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

Carbon Pricing Senior Task Force

May 19, 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 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

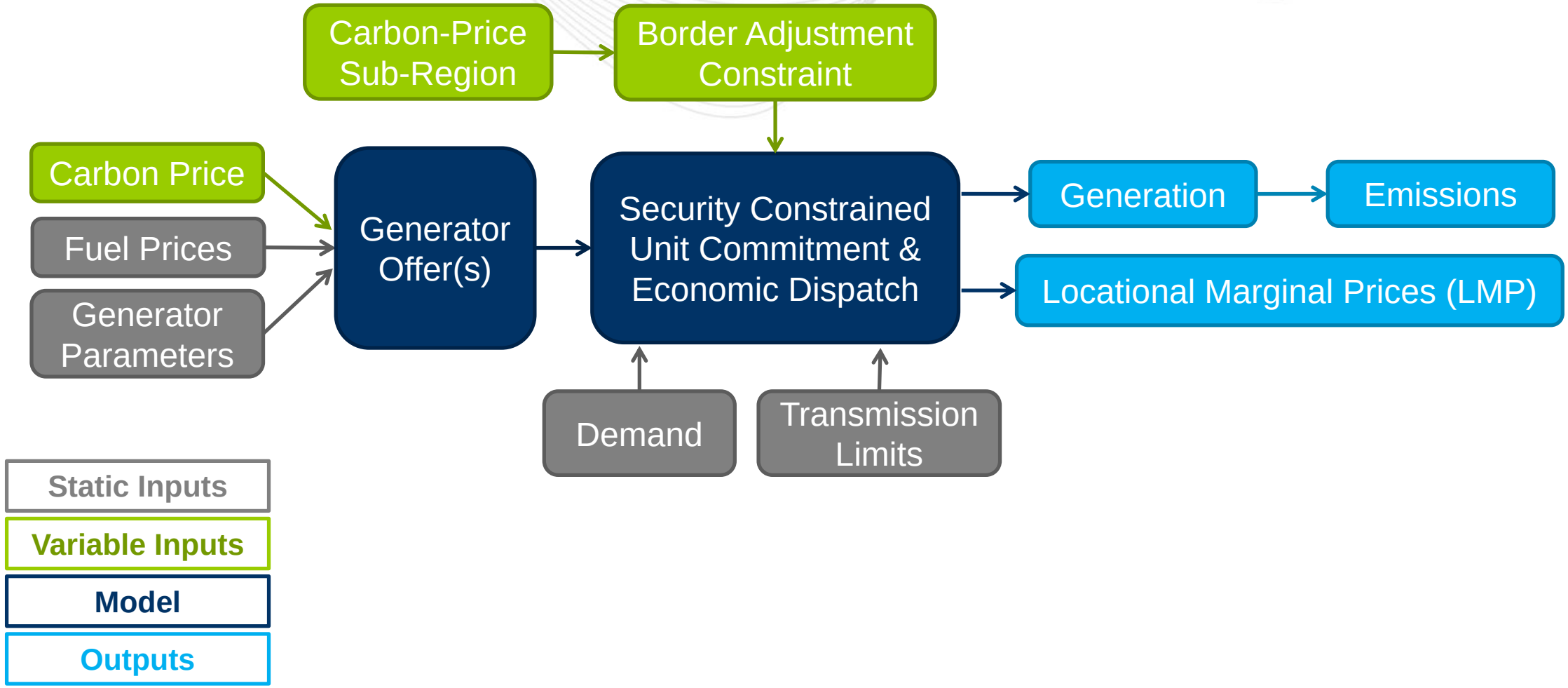
Carbon Price Region	Case Numbers	Carbon Prices*	CPSTF Materials
DE, MD, NJ	1, 2, 3	• $0/short ton (counterfactual) • $6.87/short ton (2023 RGGI ECR trigger price) • $14.88/short ton (2023 RGGI CCR trigger price)	1.14.2020
DE, MD, NJ, VA	1, 4, 5		2.25.2020
DE, MD, NJ, VA, PA	1, 6, 7		2.25.2020
DE, MD,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

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

Study Methodology: Modeling Overview



Results Overview for 5/19/2020 CPSTF

Part 1a: Impacts of higher carbon prices in a sub-region of PJM

Part 1b: Impacts of Potential Border Adjustments for Leakage Mitigation in a sub-region of PJM with higher carbon prices

Part 2: Impacts of incrementally increasing carbon prices across PJM

Part 1a Scenario Summary

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

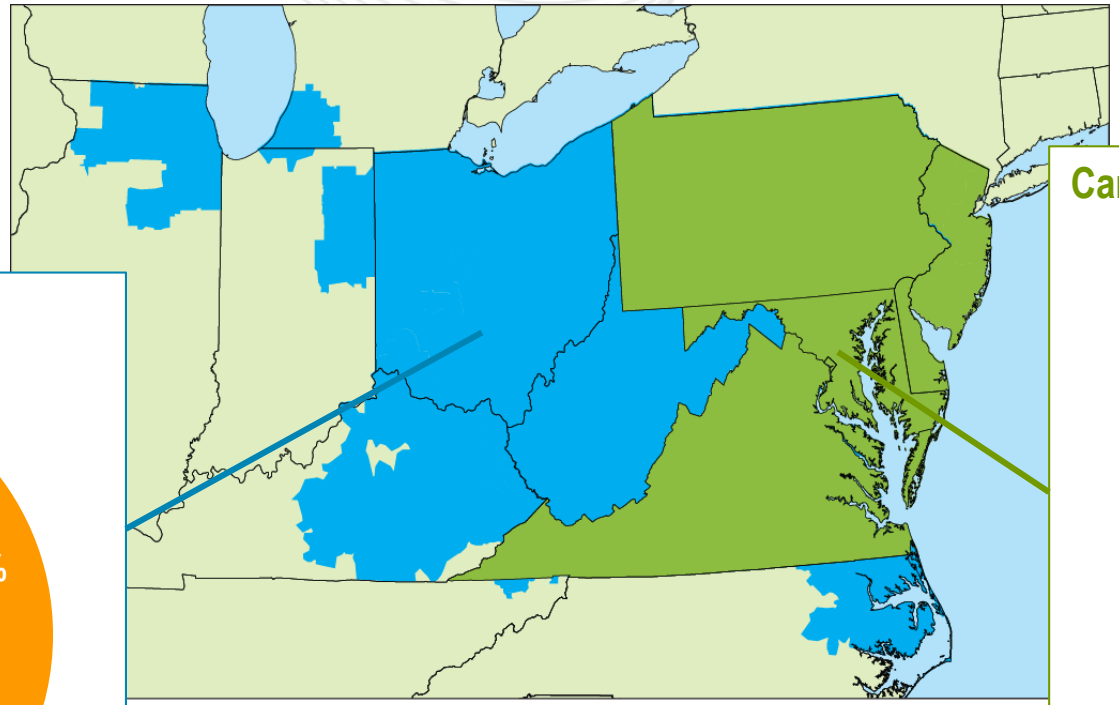
- Scenarios with higher carbon prices at $25/short ton and $50/short ton compared to a counterfactual scenario with carbon price at $0/short ton ("No RGGI") to quantify differences in:
  - Generation
  - Emissions
  - Prices
- The year 2023 was simulated for the following cases:

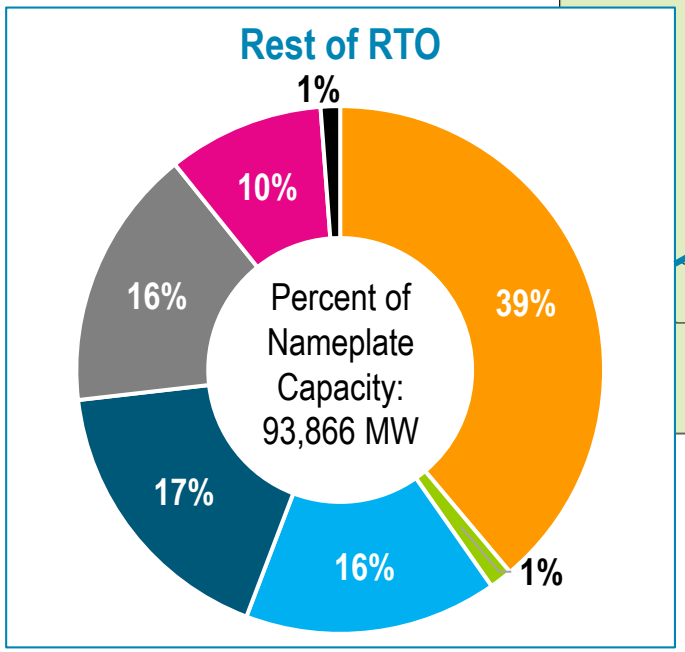
Case	Carbon Price	Border Adjustment
Case 1-0W	$0/short ton (i.e. "No RGGI Price")	None
Case 10-0W	$25/short ton	None
Case 11-0W	$50/short ton	None

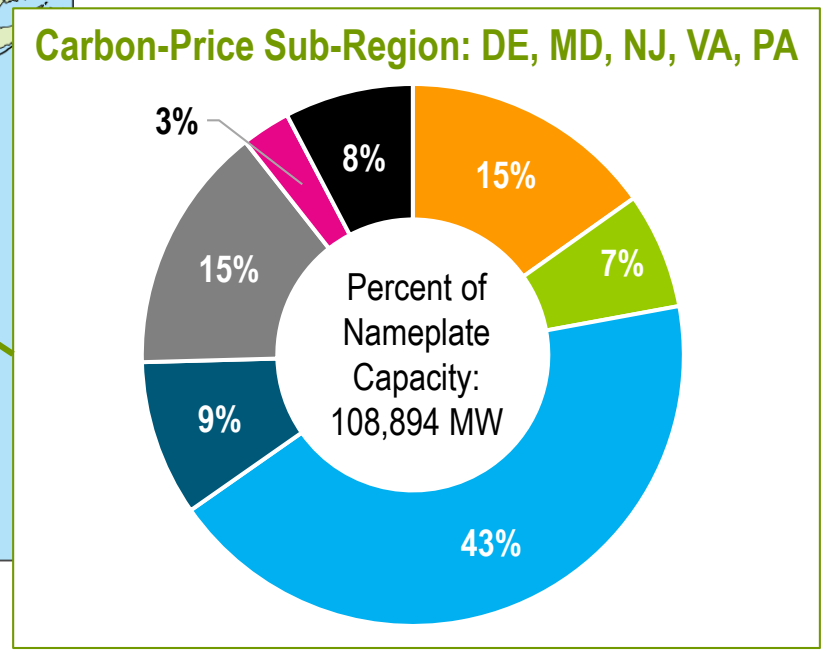
- Results are broken out by the following regions:
  - Carbon-Price Sub-Region – includes DE, MD, NJ, PA and VA
  - Rest of RTO – all other states in PJM

States included in Carbon-Pricing Sub-Region

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

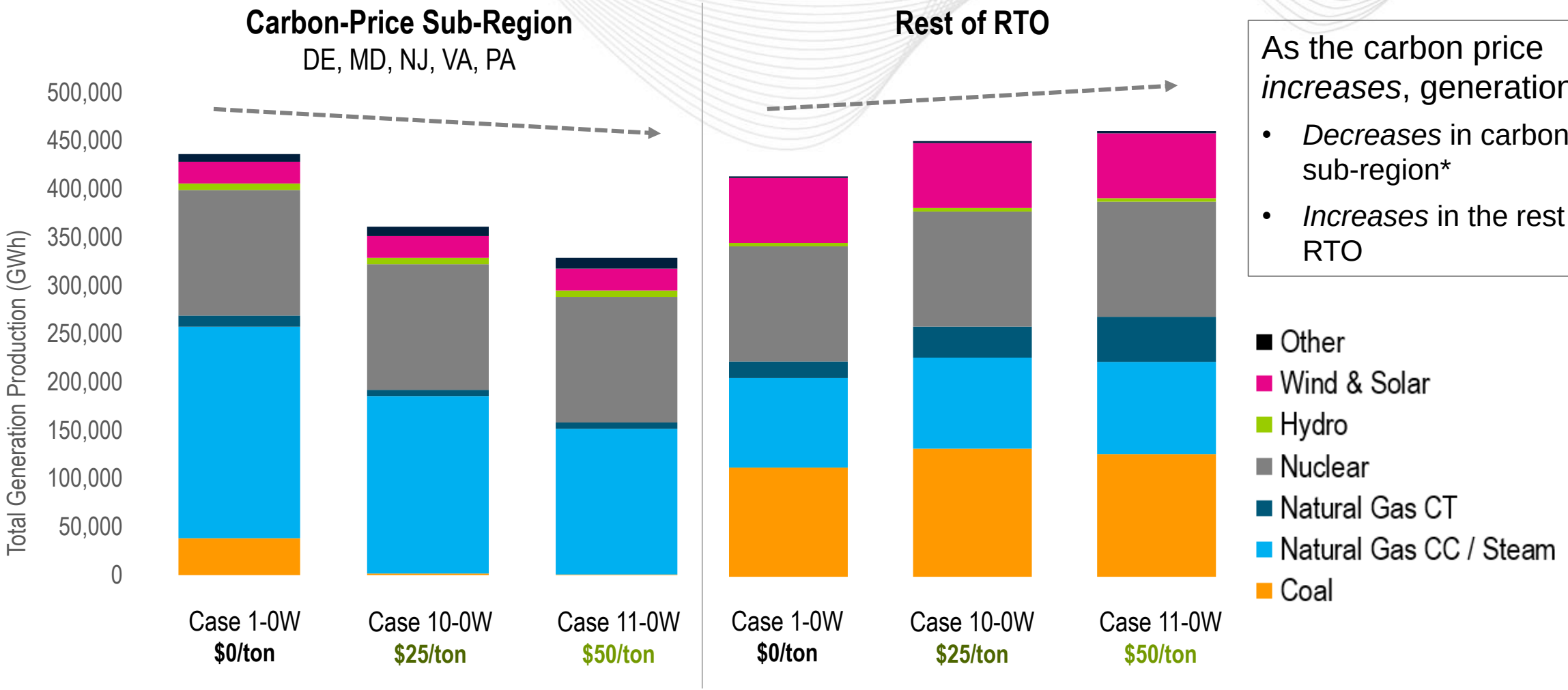






Coal
Natural Gas CT
Hydro
Other
Natural Gas CC / Steam
Nuclear
Wind & Solar

2023 Generation Production by Sub-Region

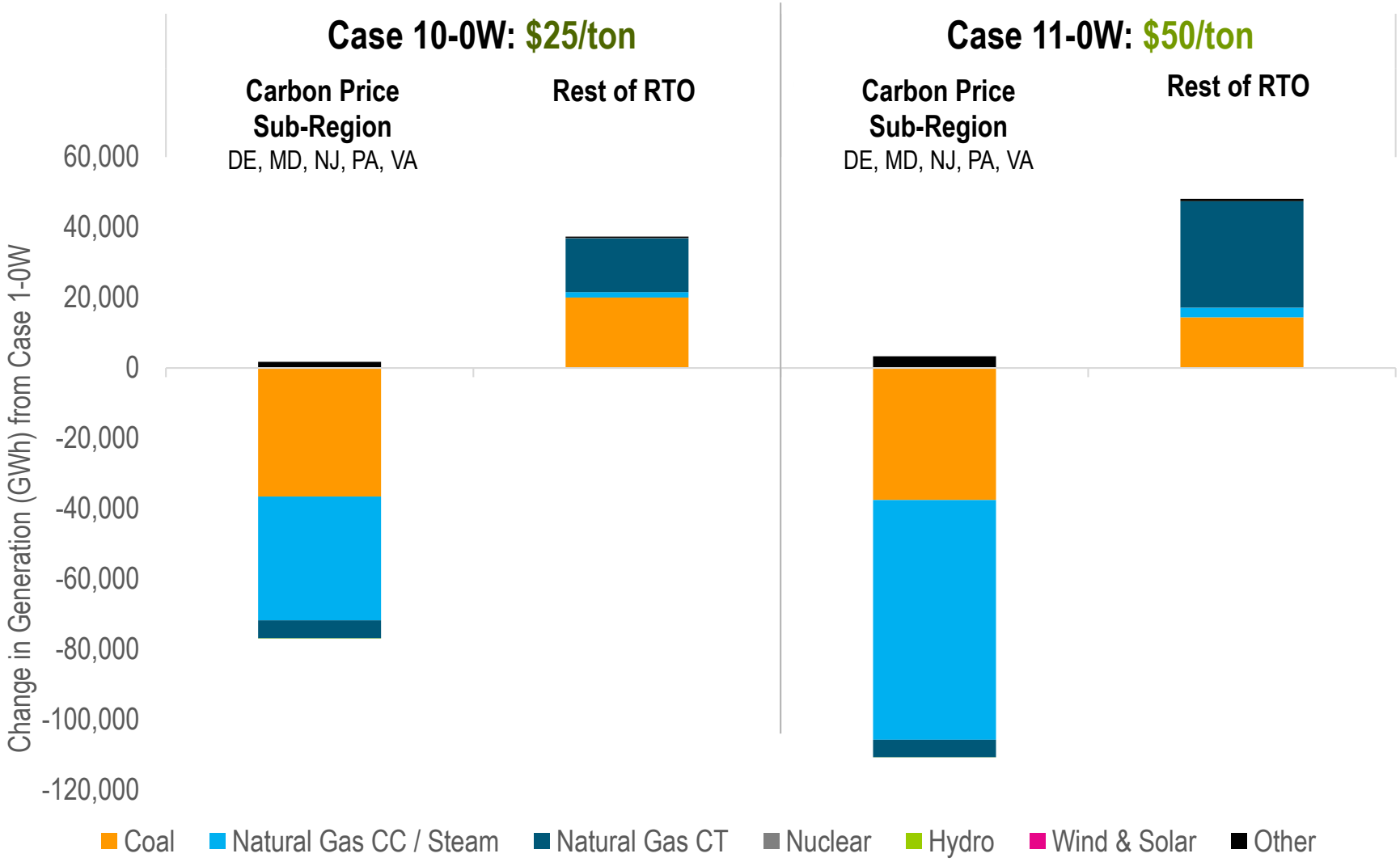


As the carbon price *increases*, generation:

- *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.

