Modeling of CO_2 Emissions and Leakage Under Various CO_2 Allocation Schemes

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1.0 Executive Summary

Maryland is part of the Regional Greenhouse Gas Initiative (RGGI), a carbon cap-and-trade agreement between several states in the Mid-Atlantic and Northeast:

- Connecticut,
- Delaware,
- Maine,
- Maryland,
- Massachusetts,
- New Hampshire,
- New York,
- Rhode Island, and
- Vermont.

As part of RGGI, each state caps the amount of carbon dioxide (CO_2) emissions that the electricity sector is allowed to generate each year. However, while Maryland is part of RGGI, many nearby states are not, including New Jersey, Ohio, Pennsylvania, Virginia, and West Virginia. However, these states, as well as Maryland, are within PJM, the regional transmission organization (RTO) that operates an electricity market and the electrical grid across all member areas. Because the RGGI caps on CO_2 emissions do not apply to many states within PJM, power generation may shift from Maryland to nearby states if the cost to produce in Maryland rises due to stricter environmental regulations. This phenomenon is known as leakage.

Maryland and other RGGI states seek to minimize the leakage of CO_2 emissions for both environmental reasons (if the same amount of CO_2 is emitted in another state, no larger benefit to the climate has occurred) and economic reasons (lost jobs and tax revenue from production shifting out of state). Maryland has two primary options to mitigate leakage within the State's direct purview: (1) alternative allowance proceeds reinvestment models; and (2) different allowance distribution schemes.

Currently, Maryland provides natural gas combined cycle producers with free allowances through a Clean Generation Set-Aside (CGSA). The CGSA is structured in a way that makes it a potentially effective leakage mitigation mechanism: since the CGSA allocates free allowances among eligible in-state generators in proportion to their heat input, it is effectively a production subsidy for them (the more they produce, the more allowances they get).

The project team examined 13 different scenarios that altered the total cap on CO_2 emissions as well as how allowances would be distributed and auction proceeds allocated. The scenarios looked at three difference CO_2 cap assumptions:

1. The cap on CO_2 emissions remains constant between 2020 and 2030;
2. The cap on CO_2 emissions declines by 2.5 percent each year between 2020 and 2030, an equivalent decline to the cap instituted by RGGI states between 2014 and 2020; and

3. The cap on CO_2 emissions declines by 5 percent each year between 2020 and 2030.

Additionally, the scenarios examined different allocation schemes. The CGSA was either maintained or eliminated. If the CGSA was eliminated, the allowances could be auctioned off or used for the creation of a new set-aside. The size of the new set-aside is assumed to be equal to 20 percent of Maryland's base allowance allocation budget plus the allowances contained in the CGSA. The emissions cap, status of the CGSA, and the recipient of the new set-aside is outlined in Figure 1 for each scenario.

Figure 1: Overview of Project Scenarios

Scenario Number	RGGI Cap	CGSA Status	New Set-Aside Recipients
1	Baseline	Maintained	Same proportions as current
2	2.5 Percent Annual Cap Reduction	Maintained	Same proportions as current
3	2.5 Percent Annual Cap Reduction	Eliminated	Allowances auctioned with proceeds allocated as usual
4	2.5 Percent Annual Cap Reduction	Eliminated	Allowances auctioned with more proceeds allocated to Energy Efficiency Programs
5	2.5 Percent Annual Cap Reduction	Eliminated	All Natural Gas Producers
6	2.5 Percent Annual Cap Reduction	Eliminated	Renewable Producers
7	2.5 Percent Annual Cap Reduction	Eliminated	Natural Gas and Renewable Producers
8	2.5 Percent Annual Cap Reduction	Eliminated	Natural Gas, Renewable, and Coal Producers
9	5 Percent Annual Cap Reduction	Maintained	Same proportions as current
10	5 Percent Annual Cap Reduction	Eliminated	Allowances auctioned with more proceeds allocated to Energy Efficiency Programs
11	5 Percent Annual Cap Reduction	Eliminated	All Natural Gas Producers
12	5 Percent Annual Cap Reduction	Eliminated	Renewable Producers
13	5 Percent Annual Cap Reduction	Eliminated	Natural Gas and Renewable Producers

Sources: MDE, RESI, RFF

The leakage of CO_2 emissions can negatively impact local economies, and mitigating leakage is critical to balancing dual goals of reducing CO_2 emissions and preserving jobs. With the recent announcement that the RGGI allowance cap will decline by 3 percent each year between 2020 and 2030, leakage will likely occur. As discussed in Section 4.2, if the allowance cap declines 2.5 percent each year, total leakage between 2020 and 2030 is estimated at 15.49 million tons of CO_2 emissions. Since the allowance cap decline is steeper, leakage should be greater than this estimate. Therefore, Maryland needs to identify ways to mitigate the leakage likely to occur.

The findings in this report generalize well across RGGI cap reductions between 0 percent and 5 percent, though they may not generalize well in situations where the cap reductions are much more stringent, driving up allowance prices. Therefore, the most relevant findings considering the 3 percent annual decline are the scenarios with a 2.5 percent annual decline. Figure 2 illustrates how CO_2 emissions vary by scenario when the RGGI cap decreases by 2.5 percent each year.

Figure 2: CO_2 Emissions in Millions of Tons in Baseline and Scenarios with a 2.5 Percent Reduction in RGGI Allowance Cap - 2020-2030

Scenario with 2.5 Percent Cap Reduction	RGGI States	Ring States	Total	Percent Total Reduction From if CGSA Maintained
CGSA Maintained (No New Set Aside)	985.1	3,498.5	4,483.5	n/a
Auction	982.9	3,497.1	4,480.0	0.08%
More Auction Proceeds to Energy Efficiency	983.9	3,493.2	4,477.1	0.14%
Allowances to Natural Gas	984.8	3,482.5	4,467.3	0.36%
Allowances to Renewables	984.3	3,489.6	4,473.8	0.22%
Allowances to Renewables and Natural Gas	983.9	3,486.3	4,470.3	0.29%
Allowances to Natural Gas, Renewables, and Coal	992.1	3,488.0	4,480.1	0.08%

Source: RFF

As shown in Figure 2, total CO_2 emissions are highest when the CGSA is maintained, rather than eliminated and replaced with one of the other scenarios. Total emissions are lowest overall when a new set-aside is created and all allowances are directed towards natural gas (existing and new natural gas combined cycle and gas-boilers) generators. Eliminating the CGSA and replacing it with a set-aside for natural gas producers is estimated to reduce total emissions by 16.2 million tons, or 0.36 percent. While this option reduces total CO_2 emissions the most, and 16.2 million tons of emissions is still a sizable amount of emissions, the differences in total emissions between each scenario are relatively minor.

To more clearly see the impact each scenario has on CO_2 emissions leakage, Figure 3 displays the amount of leakage mitigated by each scenario compared to if the CGSA is maintained and the only regulatory difference is the implementation of a 2.5 percent annual allowance cap reduction.

