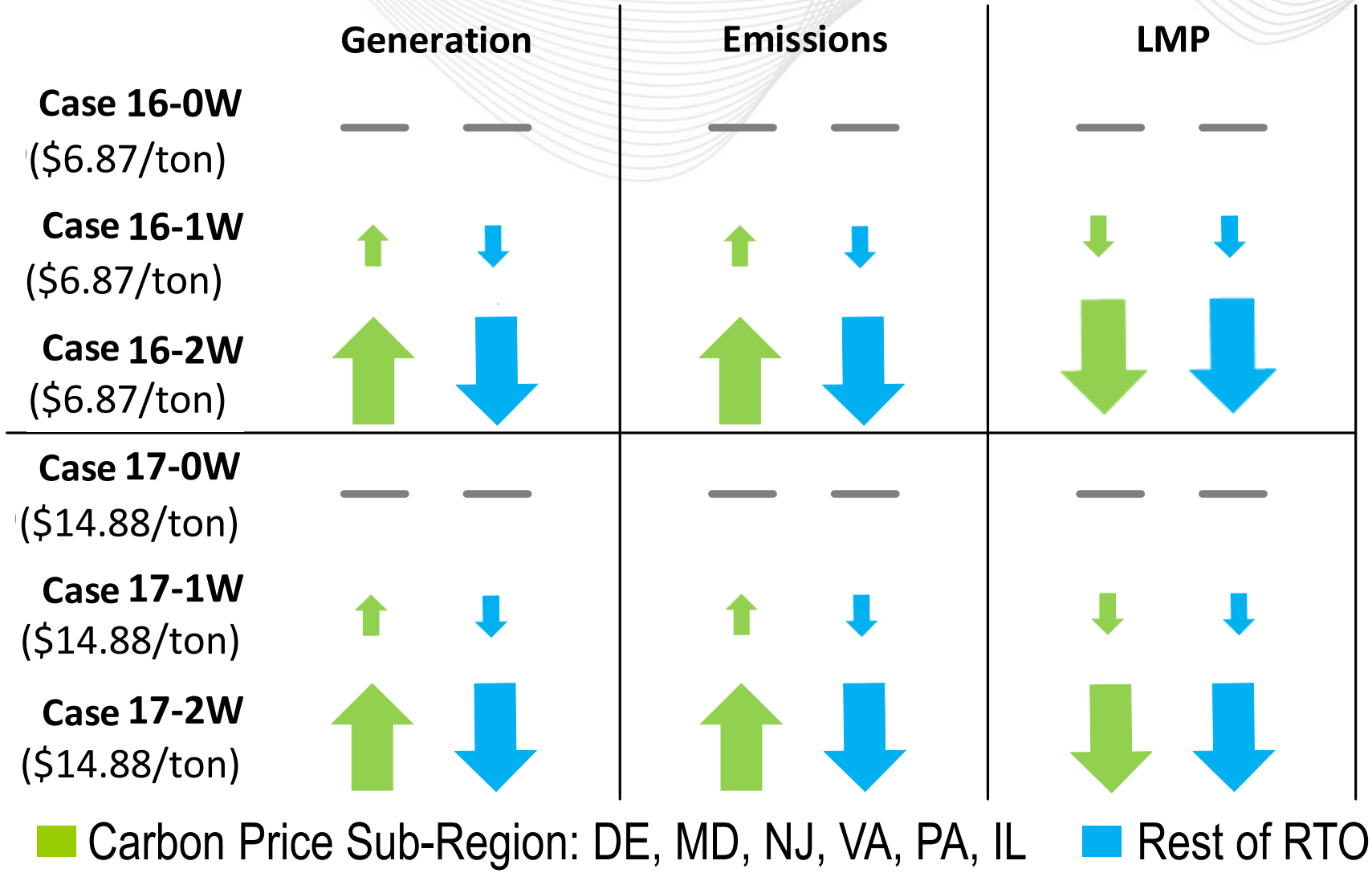
- As previously noted, compared to scenarios with no leakage mitigation, the border adjustment scenarios result in shifts in generation production from the Rest of RTO to the Carbon-Price Sub-Region.
- This could be assumed to increase the funds from CO_2 allowance sales that states would collect if 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.

Carbon Revenue (Residual Funds) from Border Adjustment Constraint

- Case 16-2W ($6.87/ton): -$3 million
- Case 17-2W ($14.88/ton): -$6.5 million
- The carbon residual fund is zero for all other simulated cases.
- For the two-way border adjustment cases above, the carbon residual fund has a deficit due to the Carbon-Price Sub-Region being a net exporter and the carbon component of the LMP being non-zero during many hours.

Results Summary

Part 2: Impacts of Potential Border Adjustments for Leakage Mitigation



- **Generation:**
  - Compared to scenarios with no leakage mitigation
    - A two-way border adjustment result in shifts in generation production from the Rest of RTO to the Carbon-Price Sub-Region.
    - A one-way border adjustment results in relatively minimal shifts.
  - This generation shift increases as the price of carbon increases.

- **Emissions:**
  - Compared to cases with no border adjustments:
    - A one-way border adjustment mechanism resulted very small shifts in emissions.
    - 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.

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