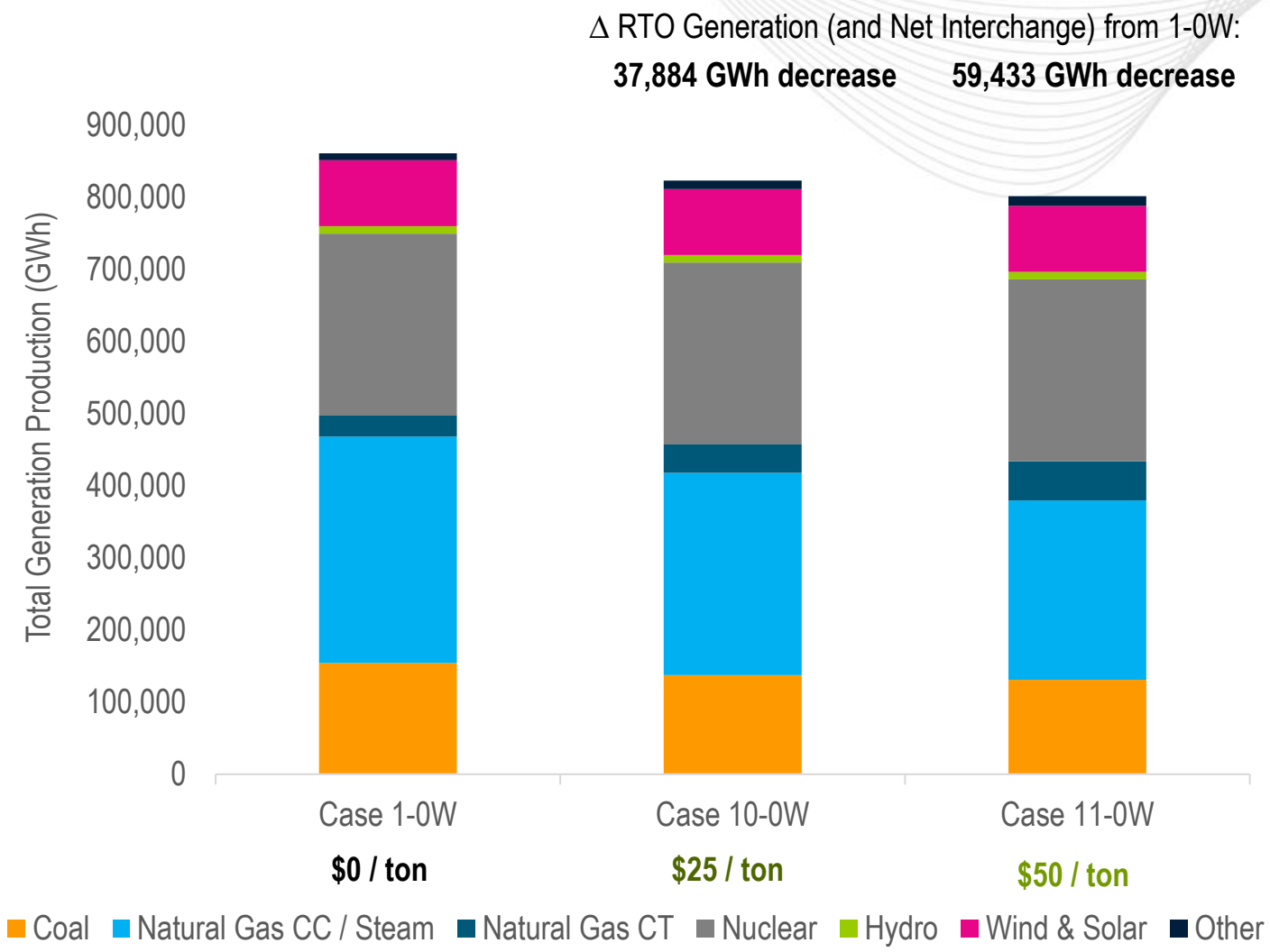
2023 Shifts in Generation Production from Case 1-0W ($0/ton CO_2) by Sub-Region

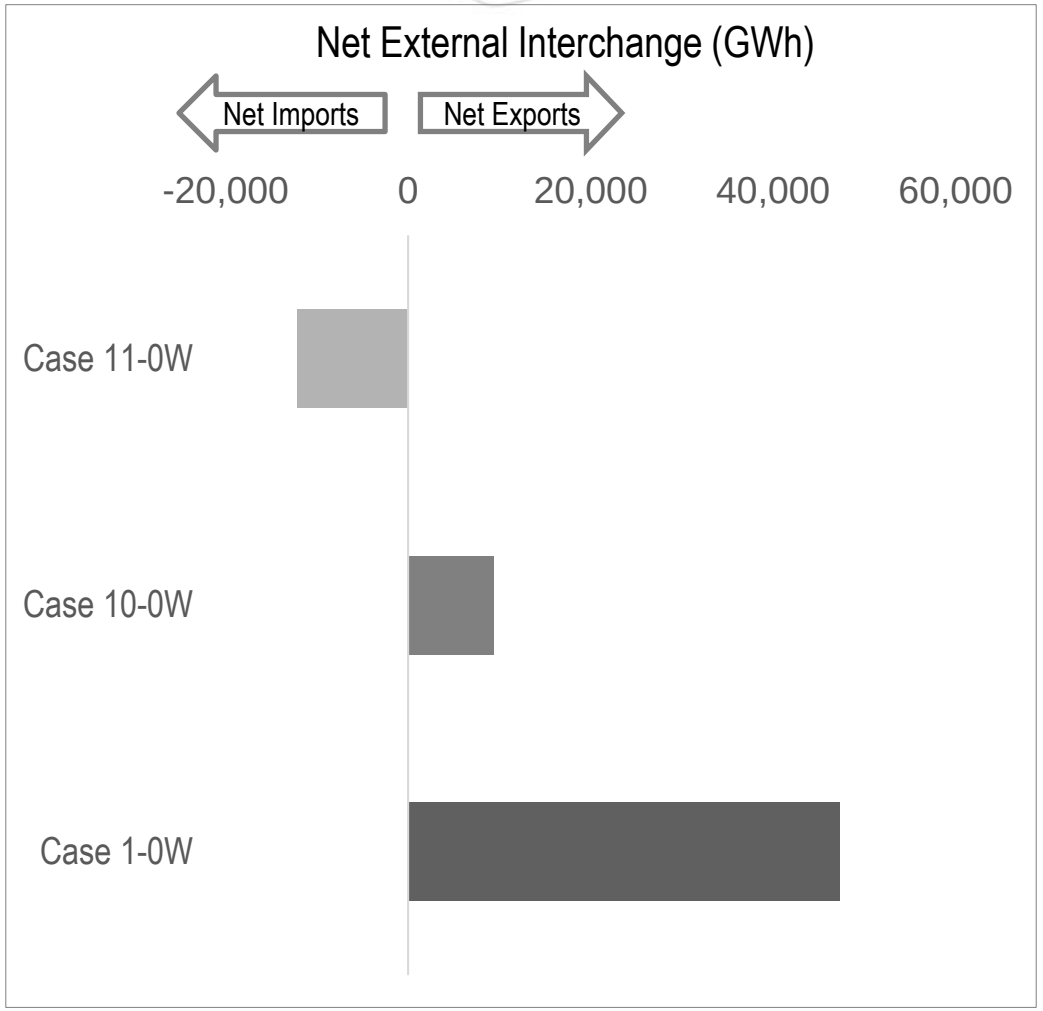


Generation displaced in carbon-price sub-region is relatively equivalent in emissions intensity to the increased generation in rest of RTO.

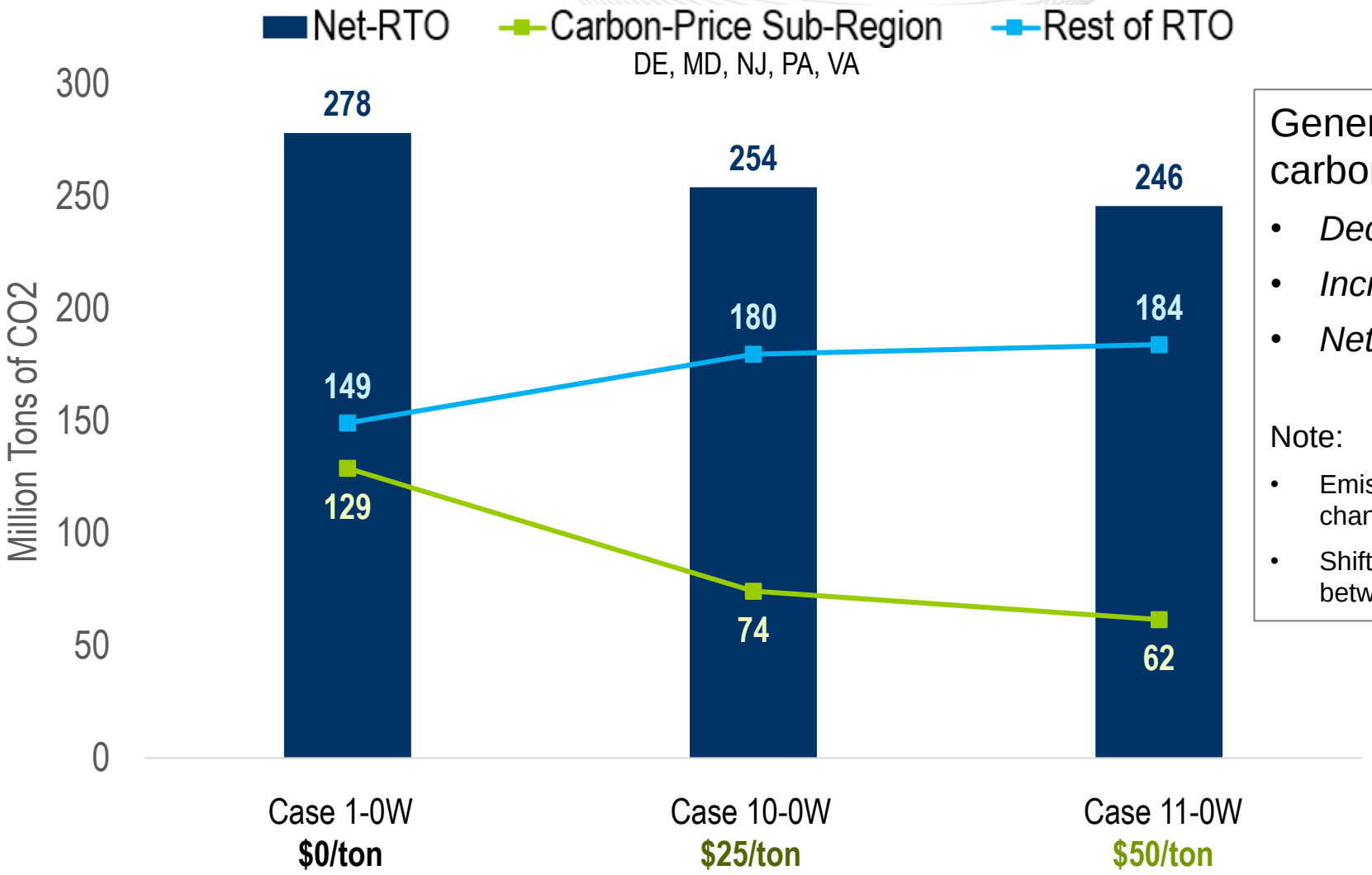
- Driven by generation mixes in each sub-region.

Interchange between PJM and External Regions





2023 Total CO_2 Emissions



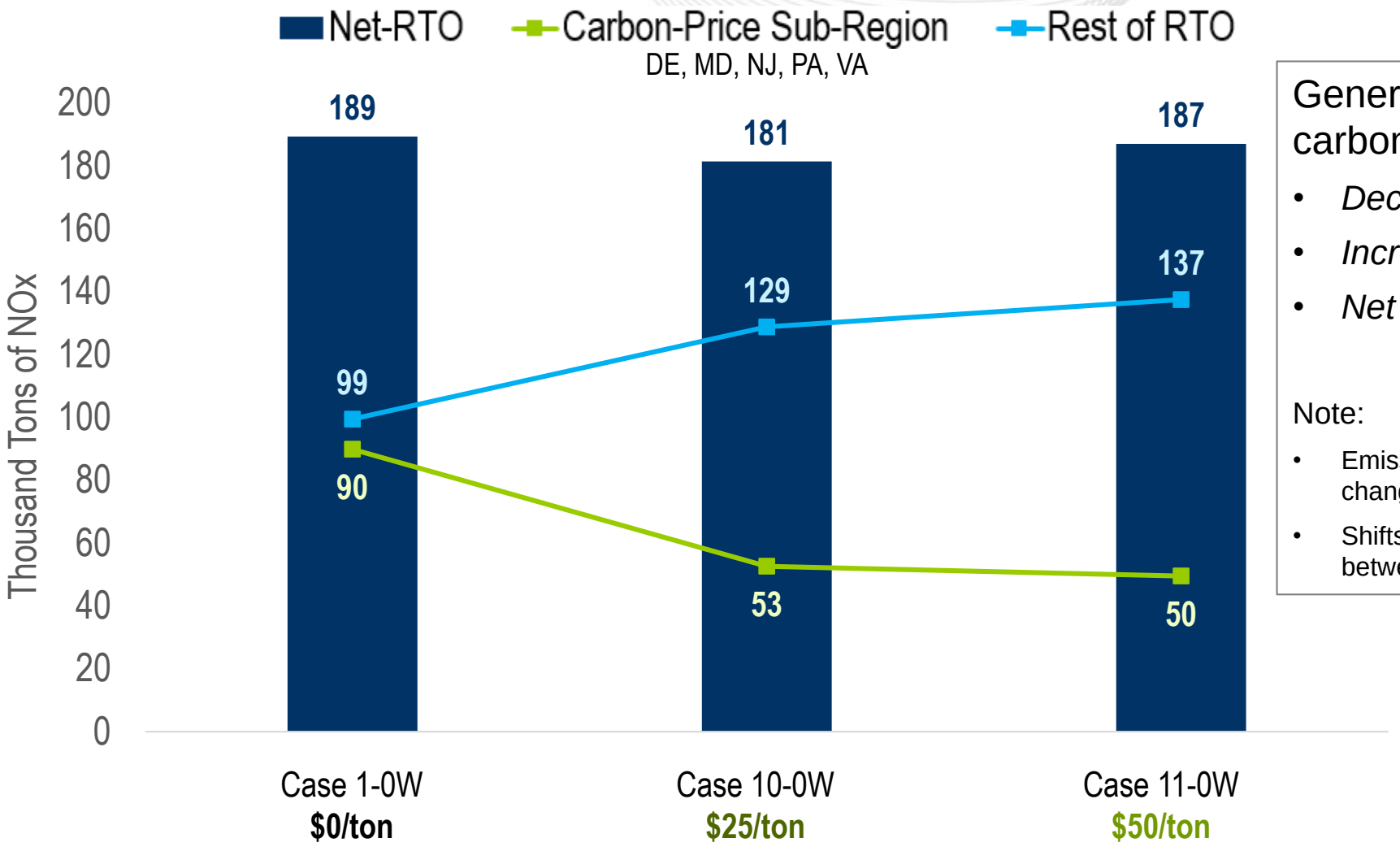
Generation shift from increasing carbon price results in CO_2:

- *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



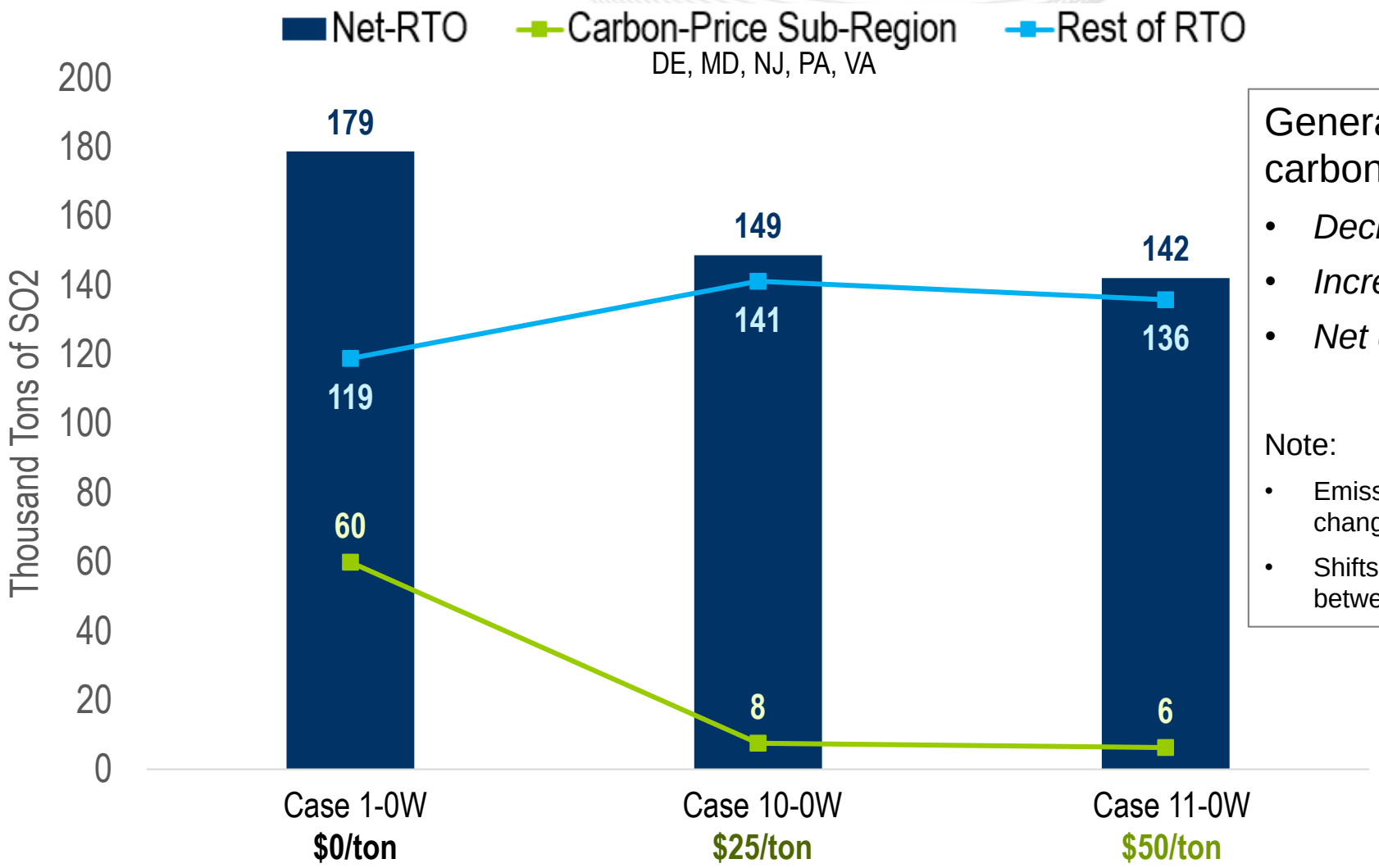
Generation shift from increasing carbon price results in CO_2:

- *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



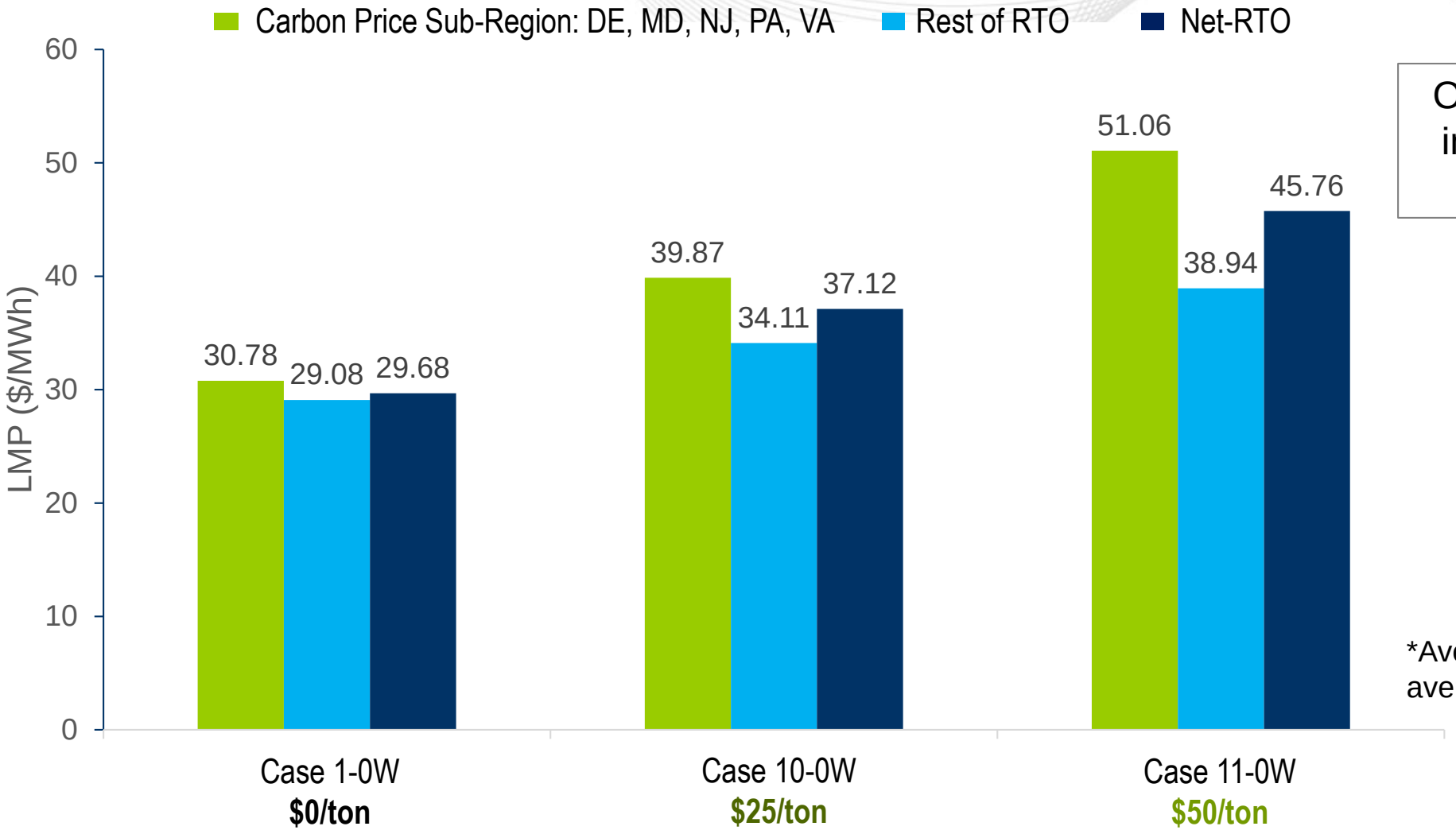
Generation shift from increasing carbon price results in CO_2:

- *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

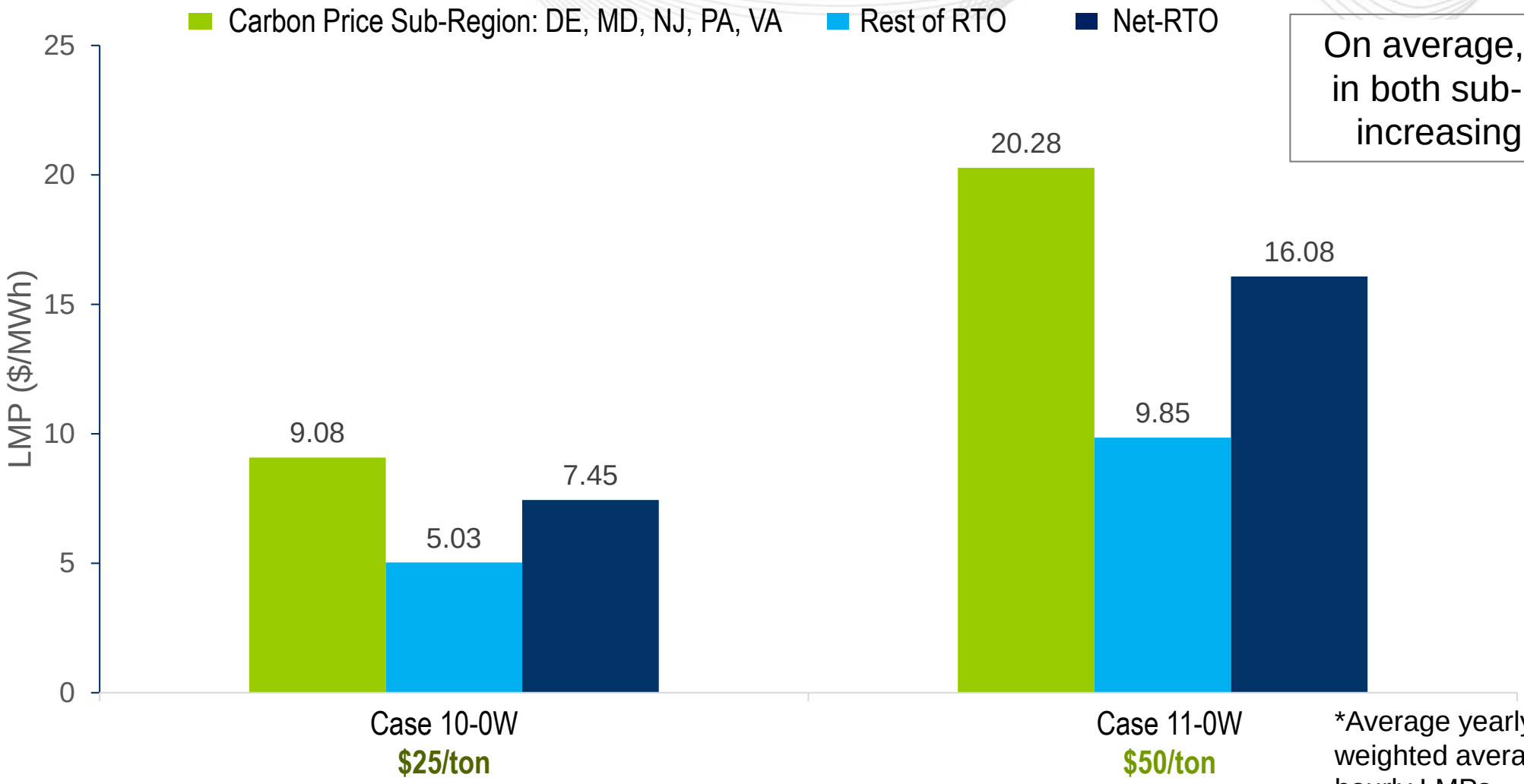
2023 PJM Average Yearly LMPs* by Sub-Region & Carbon Price



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

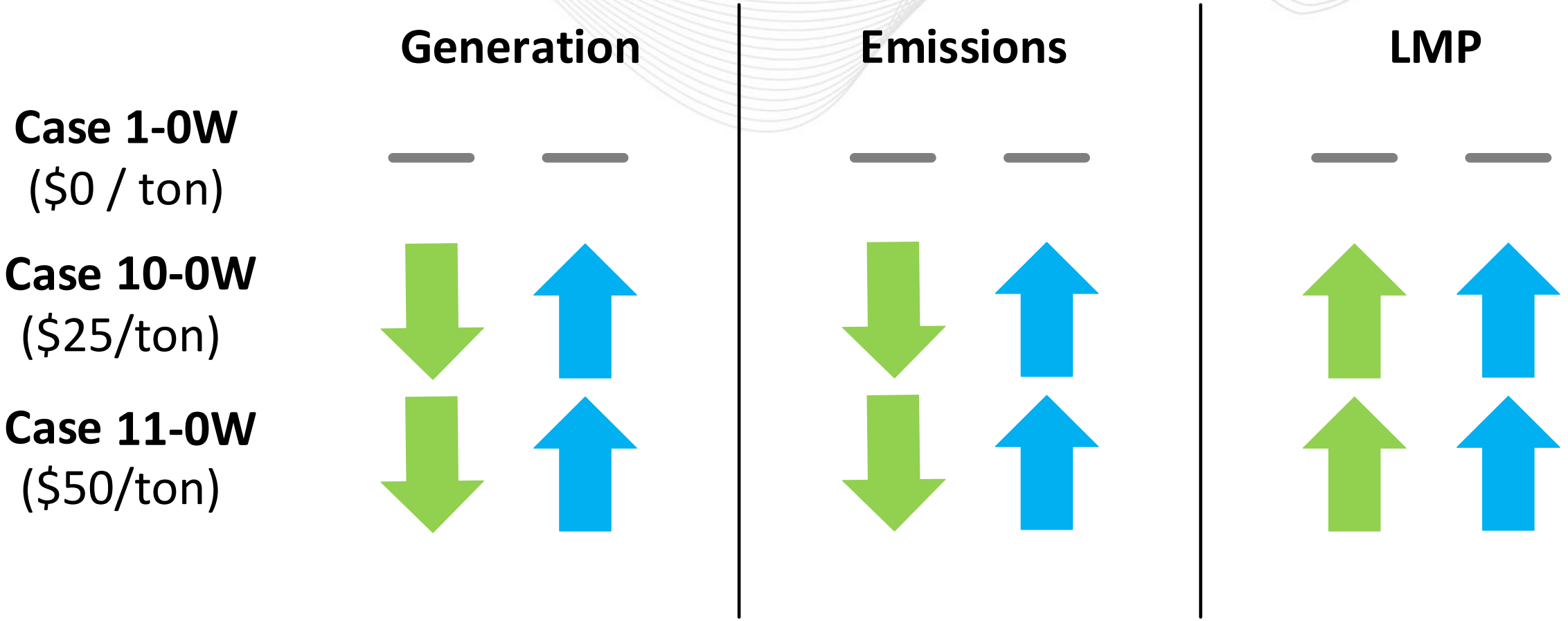


On average, LMPs increase in both sub-regions with an increasing carbon price.