Figure 3: Leakage Avoided by Scenario with 2.5 Percent Reduction in RGGI Allowance Cap – 2020-2030

Scenario with 2.5 Percent Cap Reduction	Leakage Avoided (M tons)	Leakage Avoided As Percent of Total Leakage (15.49 M tons)	Treatment Size (M tons)	Tons of Leakage Avoided Per Ton In Treatment Size
Auction	1.36	8.79%	53.31	0.03
More Auction Proceeds to Energy Efficiency	5.28	34.09%	53.31	0.10
Allowances to Natural Gas	16.02	103.43%	53.31	0.30
Allowances to Renewables	8.89	57.43%	53.31	0.17
Allowances to Renewables and Natural Gas	12.16	78.52%	53.31	0.23
Allowances to Natural Gas, Renewables, and Coal	10.48	67.65%	53.31	0.20

Source: RFF, RESI

As seen in Figure 3, the most leakage is avoided when a new set-aside is created and allowances are allocated solely to the state's natural gas producers. In fact, emissions in ring states actually decrease relative to the baseline, due to the profitability of Maryland's natural gas producers. Allocating the allowances from the set-aside to both natural gas and renewables producers also helps mitigate leakage, reducing leakage by 12 million tons (79 percent).

Eliminating the CGSA and creating a new set-aside for all natural gas producers will also lead to the reduction of emissions of other pollutants such as SO_2 and NO_X. Additionally, if this scenario is enacted, electricity prices will decrease slightly, allowing Maryland consumers to pay less money.

2.0 Introduction

Maryland is part of the Regional Greenhouse Gas Initiative (RGGI), a carbon cap-and-trade agreement between several states in the Mid-Atlantic and Northeast:

- Connecticut,
- Delaware,
- Maine,
- Maryland,
- Massachusetts,
- New Hampshire,
- New York,
- Rhode Island, and
- Vermont.

As part of RGGI, each state caps the amount of carbon dioxide (CO_2) emissions that the electricity sector is allowed to generate each year. However, while Maryland is part of RGGI, many nearby states are not, including New Jersey, Ohio, Pennsylvania, Virginia, and West Virginia. However, these states, as well as Maryland, are within PJM, the regional transmission organization (RTO) that operates an electricity market and the electrical grid across all member areas. Because the RGGI caps on CO_2 emissions do not apply to many states within PJM, power generation may shift from Maryland to nearby states if the cost to produce in Maryland rises due to stricter environmental regulations. This phenomenon is known as leakage.

Leakage does not benefit either the Maryland economy or the climate as a whole. As an example, consider what would happen if a coal plant in Maryland reduced its generation by 10 Megawatt hours (MWh) in a given year, but a similar coal plant across the border in Pennsylvania increased its generation by 10 MWh in the same year to meet the electricity demand in the region. If both plants are the same, there will be no net change in the amount of CO_2 emitted into the atmosphere, and Maryland producers will have lost out on revenue, potentially leading to a loss of jobs in the state.

In reality, the emissions increase in other states (leakage) is unlikely to exactly equal the emissions decrease in Maryland. There are many barriers, including power contracts and transmission constraints, which stop producers from simply shifting electricity generation from Maryland to a neighboring state. However, the leakage of CO_2 emissions is still a concern for Maryland and other RGGI states for both environmental and economic reasons. Maryland has two primary options to mitigate leakage within the State's direct purview: (1) alternative allowance proceeds reinvestment models; and (2) different allowance distribution schemes. Allowances, the ability to emit one ton of CO_2 emissions, are typically bought and sold at auction. The proceeds from the auction are then used to fund bill assistance programs, emission-reduction projects in the state (primarily energy efficiency), or subsidies to renewable power generators. By directing the auction proceeds in various ways, Maryland may be able to reduce leakage; although, statutory changes may be necessitated to effectuate this option.

A second option Maryland has to mitigate leakage is to provide certain in-state power generators with allowances for free, or at a substantially-reduced cost. Currently, Maryland provides natural gas combined cycle producers with free allowances through a Clean Generation Set-Aside (CGSA). The CGSA is structured in a way that makes it a potentially effective leakage mitigation mechanism: since the CGSA allocates free allowances among eligible in-state generators in proportion to their heat input, it is effectively a production subsidy for them (the more they produce, the more allowances they get).

However, precisely how effective the CGSA is in reducing CO_2 emissions is unanswered, as is how this option compares to using auction proceeds to fund other projects. To this end, the Maryland Department of the Environment (MDE) contracted with the Regional Economic Studies Institute (RESI) of Towson University to explore the effectiveness of the current CGSA program against using auction proceeds from allowance sales to fund various programs. RESI contracted with Resources for the Future (RFF) to conduct the emissions modeling. RFF utilizes a proprietary electricity market model, Haiku, to assess emissions changes as a result of various policies.

This report discusses the methodology behind the study in Section 3, as well as the results of the emissions modeling work RFF conducted in Section 4. The Conclusion, in Section 5, highlights the key findings from the report. Section 6 contains references, and the full data tables from RFF's Haiku model are presented in Appendix A.

3.0 Methodology

To measure the effectiveness of the CGSA and other allocation schemes, the Project Team (MDE, RESI, and RFF) created 13 different scenarios. The scenarios altered the total cap on CO_2 emissions as well as how allowances would be distributed and auction proceeds allocated. The scenarios looked at three difference CO_2 cap assumptions:

4. The cap on CO_2 emissions remains constant between 2020 and 2030;
5. The cap on CO_2 emissions declines by 2.5 percent each year between 2020 and 2030, an equivalent decline to the cap instituted by RGGI states between 2014 and 2020; and
6. The cap on CO_2 emissions declines by 5 percent each year between 2020 and 2030.

Additionally, the scenarios examined different allocation schemes. The CGSA was either maintained or eliminated. If the CGSA was eliminated, the allowances could be auctioned off or used for the creation of a new set-aside. The size of the new set-aside is assumed to be equal to 20 percent of Maryland's base allowance allocation budget plus the allowances contained in the CGSA. The emissions cap, status of the CGSA, and the recipient of the new set-aside is outlined in Figure 4 for each scenario.

Figure 4: Overview of Project Scenarios

Scenario Number	RGGI Cap	CGSA Status	New Set-Aside Recipients
1	Baseline	Maintained	Same proportions as current
2	2.5 Percent Annual Cap Reduction	Maintained	Same proportions as current
3	2.5 Percent Annual Cap Reduction	Eliminated	Allowances auctioned with proceeds allocated as usual
4	2.5 Percent Annual Cap Reduction	Eliminated	Allowances auctioned with more proceeds allocated to Energy Efficiency Programs
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Sources: MDE, RESI, RFF

As seen in Figure 4, in addition to the baseline scenario, seven scenarios were modeled assuming a 2.5 percent annual reduction in the RGGI Allowance Cap and five scenarios were modeled with a 5 percent annual reduction. Scenario 2 assumes a 2.5 percent cap reduction and no new set-aside, and Scenario 9 assumes a 5 percent annual cap reduction and no new set-aside.