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

Results Summary

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



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

- **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 May 19, 2020 CPSTF

Part 1a: Impacts of higher carbon prices in a sub-region of PJM

Part 1b: Impacts of Potential Border Adjustments for Leakage Mitigation in a sub-region of PJM with higher carbon prices

Part 2: Impacts of incrementally increasing carbon prices across PJM

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

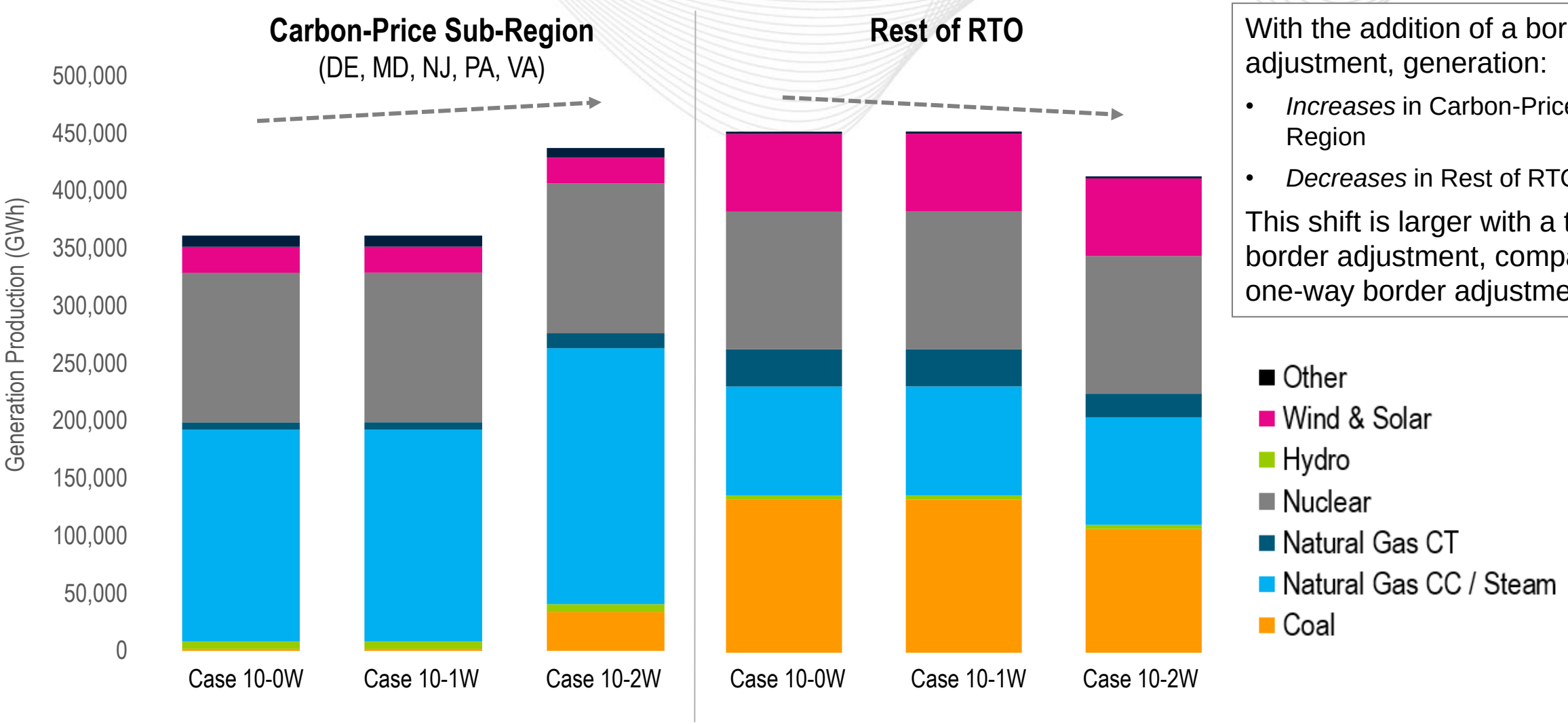
Case	RGGI Price	Border Adjustment
Case 10-0W	$25/short ton	None
Case 10-1W	$25/short ton	One-Way
Case 10-2W	$25/short ton	Two-Way
Case 11-0W	$50/short ton	None
Case 11-1W	$50/short ton	One-Way
Case 11-2W	$50/short ton	Two-Way

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, PA and VA
  - Rest of RTO – all other states in PJM

2023 Generation Production by Sub-Region: **$25/ton CO_2**

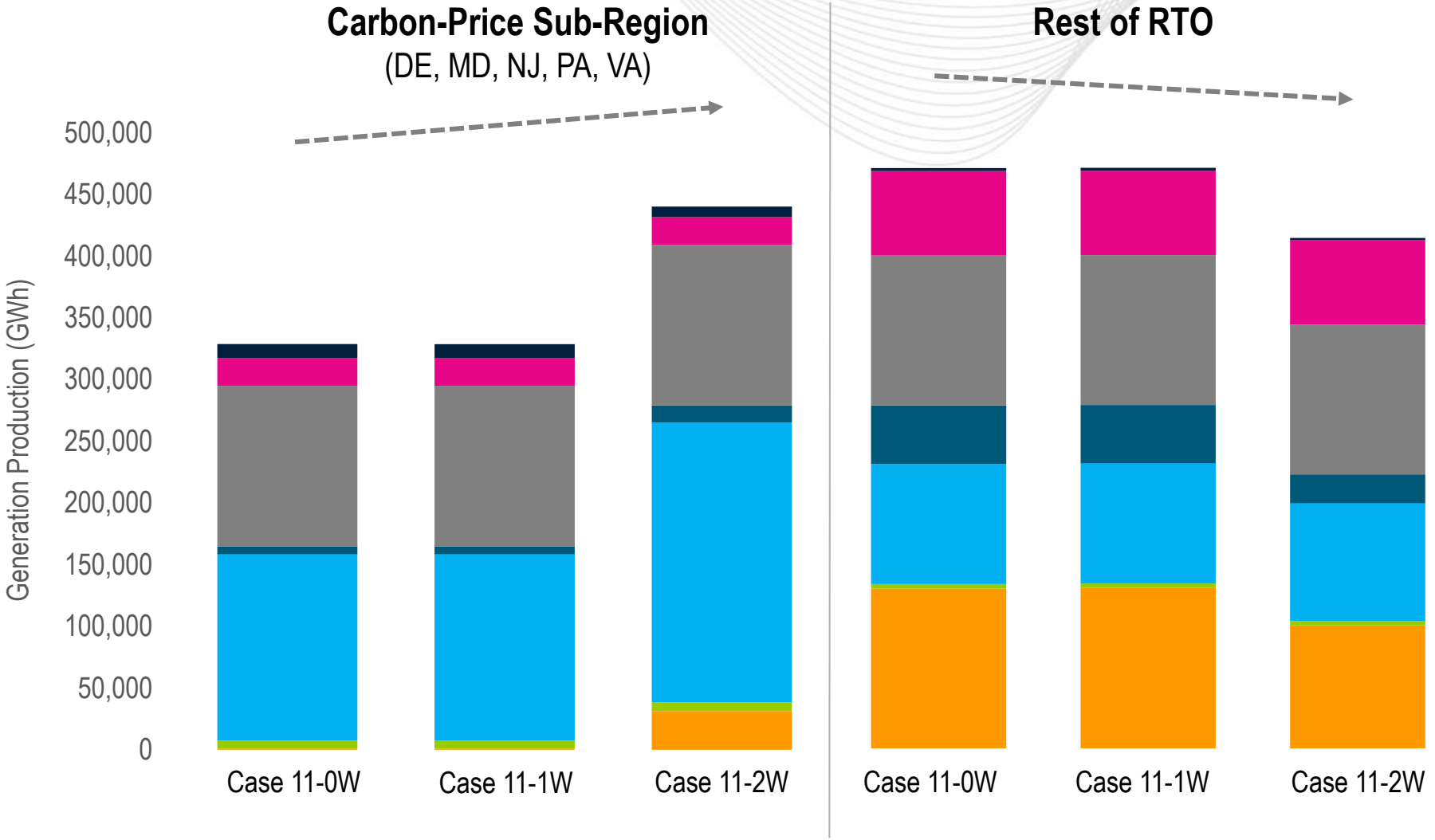


With the addition of a border adjustment, generation:

- *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: **$50/ton CO_2**



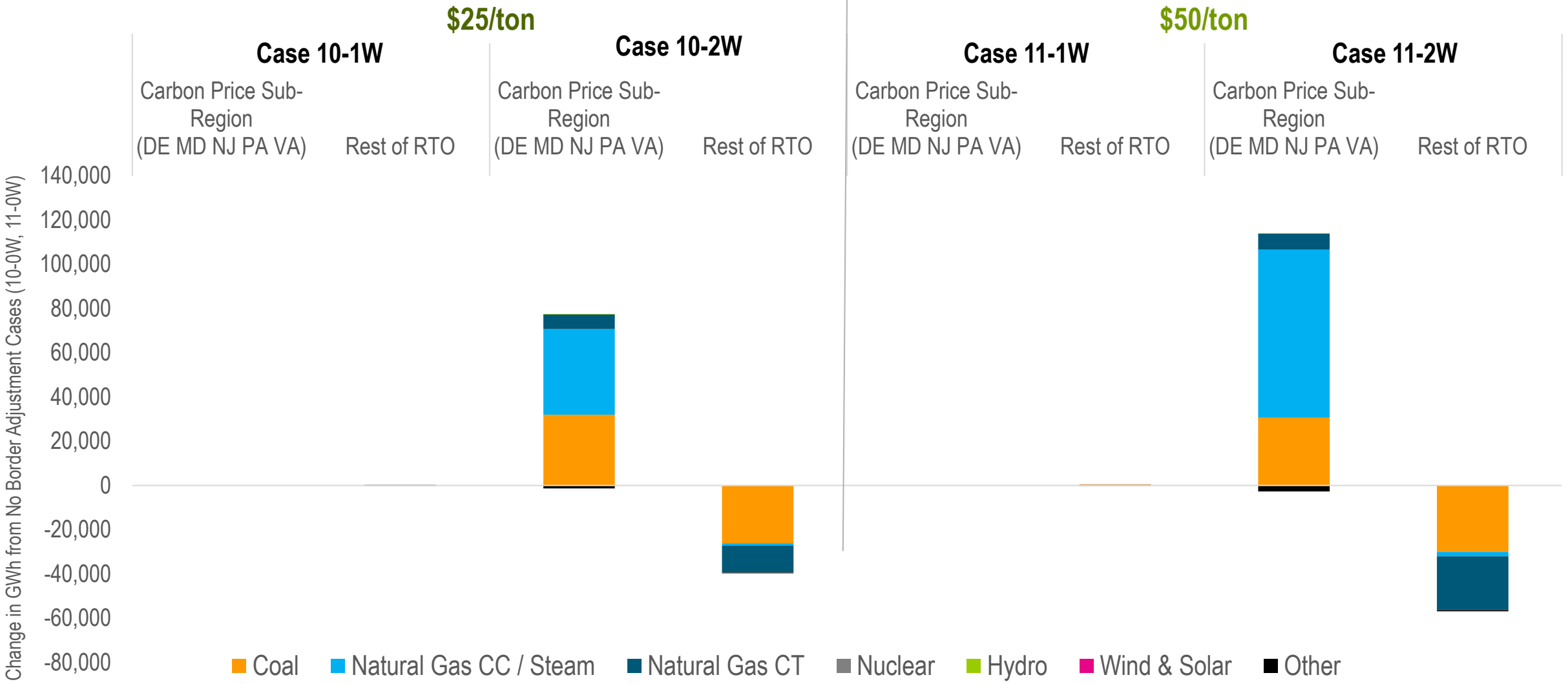
With the addition of a border adjustment, generation:

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

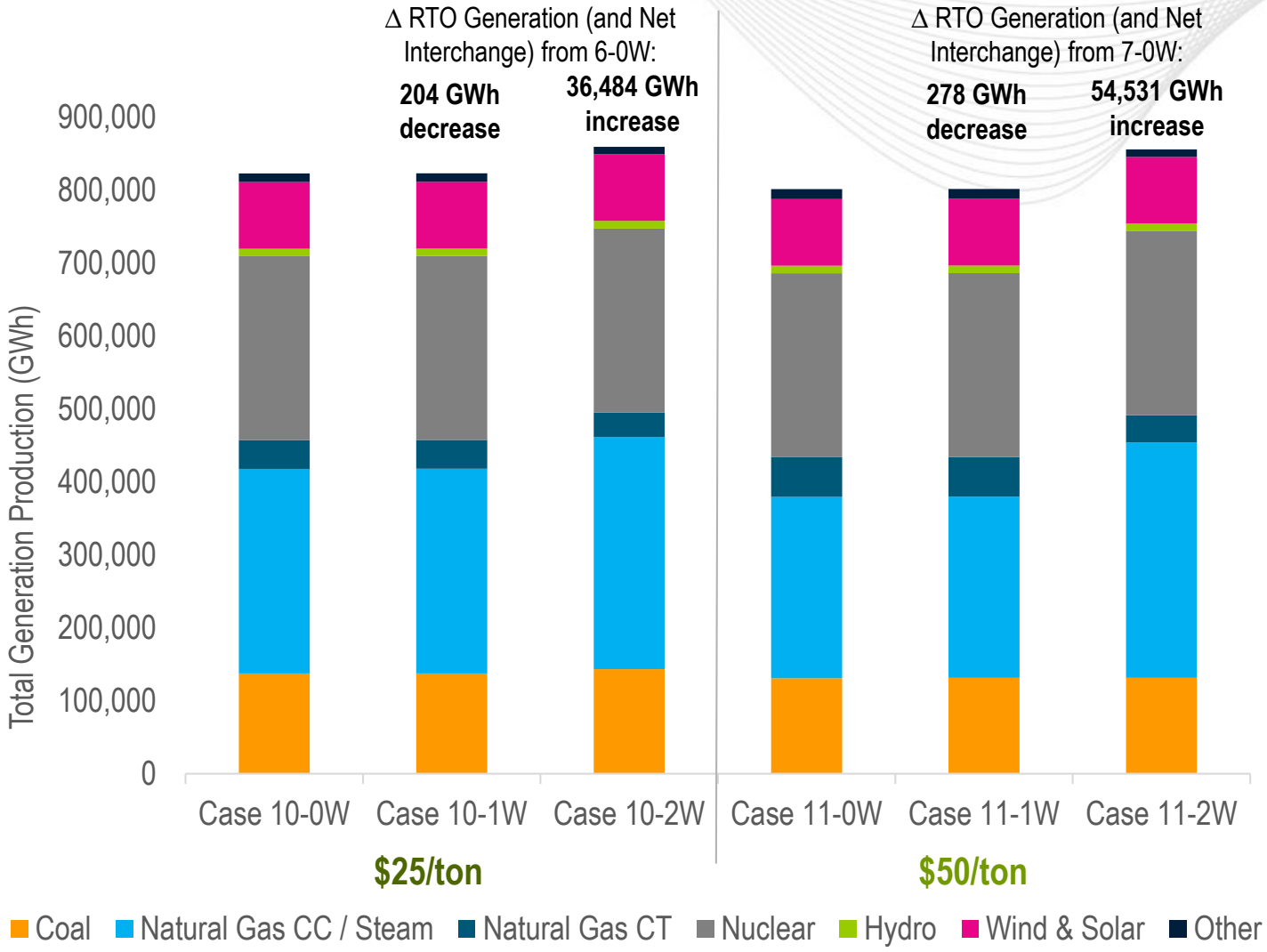
This shift is larger with a two-way border adjustment, compared to a one-way border adjustment.