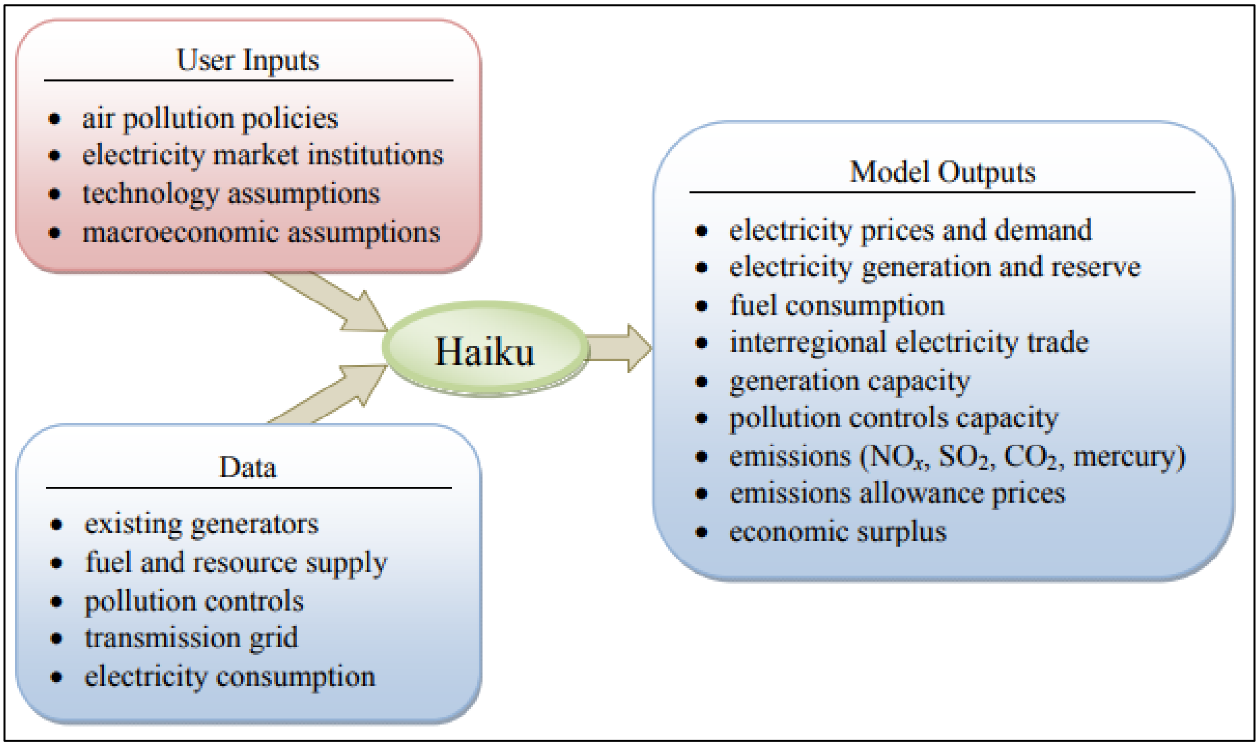
In Sscenarios 3, 4, and 10, the CGSA is eliminated and allowances from the CGSA are auctioned off with the other allowances in the auction pool. In Scenario 3, the auction proceeds are distributed per the existing statutory formula. In Scenario 4 and Scenario 10, the statutory formula is updated to direct more funds to energy efficiency programs. In these two scenarios, the proceeds from 20 percent of Maryland's base allowance allocation budget plus the allowances contained in the CGSA are directed towards energy efficiency programs, while the proceeds from the remaining allowances are distributed per the current statutory formula. In practice, the proportions of the statutory formula will be changed to reflect new priorities. The precise proportions depend on the size of the annual RGGI cap decline.

In the remaining scenarios (Scenario 5, 6, 7, 8, 11, 12, and 13), a new set-aside was created and the allowances were distributed to different producers. In Scenario 5 and Scenario 11, these allowances were distributed to all natural gas producers covered under RGGI, including new and existing natural gas combined cycle plants as well as existing gas-fired boilers. Notably, this is different from simply expanding the CGSA, since the CGSA is intended for new natural gas combined cycle plants. In Scenario 6 and 12, the allowances in the set-aside are distributed to producers of renewable electricity. In Scenario 7 and Scenario 13, both natural gas and renewable producers are eligible to receive allowances as part of the subsidy. Finally, Scenario 8 explores the impact on emissions if allowances are distributed to natural gas, renewables, and coal producers.

To model each of these scenarios, RFF used their proprietary Haiku model.[1] The model simulates electricity markets in 21 regions of the continental United States through 2030. The model is capable of taking future reductions in CO_2 emissions caps, planned plant retirements, new planned plants, and regulatory changes into account using these inputs to model utility generation by fuel type. Additionally, the model accounts for regulations to control nitrogen oxide (NOx), sulfur dioxide (SO_2), CO_2, and mercury from the electricity sector and projects future emissions levels. Figure 5 displays an overview of the inputs required and outputs produced by the Haiku model.

[1] An in-depth explanation of the Haiku model may be found in RFF's Haiku Documentation, accessible at: http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Rpt-Haiku.v2.0.pdf

Figure 5: Overview of RFF's Haiku Model



Source: RFF

For each of the 13 scenarios analyzed, RFF analyzed emissions, leakage, electricity prices, power generation by fuel type, and other variables in Maryland between 2020 and 2030.[2] Additionally, RFF modeled emissions in Maryland, all nine RGGI states, and "ring states." Ring states are those states within PJM that are not part of RGGI and which border Maryland and Delaware: New Jersey, Ohio, Pennsylvania, Virginia, and West Virginia. When discussing leakage, ring states are those where leakage is most likely to occur. While some leakage likely takes place in other PJM states, the effect is presumed to be minimal at best.

For scenarios where allowances were distributed to producers via a set-aside mechanism, the model represented this distribution mechanism in the form of a subsidy, wherein producers received compensation per megawatt hour (MWh). The subsidy was endogenous to the model, depending on the allowance prices, which varied by scenario.[3] The allowance price multiplied by the number of allowances per treatment determined the overall value of the subsidy pool. This pool was then divided by the total number of MWh produced in the state by eligible

[2] One limitation of many emissions models is their representation of the electrical grid. Within Haiku, calibration procedures exist that are designed to make annual net power trading in the baseline period similar to real-world conditions. However, the model may not perfectly capture some of the physical properties of the electrical grid. In effect, this means that some estimates of leakage and emissions may vary from real-world results. Although some variance is anticipated, directional impacts and relative magnitudes should be considered reliable.

[3] Allowance prices by scenario are displayed in Figure 15 and Figure 16.

producers to arrive at a per-MWh subsidy. The resulting subsidies delivered per MWh are displayed in Figure 6.

Figure 6: Subsidies Provided to Maryland Producers Per MWh by Scenario - 2025

Scenario	Subsidy Delivered Per MWh
Scenarios With 2.5 Percent Cap Reduction	
Subsidize Natural Gas	$5.12
Subsidize Renewable	$19.02
Subsidize Renewables and Natural Gas	$5.02
Subsidize Natural Gas, Renewables, and Coal	$3.89
Scenarios With 5 Percent Cap Reduction	
Subsidize Natural Gas	$5.31
Subsidize Renewable	$13.67
Subsidize Renewables and Natural Gas	$4.83

Source: RFF

4.0 Results

This section contains the output generated by RFF's Haiku model. Section 4.1 discusses the impact of each scenario on CO_2 emissions in RGGI states, ring states, and the total analysis region. Section 4.2 shows the impact each scenario has on leakage. Section 4.3 presents key findings from other output generated by RFF. Appendix A contains the full data output by RFF's Haiku model, and additional information on power generation, and capacity, for example, may be found there.

4.1 Mitigating Total CO_2 Emissions

The primary goal of RGGI is to reduce CO_2 emissions. Therefore, understanding how CO_2 emissions differ within RGGI states and across the study area as a whole is crucial to understanding how to craft effective policy. Understanding how emissions change by geography is also important when determining which policies best mitigate leakage in the state, as discussed in Section 4.2. Figure 7 shows how total CO_2 emissions between 2020 and 2030 vary depending on the scenario analyzed for the baseline and scenarios with a 2.5 percent reduction in the total RGGI allowance cap.

Figure 7: CO_2 Emissions in Millions of Tons in Baseline and Scenarios with a 2.5 Percent Reduction in RGGI Allowance Cap - 2020-2030

Scenario	RGGI States	Ring States	Total	Percent Total Reduction From Baseline
Baseline Scenario				
No New Set Aside	1,045.1	3,483.0	4,528.1	n/a
Scenarios With a 2.5 Percent Cap Reduction				
No New Set Aside	985.1	3,498.5	4,483.5	4.26%
Auction	982.9	3,497.1	4,480.0	4.60%
More Auction Proceeds to Energy Efficiency	983.9	3,493.2	4,477.1	4.88%
Allowances to Natural Gas	984.8	3,482.5	4,467.3	5.82%
Allowances to Renewables	984.3	3,489.6	4,473.8	5.19%
Allowances to Renewables and Natural Gas	983.9	3,486.3	4,470.3	5.53%
Allowances to Natural Gas, Renewables, and Coal	992.1	3,488.0	4,480.1	4.59%

Source: RFF

As shown in Figure 7, relative to the baseline scenario, CO_2 emissions decline within RGGI states and overall when the RGGI allowance cap falls by 2.5 percent each year. Unsurprisingly, there is evidence of leakage in the model, as emissions in Ring states increase relative to the baseline in all but one scenario, if natural gas producers receive allowances from a new set-aside. If the

CGSA continues to operate, and no new set-aside is created, CO_2 emissions are projected to decline by 4.26 percent between 2020 and 2030. However, Maryland can effect greater reductions in CO_2 emissions if it chooses to eliminate the CGSA. For example, if the CGSA is eliminated, its allowances are auctioned off, and the proceeds are distributed pursuant to the current statutory formula, CO_2 emissions will fall by 4.60 percent relative to the baseline.

However, still greater reductions in CO_2 emissions are possible by allocating allowances to certain generators at no cost (reflected in the model as subsidies), either to renewables, natural gas plants, or both. The greatest reduction in CO_2 emissions overall, 5.82 percent, occurs when the allowances from the new set-aside are given as subsidies to operators of natural gas plants.

Figure 8 displays projections for CO_2 emissions between 2020 and 2030 in the baseline scenario and in scenarios where the RGGI allowance cap falls by 5 percent each year.

Figure 8: CO_2 Emissions in Millions of Tons in Baseline and Scenarios with a 5% Reduction in RGGI Allowance Cap - 2020-2030

Scenario	RGGI States	Ring States	Total	Percent Reduction From Baseline
Baseline Scenario				
No New Set Aside	1,045.1	3,483.0	4,528.1	
Scenarios With 5 Percent Cap Reduction				
No New Set Aside	934.8	3,520.1	4,454.9	7.00%
More Auction Proceeds to Energy Efficiency	937.8	3,522.9	4,460.7	6.45%
Allowances to Natural Gas	931.6	3,513.3	4,444.9	7.96%
Allowances to Renewables	935.1	3,515.9	4,451.0	7.37%
Allowances to Renewables and Natural Gas	933.3	3,515.9	4,449.2	7.55%

Source: RFF

The results outlined in Figure 8 are generally similar to those from Figure 7, though the magnitude of the emissions reductions is greater. Compared to the baseline, CO_2 emissions decrease by at least 6.45 percent when the RGGI allowance cap declines by 5 percent each year. Similar to when the cap declines by 2.5 percent annually, the greatest reduction in CO_2 emissions occurs when the allowances from the new set-aside are distributed to natural gas producers.

The results of this analysis indicate that eliminating the CGSA generally leads to reductions in CO_2 emissions. The only scenario where this does not hold is when the allowance cap declines by 5 percent annually and the monetary value of the set-aside allowances is directed to energy efficiency projects. Replacing the CGSA with a new set-aside where allowances are distributed to certain producers reduces CO_2 emissions in RGGI states as well as in the study area as a whole. The most effective method studied for reducing CO_2 emissions in the study area is to create a set-aside and provide allowances to natural gas producers.

4.2 Mitigating CO_2 Leakage

While overall reductions in CO_2 emissions are desirable, Maryland is especially interested in minimizing the amount of leakage that occurs under different scenarios. To this end, Figure 9 displays the amount of leakage that occurs as a result of the two different annual reductions in the RGGI allowance cap tested in this project.

Figure 9: CO_2 Leakage from Baseline by Allocation Reduction – 2020-2030

Scenario	RGGI Reduction from BL (M tons)	TOTAL Reduction from BL (M tons)	Cumulative Leakage From Baseline (M tons)
2.5 Percent Cap Reduction	60.06	44.57	15.49
5 Percent Cap Reduction	110.31	73.16	37.15

Source: RFF, RESI

As seen in Figure 9, compared to the baseline, leakage does exist under both cap reduction scenarios. When the cap on allowances declines by 2.5 percent each year, the Haiku model estimates that roughly 15.5 million tons of CO_2 emissions will leak into ring states. When the allowance cap declines by 5 percent each year instead leakage more than doubles up to 37.15 million tons of CO_2 emissions between 2020 to 2030. To determine if any of the other scenarios successfully mitigate this leakage, the team analyzed CO_2 emissions in RGGI states, Ring states, and overall. Figure 10 shows leakage mitigation for each scenario with a 2.5 percent annual reduction in the RGGI allowance cap.

Figure 10: Leakage Avoided by Scenario with 2.5 Percent Reduction in RGGI Allowance Cap – 2020-2030

Scenario with 2.5 Percent Cap Reduction	Leakage Avoided (M tons)	Leakage Avoided As Percent of Total Leakage	Treatment Size (M tons)	Tons of Leakage Avoided Per Ton In Treatment Size
Auction	1.36	8.79%	53.31	0.03
More Auction Proceeds to Energy Efficiency	5.28	34.09%	53.31	0.10
Allowances to Natural Gas	16.02	103.43%	53.31	0.30
Allowances to Renewables	8.89	57.43%	53.31	0.17
Allowances to Renewables and Natural Gas	12.16	78.52%	53.31	0.23
Allowances to Natural Gas, Renewables, and Coal	10.48	67.65%	53.31	0.20

Source: RFF, RESI

As seen in Figure 10, leakage is mitigated in every scenario with the elimination of the CGSA and an annual 2.5% cap decline. The greatest amount of leakage mitigation occurs when the allowances from the new set-aside are distributed at no cost to natural gas producers, thus translating into a subsidy for these units. Under this scenario, 16.02 million tons of leakage is mitigated. This scenario not only eliminates leakage, it also reduces emissions outside RGGI states. This is due to natural gas production in Maryland becoming more profitable. Under this scenario, Maryland's natural gas electricity generation increases to where imports of electricity from other PJM states decline even though coal generation in the state is also declining. The reduction in total CO_2 emissions in this scenario is due partly to a shift of coal generation to natural gas generation in the state and partly to a decline in imports of electricity from coal plants in PJM.