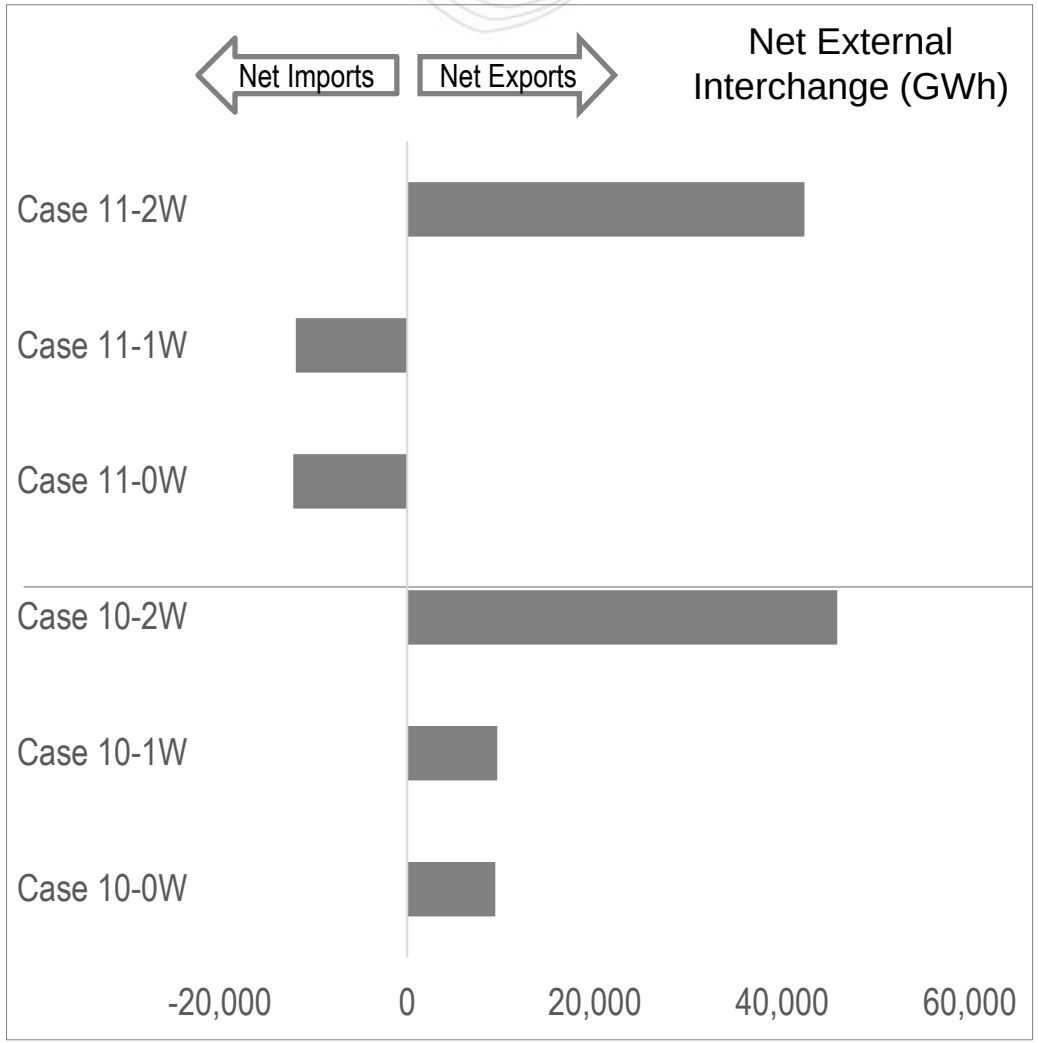
- Other
- Wind & Solar
- Hydro
- Nuclear
- Natural Gas CT
- Natural Gas CC / Steam
- Coal

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



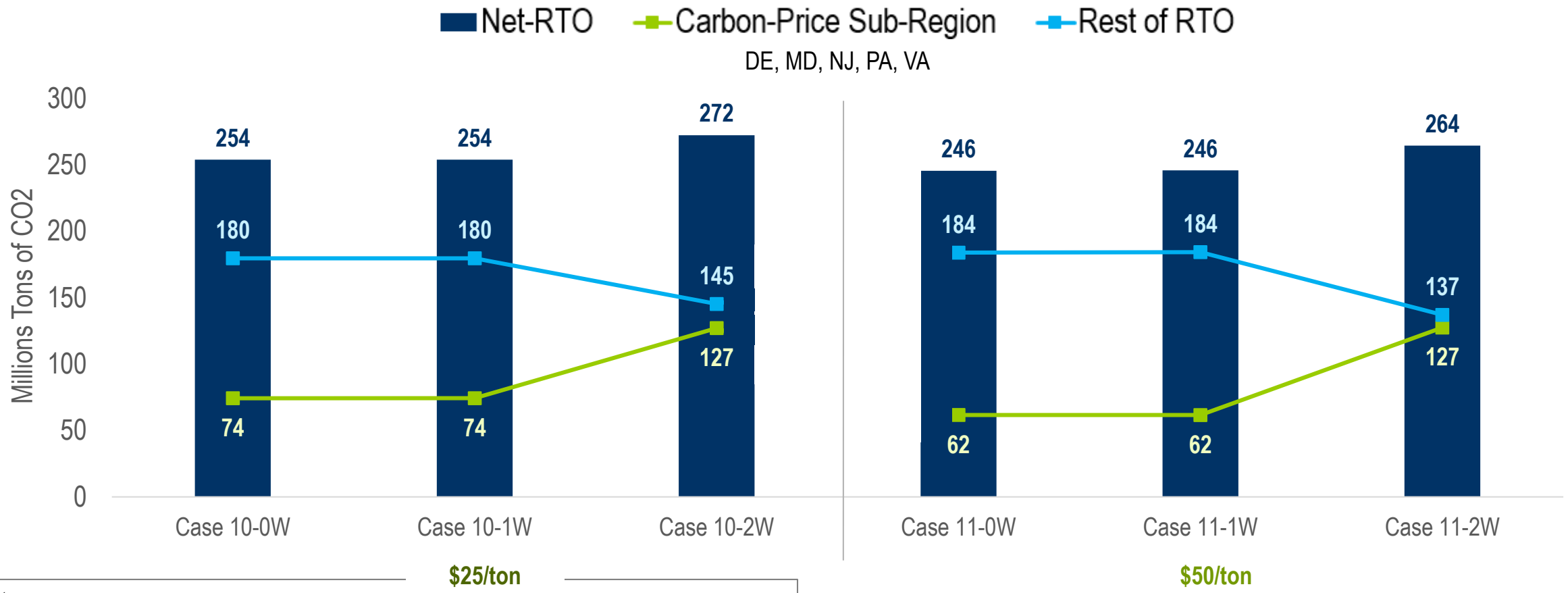
Interchange between PJM and External Regions





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.

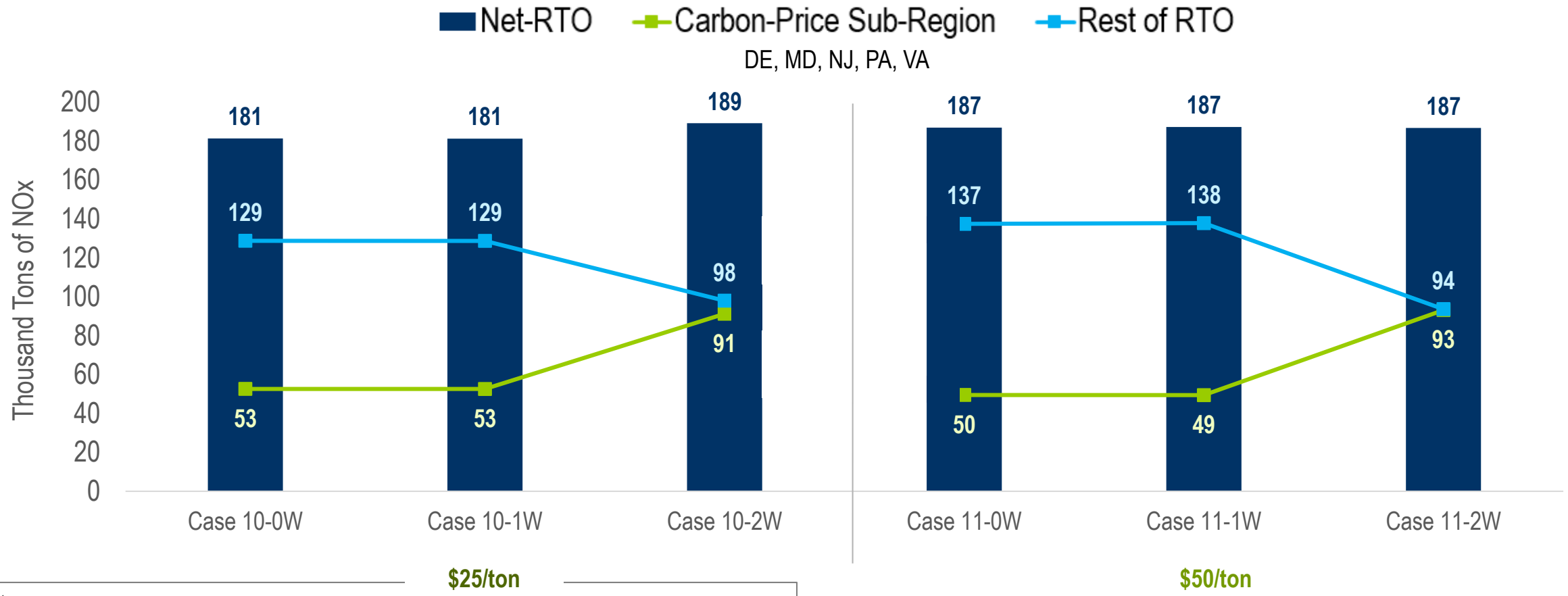


Note:

- 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.

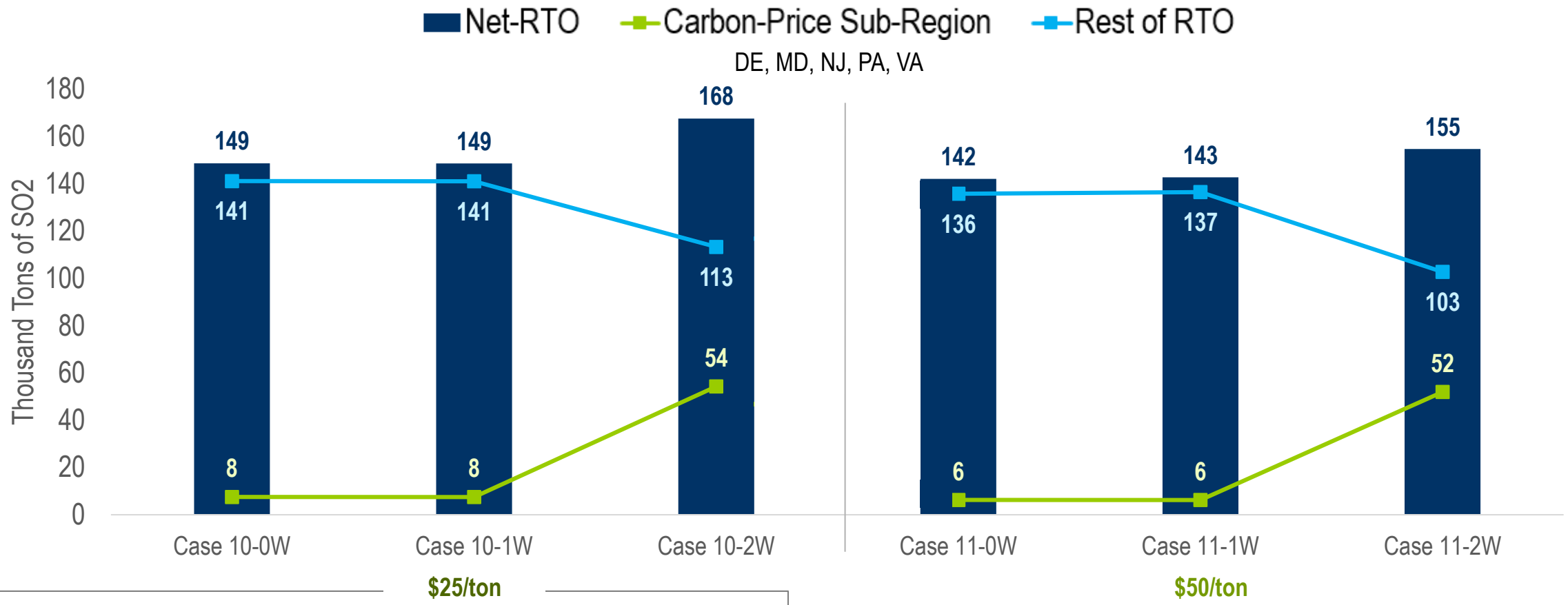


Note:

- 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

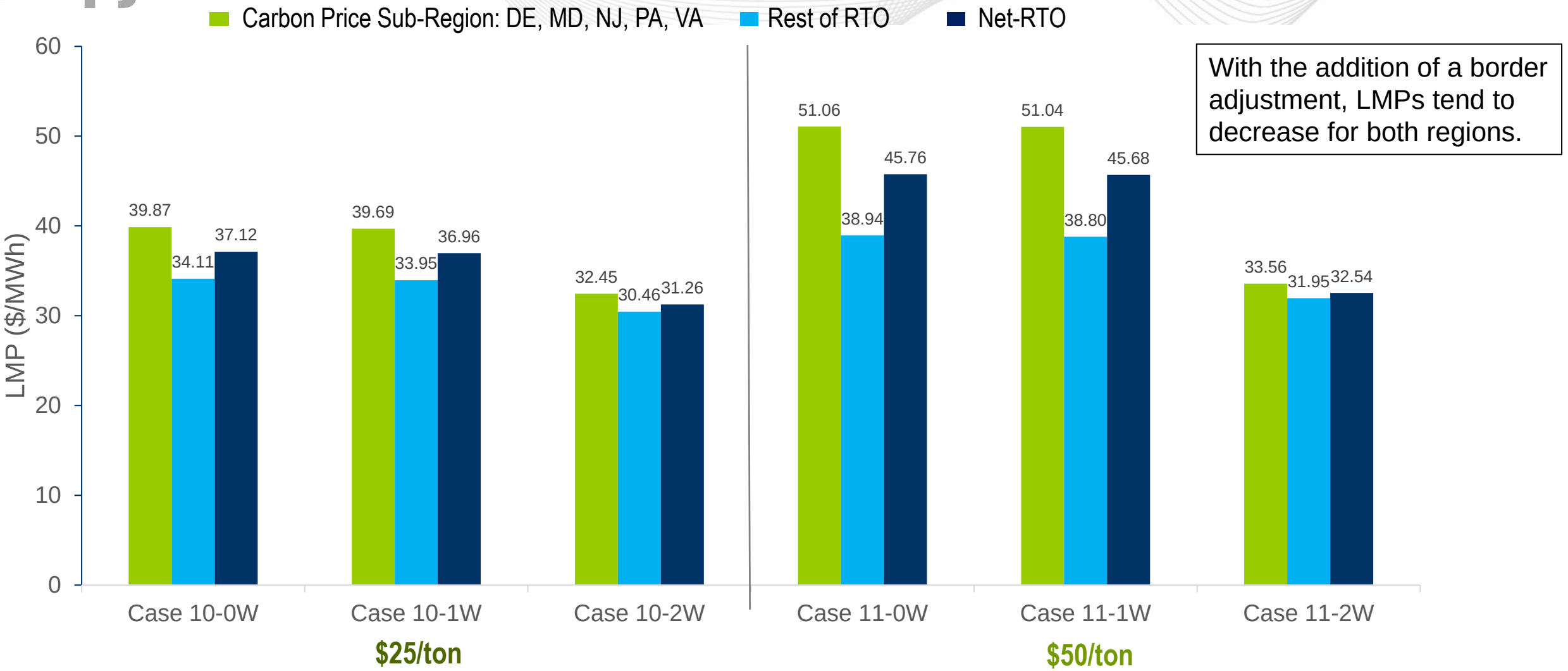
Generation shift from one-way border adjustment results in a small emissions shift between sub-regions and across Net-RTO.
Two-way border adjustment results in emissions *increase* in Carbon-Price Sub-Region, *decrease* in Rest of RTO and *net increase* across Net-RTO.