This effect size is followed by mitigation of over 12 million tons of CO_2 emission leakage when the allowances from the new set-aside are distributed to both natural gas and renewable producers. The overall size of the new set-aside in both scenarios is 53.31 million tons, meaning for every allowance allocated to either natural gas generators or both natural gas and renewables generators, the scenarios mitigate 0.3 and 0.23 tons of CO_2 emission leakage respectively. Leakage was also studied in scenarios where the RGGI allowance cap falls by 5 percent each year, and these results are shown in Figure 11.

Figure 11: Leakage Avoided by Scenario with 5 Percent Reduction in RGGI Allowance Cap – 2020-2030

Scenario with 5 Percent Cap Reduction	Leakage Avoided (M tons)	Leakage Avoided As Percent of Total Leakage	Treatment Size (M tons)	Leakage Avoided Per Ton In Treatment Size
More Auction Proceeds to Energy Efficiency	-2.77	-7.45%	48.76	-0.06
Allowances to Natural Gas	6.82	18.37%	48.76	0.14
Allowances to Renewables	4.21	11.34%	48.76	0.09
Allowances to Renewables and Natural Gas	4.27	11.49%	48.76	0.09

Source: RFF, RESI

As seen in Figure 11, creating a new set-aside generally helps prevent leakage when the cap on CO_2 emissions declines by 5 percent each year. The only exception is when the CGSA is eliminated and additional funds are diverted to energy efficiency programs. In this case, additional leakage of 2.77 million tons of CO_2 emissions actually occurs. In this scenario, the Haiku model projects emissions will rise in both RGGI and Ring states. Within Maryland, emissions increase because coal generation increases while natural gas generation decreases. In Ring states, the mechanism for emissions increasing is less clear, though one explanation is that natural gas plants in Ring states are more competitive than Maryland producers, since the CGSA no longer helps subsidize in-state producers. This effect outweighs the demand reductions from energy efficiency programs. This is the opposite of the effect seen in Figure 10 when a new set-aside is directed to natural gas producers.

As with the findings from Figure 10, leakage is mitigated most effectively when a new set-aside is created and the proceeds are distributed as subsidies to natural gas combine cycle producers. As discussed in Section 4.1, this scenario is also responsible for the greatest reduction in overall CO_2 emissions in the study area.

4.3 Other Model Results

This section presents additional model results that complement the work described previously in the report.

In addition to examining the impact of each of the 13 scenarios on CO_2 emissions, the Haiku model also reports on the impact of other pollutants, including SO_2 and NO_X. Figure 12 shows the how SO_2 emissions change by scenario between 2020 and 2030 with the RGGI cap on CO_2 emissions decreasing by 2.5 percent each year.

Figure 12: SO_2 Emissions in Thousands of Tons in Baseline and Scenarios with a 2.5 Percent Reduction in RGGI Allowance Cap - 2020-2030

Scenario	RGGI	Ring	Total	Total Percent Reduction from Baseline
Baseline Scenario				
No New Set Aside	100	2,204	2,304	
Scenarios With 2.5 Percent Cap Reduction				
No New Set Aside	97	2,196	2,293	11.2%
Auction	99	2,197	2,296	8.3%
More Auction Proceeds to Energy Efficiency	99	2,194	2,293	10.9%
Allowances to Natural Gas	94	2,195	2,288	15.5%
Allowances to Renewables	98	2,201	2,299	4.8%
Allowances to Renewables and Natural Gas	94	2,186	2,280	23.5%
Allowances to Natural Gas, Renewables, and Coal	101	2,212	2,313	-9.4%

Source: RFF

As seen in Figure 12, SO_2 emissions generally decline compared to the baseline when the RGGI cap decreases by 2.5 percent annually. However, when a new set-aside is created and the allowances are distributed to natural gas, renewable, and coal producers, the total amount of SO_2 emitted actually increases by 9.4 percent. This increase is due to an increase in coal generation, as illustrated later in this section in Figure 18. The steepest decreases in SO_2 emissions occurs when a new set-aside is created and the proceeds are distributed to both renewable and natural gas producers. Under this scenario, SO_2 emissions decrease by 23.5 percent compared to the baseline.

Figure 13: NO_x Emissions in Thousands of Tons in Baseline and Scenarios with a 2.5 Percent Reduction in RGGI Allowance Cap - 2020-2030

	RGGI	Ring	Total	Total Percent Reduction from Baseline
Baseline Scenario				
No New Set Aside	887	2067	2954	
Scenarios With 2.5% Cap Reduction				
No New Set Aside	884	2055	2939	1.7%
Auction	887	2051	2938	1.8%
More Auction Proceeds to Energy Efficiency	886	2057	2943	1.2%
Allowances to Natural Gas	877	2051	2928	3.0%
Allowances to Renewables	884	2059	2943	1.3%
Allowances to Renewables and Natural Gas	882	2046	2929	2.9%
Allowances to Natural Gas, Renewables, and Coal	892	2048	2941	1.5%

Source: RFF

As seen in Figure 13, NO_X emissions also fall when compared to the baseline in scenarios where the RGGI cap declines by 2.5 percent each year. Maintaining the CGSA reduces NO_X emissions compared to either an auction with increased energy efficiency funds or a new set-aside with allowances directed to subsidize natural gas, renewables, and coal producers. However, the greatest reductions, 3.0 percent from the baseline, in NO_X emissions occurs when a new set-aside is created and the proceeds are distributed as a subsidy to natural gas producers. Similarly, a 2.9 percent decrease in NO_X emissions occurs when a new set-aside is created with allowances directed to both renewables and natural gas producers.

Figure 14: Electricity Prices and Consumption in Maryland in Baseline and Scenarios with 2.5 Percent Reduction in RGGI Allowance Cap - 2025

Scenario	Electricity Price ($/MWh)	Electricity Consumption (TWh)
Baseline Scenario		
No New Set Aside	123.39	70.77
Scenarios With 2.5 Percent Cap Reduction		
No New Set Aside	123.69	70.67
Auction	124.12	70.52
More Auction Proceeds to Energy Efficiency	124.27	69.54
Allowances to Natural Gas	124.12	70.81
Allowances to Renewables	123.64	70.81
Allowances to Renewables and Natural Gas	123.86	70.83
Allowances to Natural Gas, Renewables, and Coal	123.29	70.84

Source: RFF

Figure 14 shows small variations in electricity pricing and consumption within Maryland in 2025. Despite the different price and quantity signals shown in the figure, it is important to note that the absolute price of electricity and the quantity consumed does not change much between scenarios. The price of electricity increases over the baseline in every 2.5 percent reduction scenario except for when coal is provided with a subsidy. The largest increase in price occurs when the CGSA is eliminated and the statutory policy is altered so additional auction proceeds are directed towards energy efficiency. In this scenario, prices increase by $0.88/MWh (or 0.7 percent) in Maryland by 2025. This price increase generally occurs because the demand for electricity in the state is lower in this scenario than in any other. However, this does not correlate precisely with leakage mitigation, as discussed in Section 4.2. With the elimination of the CGSA, energy production shifts from natural gas to coal, increasing CO_2 emissions relative to other scenarios.