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

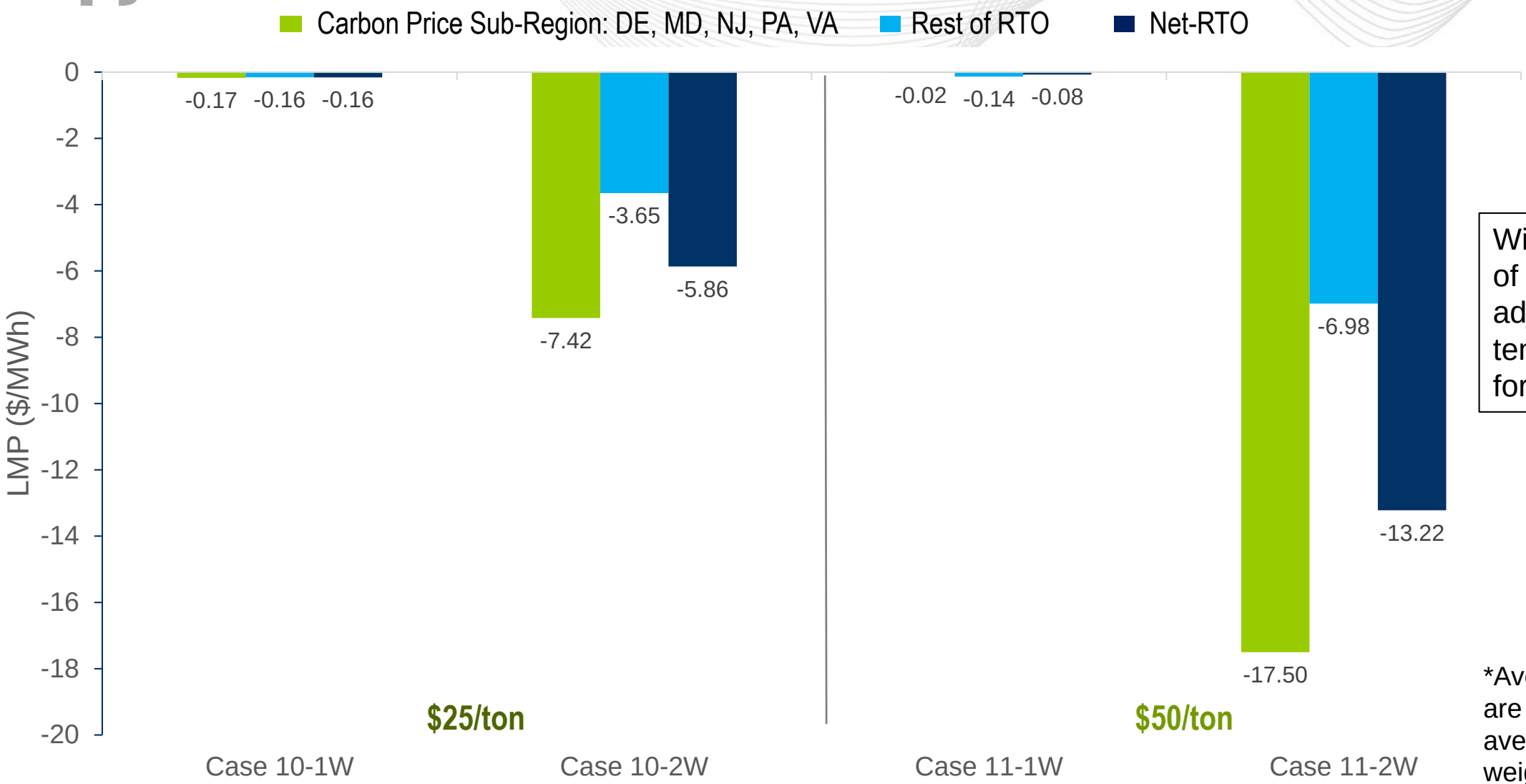
2023 PJM Average Yearly LMPs* by Sub-Region



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.

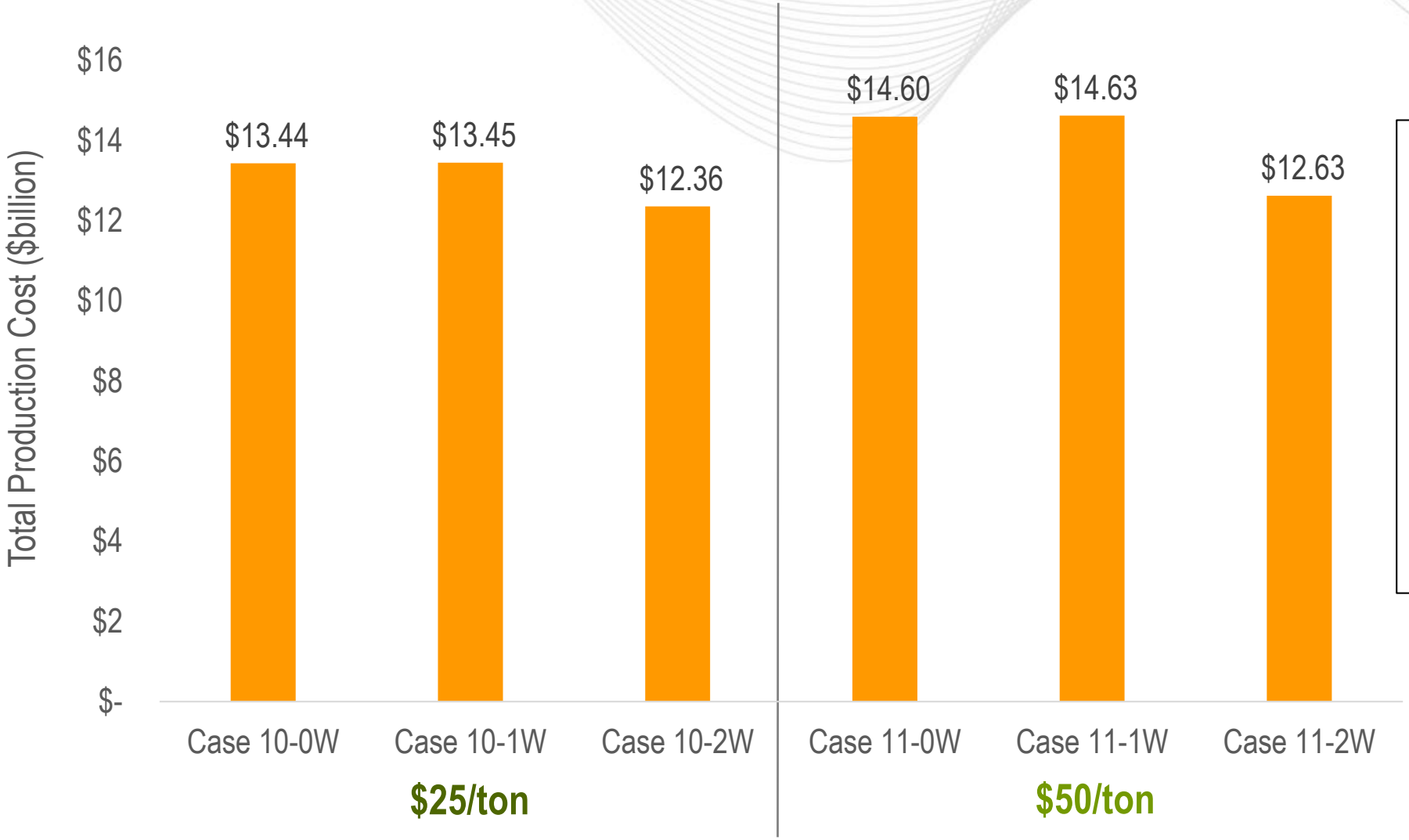
2023 Difference in Average Yearly LMPs* from Case 0W by Sub-Region and RGGI Price



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



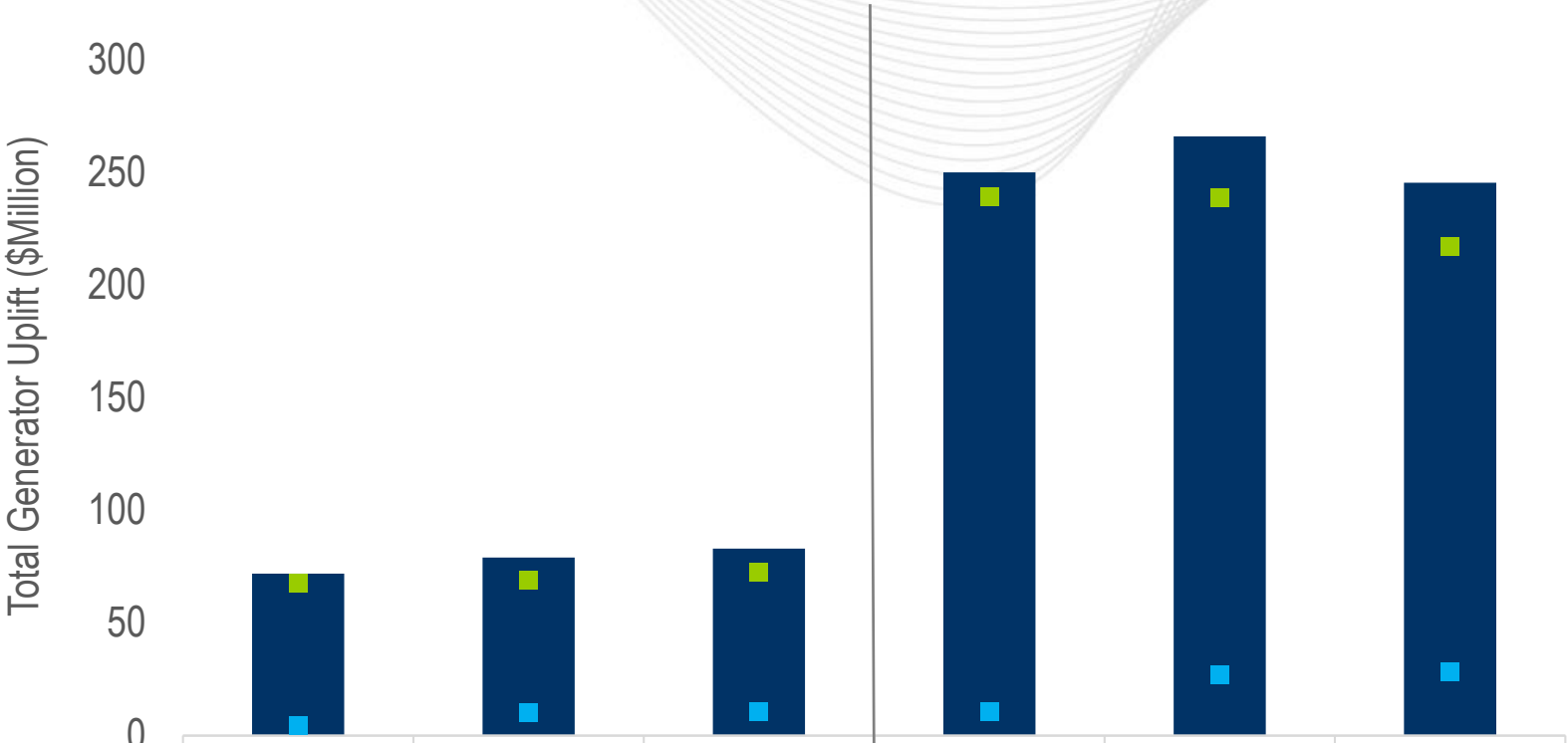
Total System Production Cost:

- *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 10-0W	Case 10-1W	Case 10-2W	Case 11-0W	Case 11-1W	Case 11-2W
Net-RTO	$71.92	$79.12	$83.06	$250.19	$266.15	$245.55
Carbon-Price Sub-Region (DE, MD, NJ, VA, PA)	$67.62	$68.95	$72.42	$239.59	$239.05	$217.33
Rest of RTO	$4.30	$10.17	$10.63	$10.60	$27.10	$28.22

$25/ton **$50/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

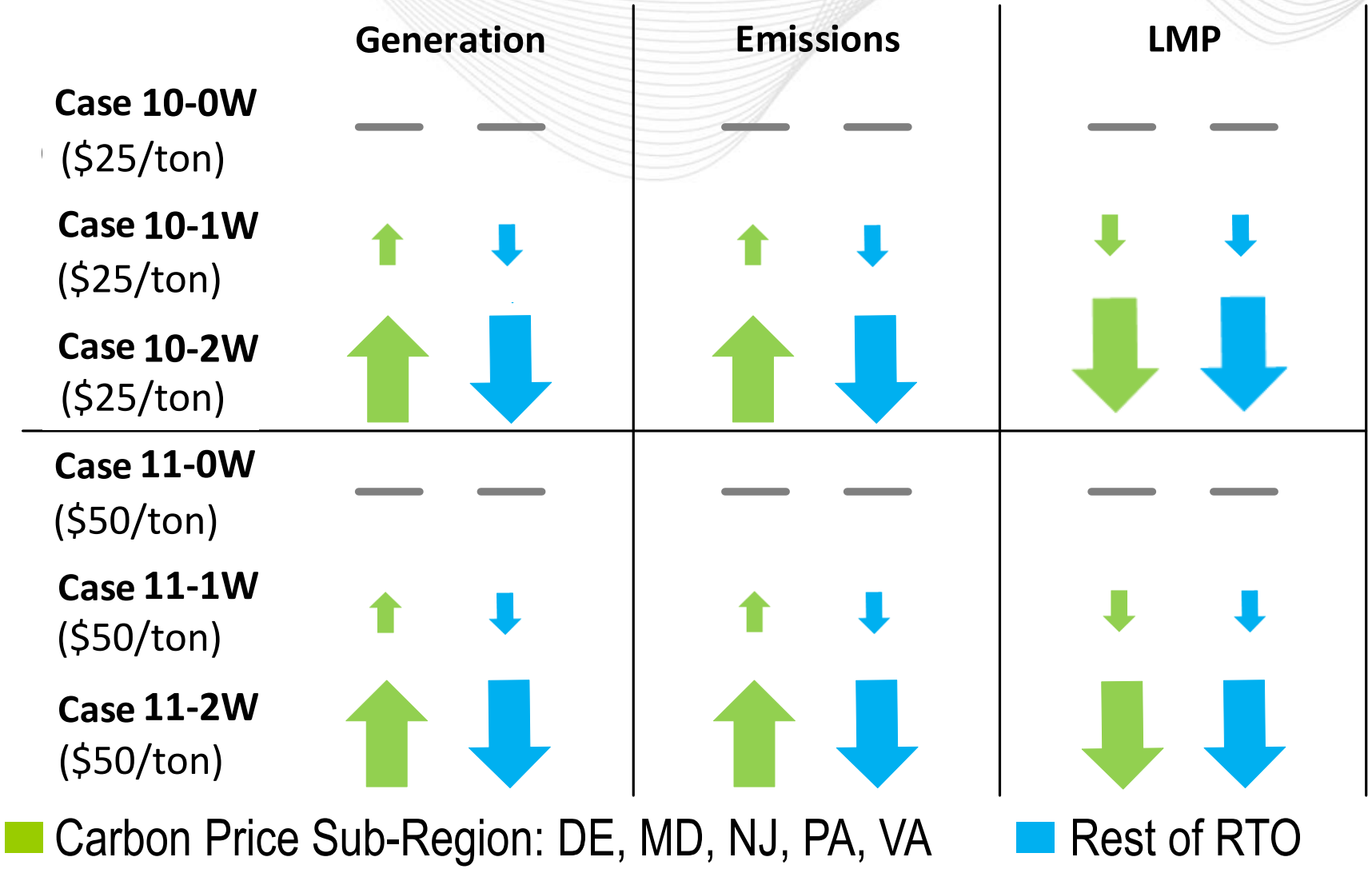
Impact of Border Adjustment on CO_2 Emission Costs to Generators

- 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 1b: 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.

Results Overview for 5/19/2020 CPSTF

Part 1a: Impacts of higher carbon prices in a sub-region of PJM

Part 1b: Impacts of Potential Border Adjustments for Leakage Mitigation in a sub-region of PJM with higher carbon prices

Part 2: Impacts of incrementally increasing carbon prices across PJM

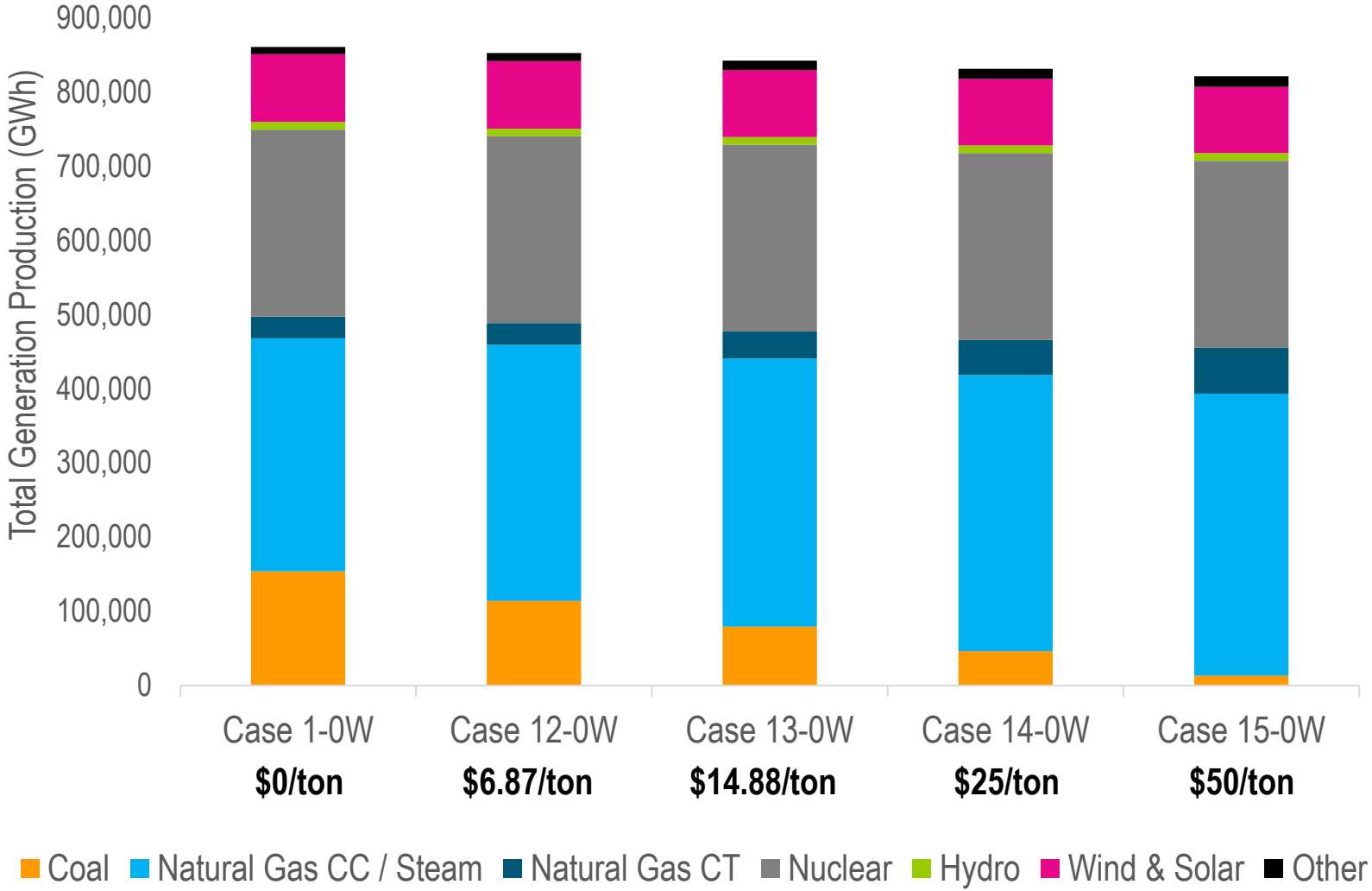
Part 2 Scenario Summary

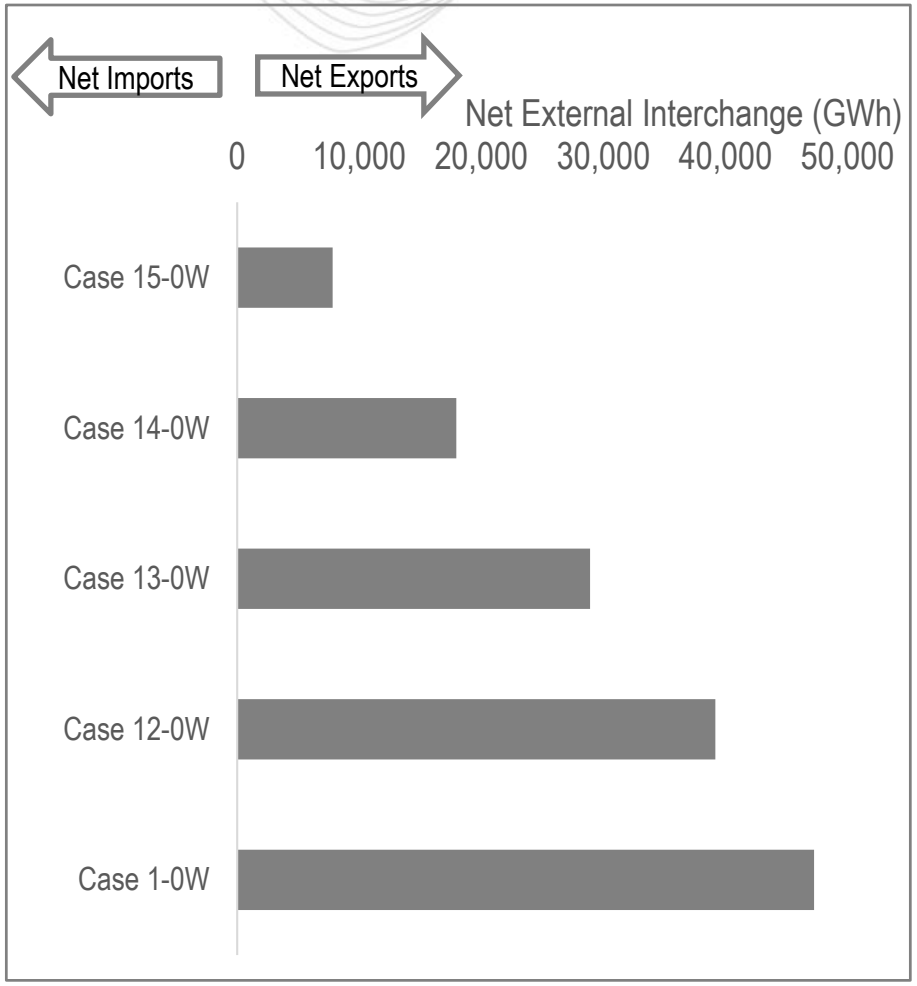
Impacts Incrementally Increasing Carbon Prices Across PJM

- Scenarios with system-wide carbon price at $6.87/short ton, $14.88/short ton, $25/short ton and $50/short ton compared to a counterfactual scenario with RGGI price at $0/short ton to quantify differences in:
  - Generation
  - Emissions
  - Prices
- The year 2023 was simulated for the following cases:

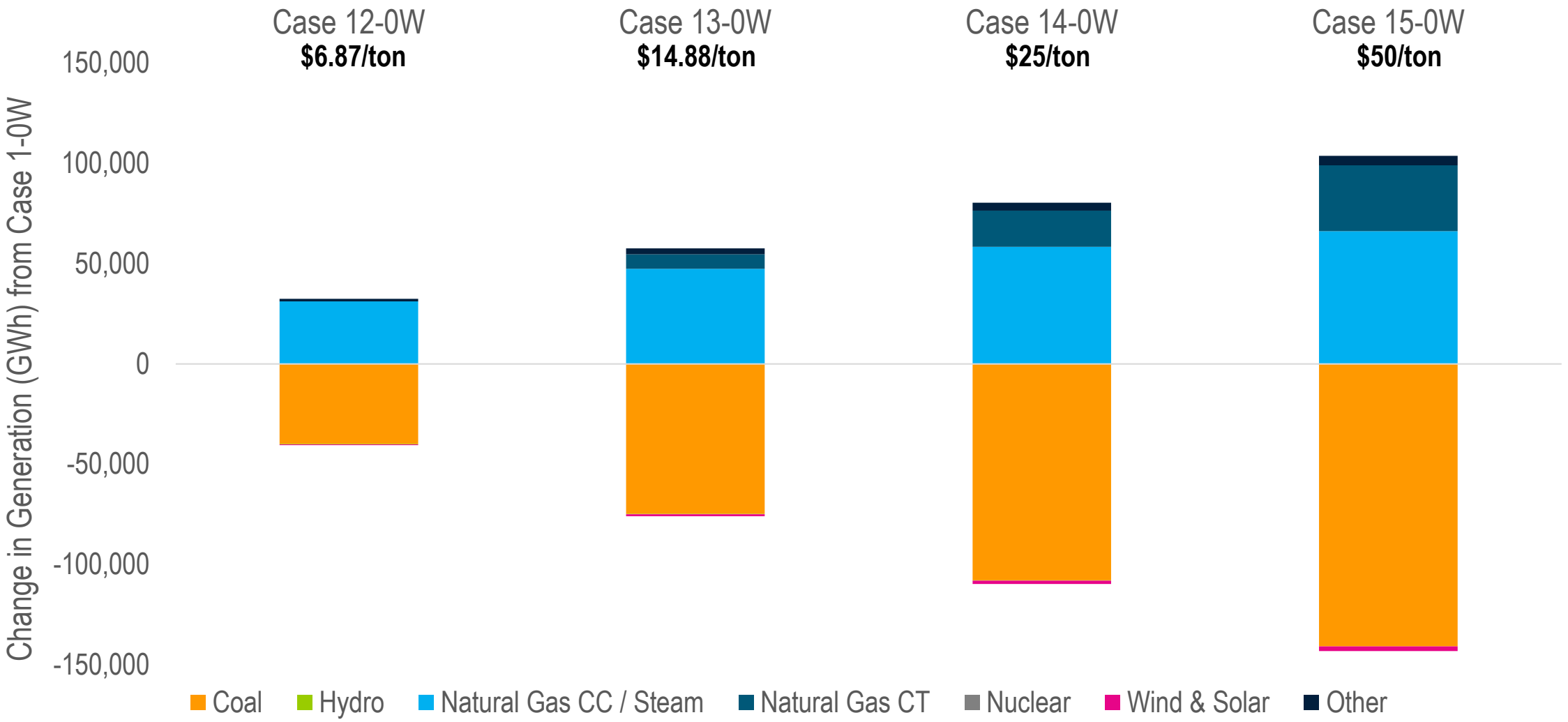
Case	Carbon Price	Border Adjustment
Case 1-0W	$0/short ton	None
Case 12-0W	$6.87/short ton	None
Case 13-0W	$14.88/short ton	None
Case 14-0W	$25/short ton	None
Case 15-0W	$50/short ton	None

Impact of System-Wide Carbon Price Generation Production

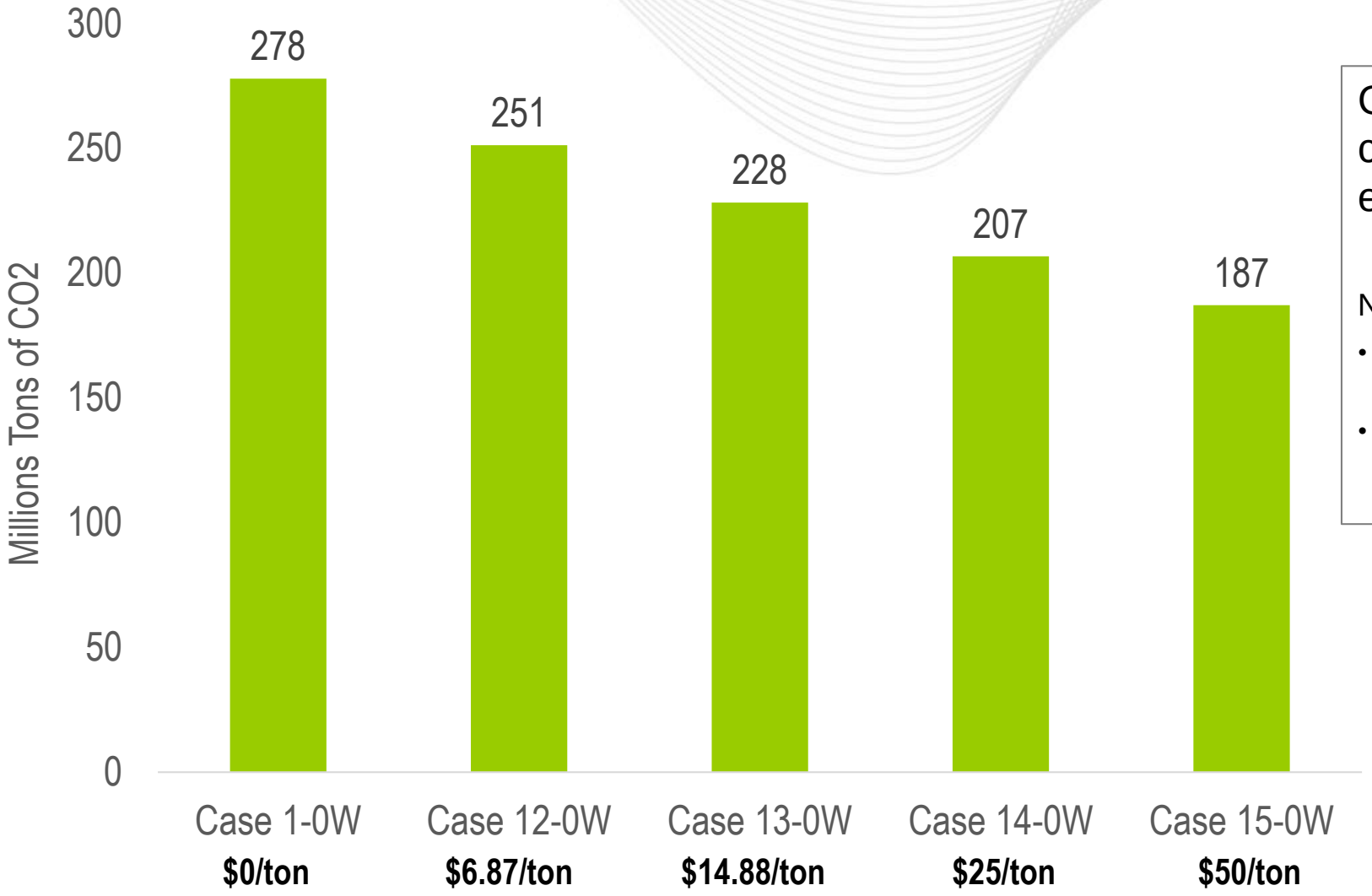




RTO Shifts in Generation Production from Case 1-0W ($0/ton CO_2)



2023 Total RTO CO_2 Emissions

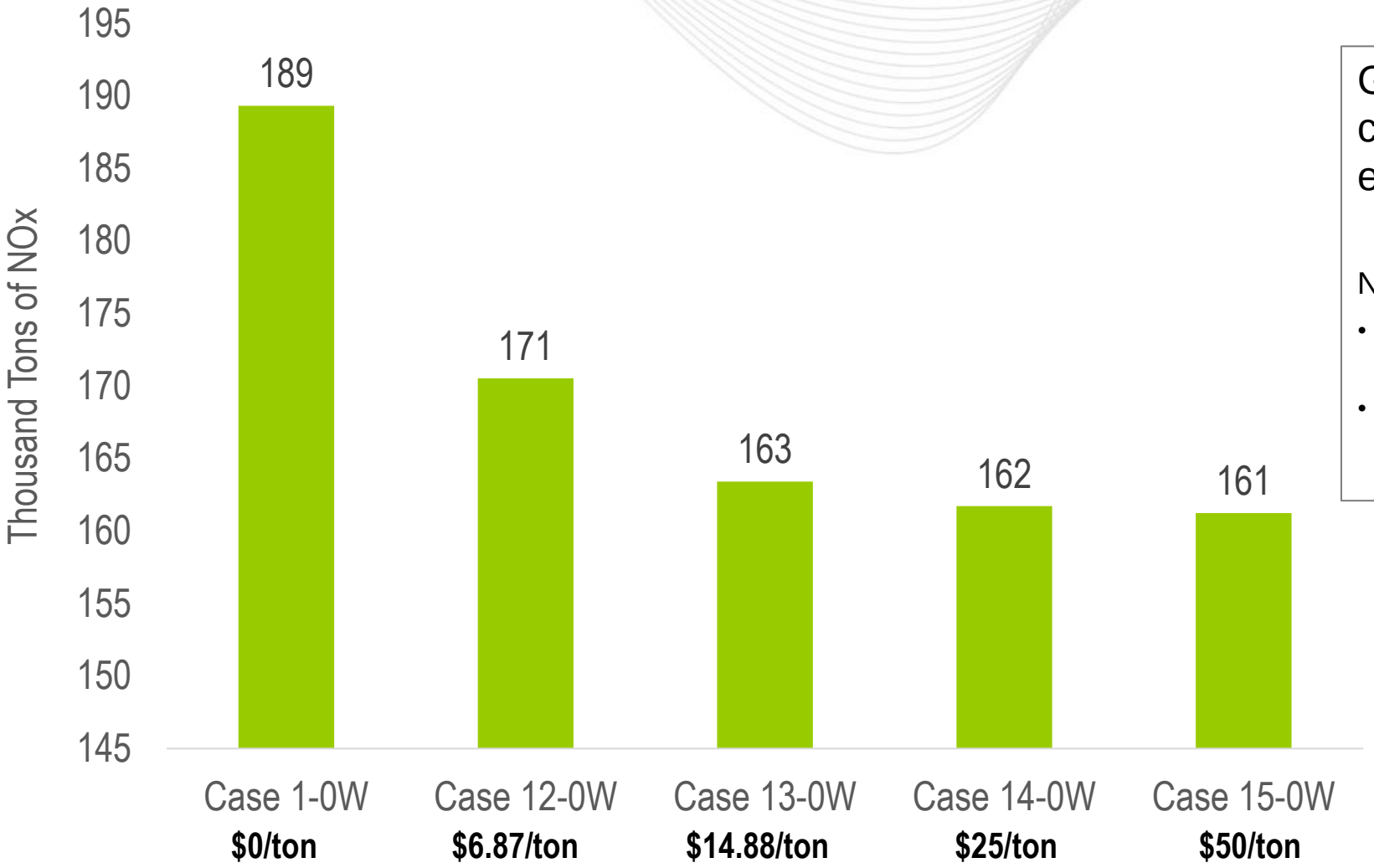


Generation shift from increasing carbon price results in CO_2 emissions decrease.