Total electricity consumption in Maryland increases in all scenarios where a new set-aside is created and allowances are distributed directly to producers. This is mostly caused by a reduction in the money distributed to energy efficiency programs, since allowance auction revenues decrease when 20 percent of the base allowance allocation are diverted to the new set-aside. Figure 15 shows how electricity prices and consumption changes when the annual RGGI allowance cap declines by 5 percent each year instead of 2.5 percent.

Figure 15: Electricity Prices and Consumption in Maryland in Baseline and Scenarios with 5 Percent Reduction in RGGI Allowance Cap - 2025

Scenario	Electricity Price ($/MWh)	Electricity Consumption (TWh)
Baseline Scenario		
No New Set Aside	123.39	70.77
Scenarios With 5 Percent Cap Reduction		
No New Set Aside	124.04	70.64
More Auction Proceeds to Energy Efficiency	125.42	69.40
Allowances to Natural Gas	123.20	70.86
Allowances to Renewables	123.66	70.75
Allowances to Renewables and Natural Gas	123.52	70.85

Source: RFF

Similar to the results from Figure 14, Figure 15 shows that electricity prices and the quantity consumed in Maryland remain relatively constant through 2025, regardless of scenario. Relative to the baseline, electricity prices increase when the allowance cap decreases by 5 percent annually and no other regulatory or statutory changes are implemented. Compared to the scenario where the CGSA is maintained and a 5 percent cap reduction occurs, electricity prices drop when allowances are distributed directly to producers. This price drop occurs because producers become slightly more profitable with offsets to RGGI compliance costs. This price decrease leads consumers to consume more electricity than if the CGSA were maintained.

However, as discussed in Section 4.2, RGGI emissions still fall, mostly because coal production decreases in favor of increased generation from cleaner sources.

Figure 16 through Figure 19 illustrate how each scenario impacts the capacity and generation of different fuel types in Maryland. Figure 16 shows how fuel capacity changes in the baseline scenario as well as when the annual RGGI allowance cap decreases by 2.5 percent each year.

Figure 16: Natural Gas Combined Cycle, Wind and Solar, and Steam O/G Capacity in Maryland in Baseline and Scenarios with 2.5 Percent Reduction in RGGI Allowance Cap - 2025

Scenario	New Natural Gas Combined Cycle Capacity (GW)	Wind and Solar Capacity (GW)	Steam O/G Capacity (GW)
Baseline Scenario			
No New Set Aside	3.45	0.80	2.09
Scenarios With 2.5 Percent Cap Reduction			
No New Set Aside	3.46	0.84	2.08
Auction	3.37	0.91	2.14
More Auction Proceeds to Energy Efficiency	3.37	0.75	2.09
Allowances to Natural Gas	3.56	0.74	2.09
Allowances to Renewables	3.37	1.40	2.06
Allowances to Renewables and Natural Gas	3.37	0.90	2.14
Allowances to Natural Gas, Renewables, and Coal	3.37	0.84	2.14

Source: RFF

When the RGGI allowance cap decreases by 2.5 percent each year, only three fuel types show variation depending on the scenario: new natural gas combined cycle, wind and solar, and steam generators. As seen in Figure 16, the capacity of wind and solar increases by 75 percent over the baseline when renewables receive all allowances in the set-aside. This expansion is in addition to increases that would occur through Maryland's renewable portfolio standards (RPS). There is a smaller increase in capacity for renewables when renewable providers share the set-aside allowances with natural gas providers, or in the basic auction scenario. The natural gas sector also experiences an increase in capacity when it receives all allowances in the set-aside. However, if the CGSA is eliminated, and allowances are not solely directed towards natural gas producers, future increases in natural gas combined cycle capacity do not occur. This is because the CGSA is earmarked towards new natural gas combined cycle plants, while the subsidy will be received by all existing natural gas plants, reducing the incentive for new capacity to come online.

Figure 17: Natural Gas Combined Cycle, Wind and Solar, and Steam O/G Capacity in Maryland in Baseline and Scenarios with 5 Percent Reduction in RGGI Allowance Cap - 2025

Scenario	New Natural Gas Combined Cycle Capacity (GW)	Wind and Solar Capacity (GW)	Steam O/G Capacity (GW)
Baseline Scenario			
No New Set Aside	3.45	0.80	2.09
Scenarios With 5 Percent Cap Reduction			
No New Set Aside	3.47	0.85	2.12
More Auction Proceeds to Energy Efficiency	3.37	0.74	2.06
Allowances to Natural Gas	3.55	0.72	2.07
Allowances to Renewables	3.37	2.25	2.08
Allowances to Renewables and Natural Gas	3.39	0.92	2.10

Source: RFF

When the allowance cap declines by 5 percent each year, capacity varies by scenario for only three fuel types: new natural gas combined cycle, wind and solar, and steam generators. The capacity of wind and solar experiences a dramatic increase of 181.25 percent over the baseline when the cap reduction is doubled to 5 percent. Other than this change, there are only very small shifts in capacity between 2.5 percent and 5 percent scenarios.

However, the creation of new plants is only part of the story. Figure 18 and Figure 19 show how fuel generation vary by scenario and how the RGGI allowance cap changes each year. These figures show how generation varies by

Figure 18: Maryland Power Generation from Various Sources in Baseline and Scenarios with 2.5 Percent Reduction in RGGI Allowance Cap - 2025

Scenario	Coal Generation (TWh)	New Natural Gas Combined Cycle Generation (TWh)	Wind and Solar Generation (TWh)	Total Generation (TWh)	Net Interregional Imports (TWh)
Baseline Scenario					
No New Set Aside	7.89	7.18	1.93	35.61	39.98
Scenarios With 2.5 Percent Cap Reduction					
No New Set Aside	7.53	7.25	2.04	35.47	40.17
Auction	7.76	5.74	2.20	34.11	41.52
More Auction Proceeds to Energy Efficiency	7.66	5.89	1.78	33.68	40.49
Allowances to Natural Gas	5.77	10.85	1.75	37.32	38.73
Allowances to Renewables	7.61	5.60	3.37	35.18	40.70
Allowances to Renewables and Natural Gas	5.87	9.26	2.19	36.08	39.84
Allowances to Natural Gas, Renewables, and Coal	8.46	6.80	2.02	35.81	39.87

Source: RFF

Similar to the changes in capacity to wind and solar discussed above, there is a significant increase in wind and solar generation when renewables receive the only allowances from the set-aside. Providing solely natural gas providers with set-aside allowances results in a similar increase in natural gas capacity, with both renewables and natural gas experiencing smaller increases when both are subsidized. Notably, natural gas generation does not increase when all three sectors are subsidized. The resulting increase in coal generation appears to offset any benefits for natural gas, which decreases below the baseline. The results as a whole suggest a substitution effect between natural gas and coal, with coal generation experiencing significant drops when natural gas is subsidized but not when only renewables receive the subsidy.

Total electricity generation in Figure 18 increases only in scenarios when natural gas receives allowances, with the increase becoming smaller as the set-aside allowances are split between more energy sectors. When more auction proceeds are put towards energy efficiency, there is a decrease in generation from all three energy sectors displayed in the figure (with natural gas experiencing the largest percentage decrease), resulting in the largest total decrease across all scenarios. It should be noted that there are additional sectors not listed in the figure due to the fact that they are unaffected by these scenarios. As a result, the total generation does not equal the sum of values displayed in the figure. Net interregional imports are highest in the auction scenario, and are lowest when natural gas receives a subsidy. As with total generation, the size of this decrease in imports is mitigated somewhat as the subsidy becomes split between additional sectors.

Figure 19: Maryland Power Generation From Various Sources in Baseline and Scenarios with 5 Percent Reduction in RGGI Allowance Cap - 2025

Scenario	Coal Generation (TWh)	New Natural Gas Combined Cycle Generation (TWh)	Wind and Solar Generation (TWh)	Total Generation (TWh)	Net Interregional Imports (TWh)
Baseline Scenario					
No New Set Aside	7.89	7.18	1.93	35.61	39.98
Scenarios With 5 Percent Cap Reduction					
No New Set Aside	6.71	7.26	2.04	34.54	41.17
More Auction Proceeds to Energy Efficiency	7.51	5.63	1.75	33.32	41.14
Allowances to Natural Gas	4.73	10.66	1.70	35.99	39.39
Allowances to Renewables	7.18	5.54	4.68	35.91	39.99
Allowances to Renewables and Natural Gas	4.78	9.76	2.23	35.64	40.24

Source: RFF

Energy generation mostly follows the same patterns at a 5 percent cap reduction as it does at the smaller 2.5 percent reduction, but with larger magnitudes. Coal generation decreases in every scenario analyzed, with increases in natural gas having the largest correspondence with decreases in coal. Total generation now experiences an increase in all scenarios with a new set-aside created for producers instead of just those involving natural gas. Net interregional imports increase in every scenario except for a decrease when natural gas receives all allowances in the set-aside.

Figure 20: Projected RGGI Allowance Price in Baseline and Scenarios with 2.5 Percent Reduction in RGGI Allowance Cap - 2025

Scenario	RGGI Allowance Price ($/ton)
Baseline Scenario	
No New Set Aside	$9.49
Scenarios With 2.5 Percent Cap Reduction	
No New Set Aside	$11.74
Auction	$11.61
More Auction Proceeds to Energy Efficiency	$11.65
Allowances to Natural Gas	$11.72
Allowances to Renewables	$11.33
Allowances to Renewables and Natural Gas	$11.65
Allowances to Natural Gas, Renewables, and Coal	$12.29

Source: RFF

Although the RGGI allowance price increases above the baseline in every scenario, the largest increase is seen when coal producers receive allowances from the new set-aside. The smallest increase in price occurs when only renewables receive the allowances.

Figure 21: Projected RGGI Allowance Price in Baseline and Scenarios with 5 Percent Reduction in RGGI Allowance Cap - 2025

Scenario	RGGI Allowance Price ($/ton)
Baseline Scenario	
No New Set Aside	$9.49
Scenarios With 5 Percent Cap Reduction	
No New Set Aside	$13.11
More Auction Proceeds to Energy Efficiency	$12.94
Allowances to Natural Gas	$13.08
Allowances to Renewables	$12.96
Allowances to Renewables and Natural Gas	$12.84

Source: RFF

When the cap reduction is increased to 5 percent each year, the RGGI allowance price similarly increases across all scenarios. However, the smallest increase is now seen when both renewables and natural gas receive the allowances from the set-aside.

5.0 Conclusion

The leakage of CO_2 emissions can negatively impact local economies, and mitigating leakage is critical to balancing dual goals of reducing CO_2 emissions and preserving jobs. With the recent announcement that the RGGI allowance cap will decline by 3 percent each year between 2020 and 2030, leakage will likely occur. As discussed in Section 4.2, if the allowance cap declines 2.5 percent each year, total leakage between 2020 and 2030 is estimated at 15.49 million tons of CO_2 emissions. Since the allowance cap decline is steeper, leakage should be greater than this estimate. Therefore, Maryland needs to identify ways to mitigate this leakage.

The findings in this report generalize well across RGGI cap reductions between 0 percent and 5 percent, though they may not generalize well in situations where the cap reductions are much more stringent, driving up allowance prices. Therefore, the most relevant findings considering the 3 percent annual decline are the scenarios with a 2.5 percent annual decline.[4] Figure 24 illustrates how CO_2 emissions vary by scenario when the RGGI cap decreases by 2.5 percent each year.

Figure 22: CO_2 Emissions in Millions of Tons in Baseline and Scenarios with a 2.5 Percent Reduction in RGGI Allowance Cap - 2020-2030

Scenario with 2.5 Percent Cap Reduction	RGGI States	Ring States	Total	Percent Total Reduction From if CGSA Maintained
CGSA Maintained (No New Set Aside)	985.1	3,498.5	4,483.5	n/a
Auction	982.9	3,497.1	4,480.0	0.08%
More Auction Proceeds to Energy Efficiency	983.9	3,493.2	4,477.1	0.14%
Allowances to Natural Gas	984.8	3,482.5	4,467.3	0.36%
Allowances to Renewables	984.3	3,489.6	4,473.8	0.22%
Allowances to Renewables and Natural Gas	983.9	3,486.3	4,470.3	0.29%
Allowances to Natural Gas, Renewables, and Coal	992.1	3,488.0	4,480.1	0.08%

Source: RFF

As shown in Figure 24, total CO_2 emissions are highest when the CGSA is maintained, rather than eliminated and replaced with one of the other scenarios. Total emissions are lowest overall when a new set-aside is created and all allowances are directed towards natural gas

[4] Maryland Department of the Environment. "Maryland, RGGI States to Strengthen Emissions Cap." August 24, 2017. Accessed August 24, 2017. http://news.maryland.gov/mde/ 2017/08/24/2422/

(existing and new natural gas combined cycle and gas-boilers) generators. Eliminating the CGSA and replacing it with a set-aside for natural gas producers is estimated to reduce total emissions by 16.2 million tons, or 0.36 percent. While this option reduces total CO_2 emissions the most, and 16.2 million tons of emissions is still a sizable amount of emissions, the differences in total emissions between each scenario are relatively minor.

To more clearly see the impact each scenario has on CO_2 emissions leakage, Figure 23 displays the amount of leakage mitigated by each scenario compared to if the CGSA is maintained and the only regulatory difference is the implementation of a 2.5 percent annual allowance cap reduction.

Figure 23: Leakage Avoided by Scenario with 2.5 Percent Reduction in RGGI Allowance Cap – 2020-2030

Scenario with 2.5 Percent Cap Reduction	Leakage Avoided (M tons)	Leakage Avoided As Percent of Total Leakage (15.49 M tons)	Treatment Size (M tons)	Tons of Leakage Avoided Per Ton In Treatment Size
Auction	1.36	8.79%	53.31	0.03
More Auction Proceeds to Energy Efficiency	5.28	34.09%	53.31	0.10
Allowances to Natural Gas	16.02	103.43%	53.31	0.30
Allowances to Renewables	8.89	57.43%	53.31	0.17
Allowances to Renewables and Natural Gas	12.16	78.52%	53.31	0.23
Allowances to Natural Gas, Renewables, and Coal	10.48	67.65%	53.31	0.20

Source: RFF, RESI

As seen in Figure 25, the most leakage is avoided when a new set-aside is created and allowances are allocated solely to the state's natural gas producers. In fact, emissions in ring states actually decrease relative to the baseline, due to the profitability of Maryland's natural gas producers. Allocating the allowances from the set-aside to both natural gas and renewables producers also helps mitigate leakage, reducing leakage by 12 million tons (79 percent).