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 RTO NO_X Emissions

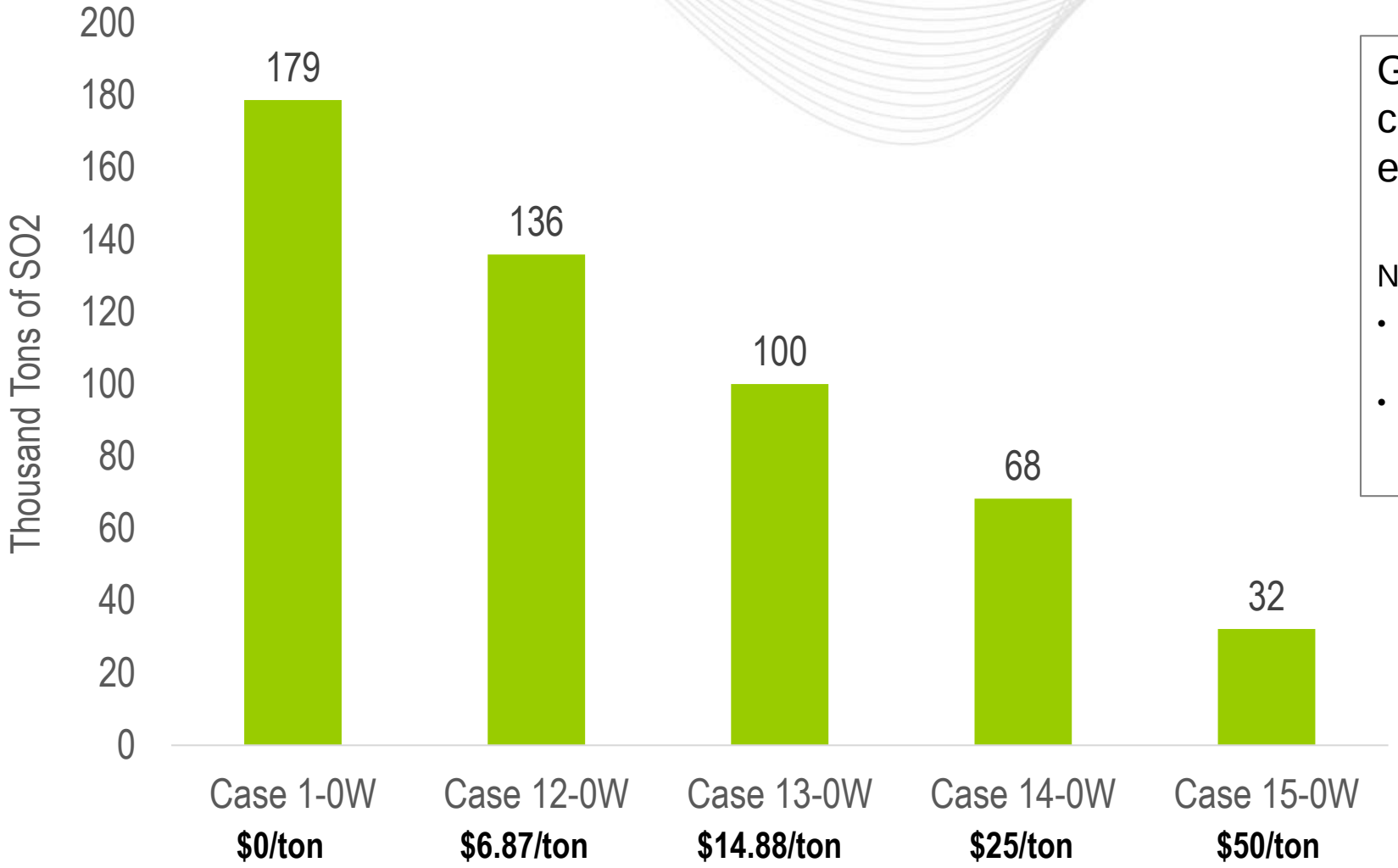


Generation shift from increasing carbon price results in NO_X emissions decrease.

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 RTO SO_2 Emissions

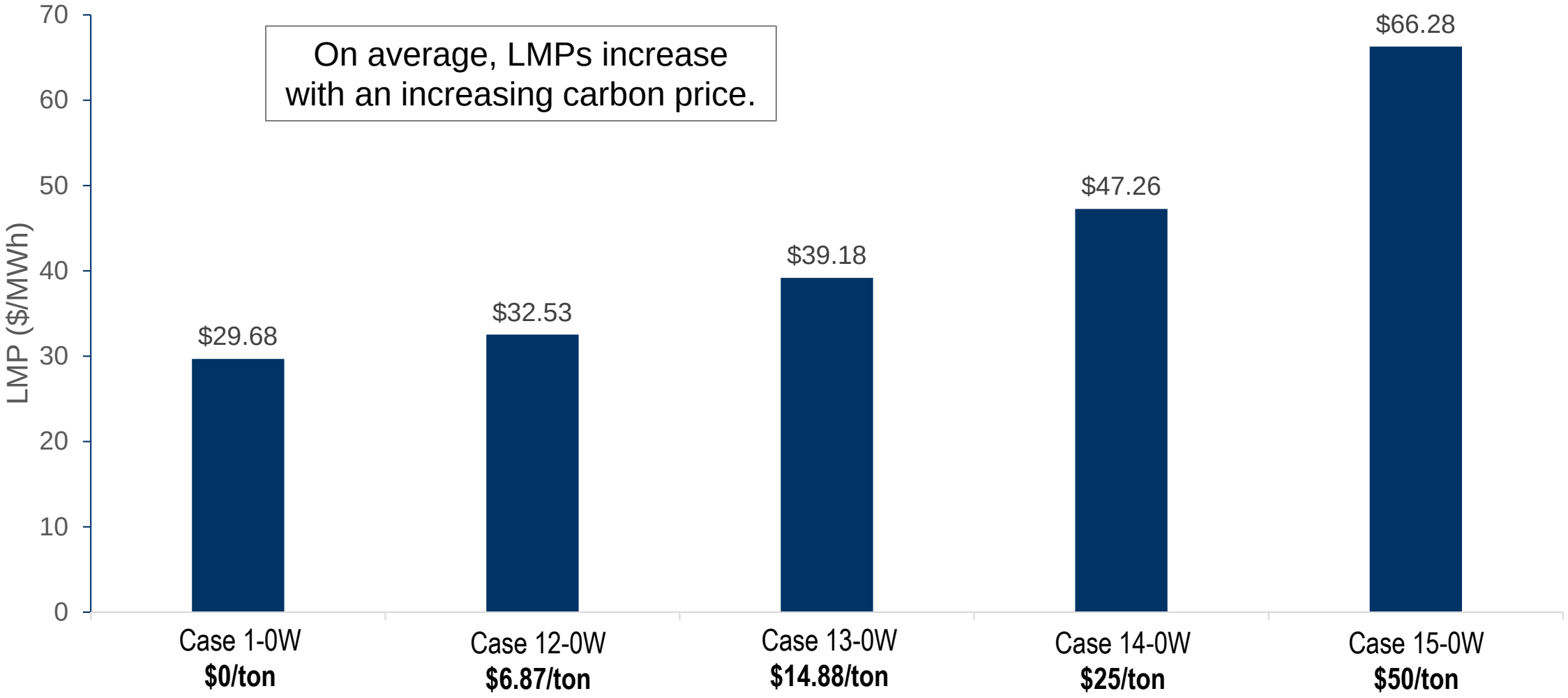


Generation shift from increasing carbon price results in SO_2 emissions decrease.

Note:

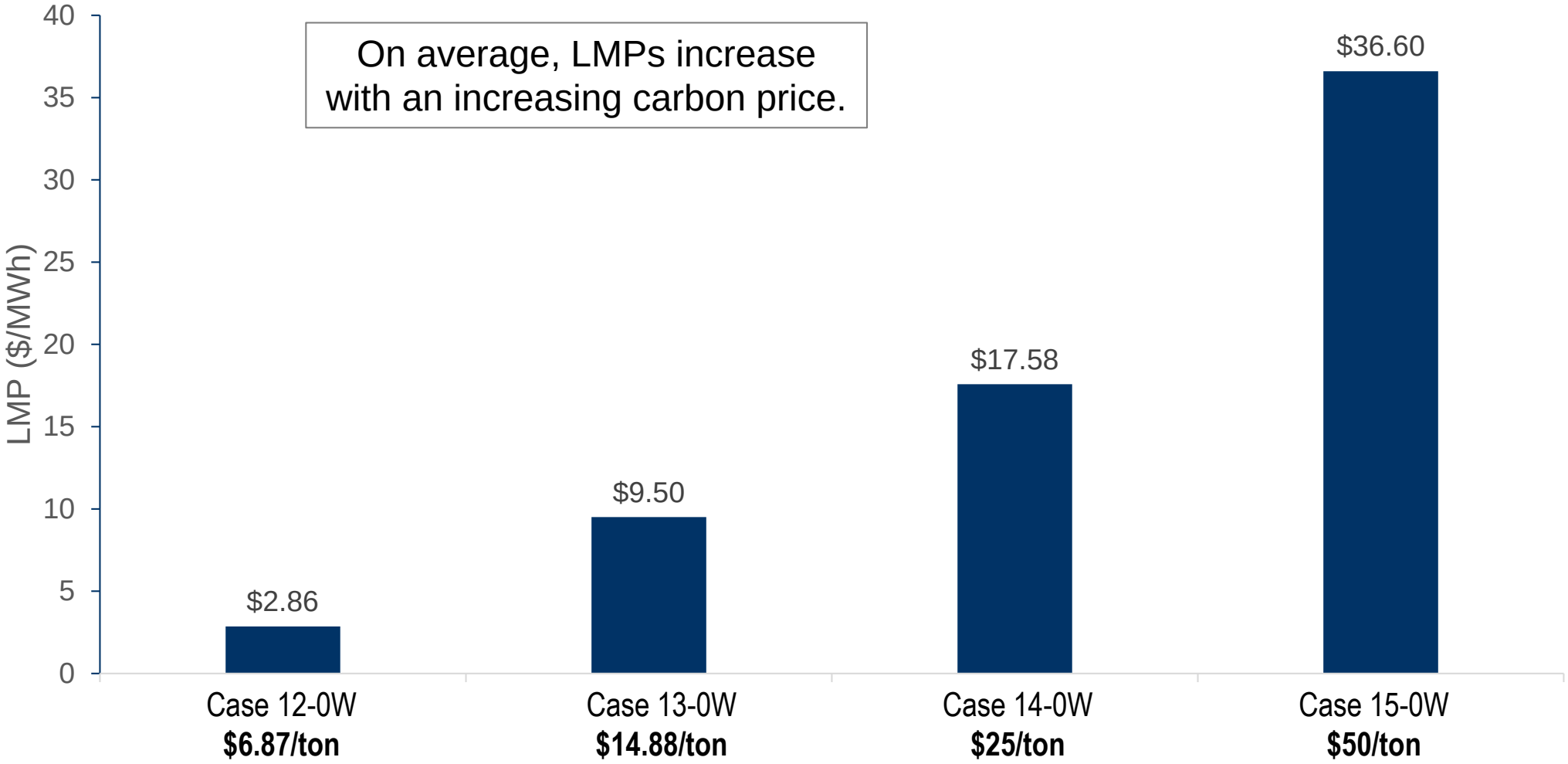
- Emissions are for PJM only and do not account for changes in external regions
- Shifts in RTO generation and external interchange between cases are driving changes in emissions

2023 PJM Average Yearly LMPs* by Carbon Price



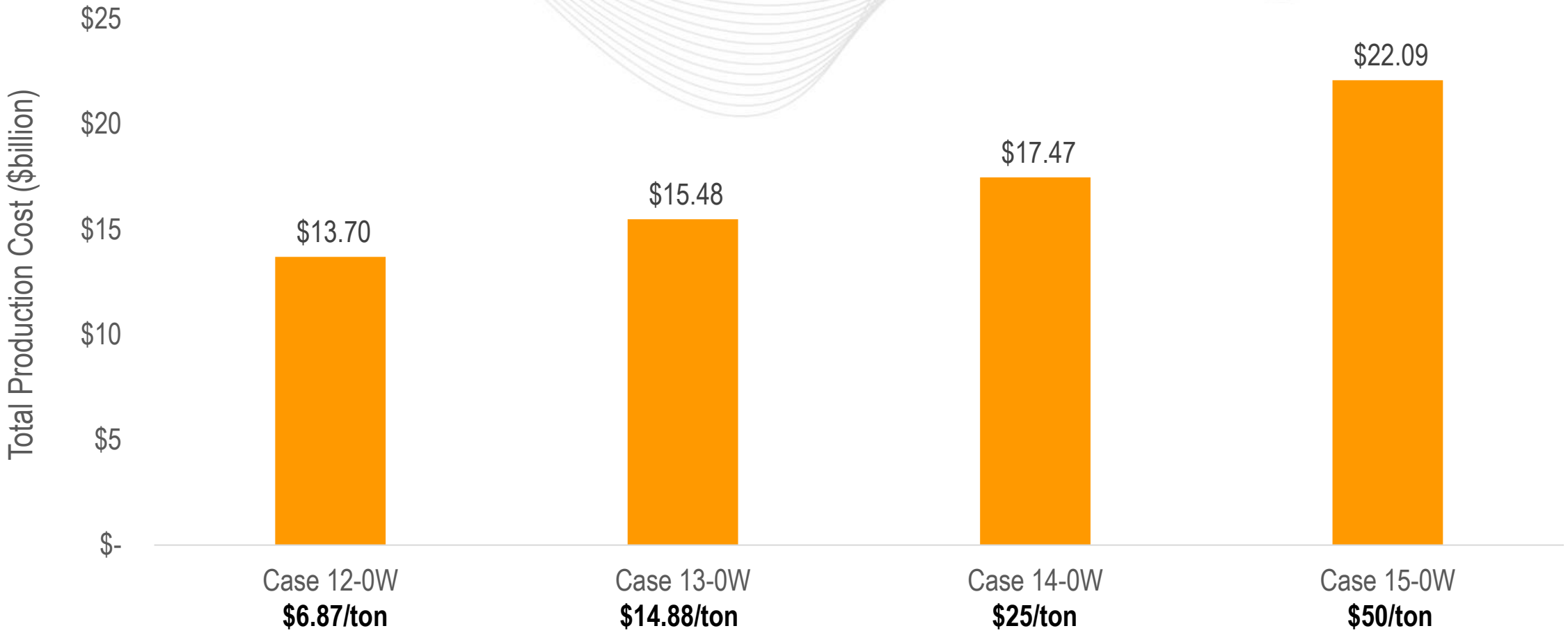
*Average yearly LMPs are time-weighted averages of load-weighted hourly LMPs.

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



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

Impact of an Increasing System-wide Carbon Price on Total Production Cost



- **Generation:**
  - Compared to the no carbon price scenario, the carbon price scenarios result in shifts in generation production from higher-emitting resources to lower-emitting resources.
- **Emissions:**
  - The shift in generation production results in a decrease in emissions across the RTO.
- **Energy Prices:**
  - Compared to the scenario with no carbon price, on average, LMPs increase across the RTO as the carbon price increases.