Eliminating the CGSA and creating a new set-aside for all natural gas producers will also lead to the reduction of emissions of other pollutants such as SO_2 and NO_X. Additionally, if this scenario is enacted, electricity prices will decrease slightly, allowing Maryland consumers to pay less money.

The results in this report are generalizable across potential set-aside sizes, with caveats. In this report, new set-asides have been studied as 20 percent of Maryland's base budget for allowances, plus the entire CGSA. As seen in Figure 23, this translates to allowances for roughly 53.31 million tons of CO_2 emissions between 2020 and 2030. The findings from this report should scale proportionately if the new set-aside is only 10 percent of the base budget and half of the CGSA. However, if 20 percent of the base budget but none of the CGSA were set aside, it is less likely that the findings in this report would generalize.

The findings in this report do not generalize well to other states. The findings in this report generalize to states with similar existing capacity profiles, fuel costs, renewable performance, RPS policy, and a variety of other factors. While the findings in this report may generalize to Virginia, which has a similar fuel cost and has similar performance from renewable plants, they would not apply in most other places. For example, in Arizona, solar power is much more efficient, affecting the supply curve of solar power. Similarly, the results in this report would not generalize to Vermont, since the state has minimal existing fossil fuel generation.

6.0 References

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Appendix A Detailed Data

A.1 General Results

Figure 24: Projected Electricity Prices, Consumption, and Energy Efficiency Reductions by Scenario

Scenario	Electricity Price ($/MWh)	Electricity Consumption (TWh)	Cumulative EE Reductions (TWh)	First-year EE Reductions (TWh)
Baseline Scenario				
No New Set Aside	123.39	70.77	0.52	0.15
Scenarios With 2.5% Cap Reduction				
No New Set Aside	123.69	70.67	0.57	0.15
Auction	124.12	70.52	0.65	0.17
Auction Proceeds to Energy Efficiency	124.27	69.54	1.62	0.43
Subsidize Natural Gas	124.12	70.81	0.42	0.11
Subsidize Renewable	123.64	70.81	0.41	0.11
Subsidize Renewables and Natural Gas	123.86	70.83	0.42	0.11
Subsidize Natural Gas, Renewables, and Coal	123.29	70.84	0.44	0.12
Scenarios With 5% Cap Reduction				
No New Set Aside	124.04	70.64	0.57	0.14
Auction Proceeds to Energy Efficiency	125.42	69.40	1.67	0.42
Subsidize Natural Gas	123.20	70.86	0.42	0.10
Subsidize Renewable	123.66	70.75	0.41	0.10
Subsidize Renewables and Natural Gas	123.52	70.85	0.41	0.10

Source: RFF

Figure 25: Projected Capacity by Energy Source by Scenario

Scenario	Coal (GW)	Ex NGCC (GW)	New NGCC (GW)	Nuclear (GW)	Wind (GW)	Solar (GW)	CT (GW)	Steam O/G (GW)	Hydro (GW)	Other (GW)	Total (GW)
Baseline Scenario											
No New Set Aside	2.86	0.29	3.45	1.86	0.49	0.31	3.00	2.09	0.55	0.40	15.31
Scenarios With 2.5% Cap Reduction											
No New Set Aside	2.86	0.29	3.46	1.86	0.54	0.31	3.00	2.08	0.55	0.39	15.34
Auction	2.86	0.29	3.37	1.86	0.60	0.31	3.00	2.14	0.55	0.40	15.37
Auction Proceeds to Energy Efficiency	2.86	0.29	3.37	1.86	0.45	0.31	3.00	2.09	0.55	0.39	15.17
Subsidize Natural Gas	2.86	0.29	3.56	1.86	0.43	0.31	3.00	2.09	0.55	0.40	15.35
Subsidize Renewable	2.86	0.29	3.37	1.86	1.09	0.31	3.00	2.06	0.55	0.40	15.79
Subsidize Renewables and Natural Gas	2.86	0.29	3.37	1.86	0.60	0.31	3.00	2.14	0.55	0.40	15.37
Subsidize Natural Gas, Renewables, and Coal	2.86	0.29	3.37	1.86	0.54	0.31	3.00	2.14	0.55	0.40	15.31
Scenarios With 5% Cap Reduction											
No New Set Aside	2.86	0.29	3.47	1.86	0.54	0.31	3.00	2.12	0.55	0.39	15.39
Auction Proceeds to Energy Efficiency	2.86	0.29	3.37	1.86	0.43	0.31	3.00	2.06	0.55	0.39	15.12
Subsidize Natural Gas	2.86	0.29	3.55	1.86	0.41	0.31	3.00	2.07	0.55	0.39	15.31
Subsidize Renewable	2.86	0.29	3.37	1.86	1.09	1.16	3.00	2.08	0.55	0.40	16.66
Subsidize Renewables and Natural Gas	2.86	0.29	3.39	1.86	0.61	0.31	3.00	2.10	0.55	0.40	15.36

Source: RFF

Figure 26: Projected Energy Generation by Source by Scenario

Scenario	Coal (TWh)	Ex NGCC (TWh)	New NGCC (TWh)	Nuclear (TWh)	Wind (TWh)	Solar (TWh)	CT (TWh)	Steam O/G (TWh)	Hydro (TWh)	Other (GW)	Total (TWh)	Net Interregional imports (TWh)
Baseline Scenario												
No New Set Aside	7.89	0.15	7.18	14.45	1.41	0.51	0.23	0.06	1.79	1.94	35.61	39.98
Scenarios With 2.5% Cap Reduction												
No New Set Aside	7.53	0.11	7.25	14.51	1.53	0.51	0.24	0.06	1.79	1.96	35.47	40.17
Auction	7.76	0.11	5.74	14.29	1.69	0.51	0.24	0.06	1.79	1.90	34.11	41.52
Auction Proceeds to Energy Efficiency	7.66	0.12	5.89	14.23	1.27	0.51	0.24	0.06	1.79	1.90	33.68	40.49
Subsidize Natural Gas	5.77	0.35	10.85	14.51	1.24	0.51	0.26	0.07	1.79	1.96	37.32	38.73
Subsidize Renewable	7.61	0.15	5.60	14.44	2.85	0.51	0.25	0.06	1.79	1.91	35.18	40.70
Subsidize Renewables and Natural Gas	5.87	0.34	9.26	14.35	1.68	0.51	0.27	0.08	1.79	1.93	36.08	39.84
Subsidize Natural Gas, Renewables, and Coal	8.46	0.14	6.80	14.35	1.50	0.51	0.26	0.06	1.79	1.92	35.81	39.87
Scenarios With 5% Cap Reduction												
No New Set Aside	6.71	0.14	7.26	14.37	1.53	0.51	0.26	0.05	1.79	1.92	34.54	41.17
Auction Proceeds to Energy Efficiency	7.51	0.16	5.63	14.27	1.24	0.51	0.25	0.05	1.79	1.90	33.32	41.14
Subsidize Natural Gas	4.73	0.33	10.66	14.50	1.19	0.51	0.26	0.06	1.79	1.96	35.99	39.39
Subsidize Renewable	7.18	0.11	5.54	14.38	2.85	1.83	0.25	0.05	1.79	1.91	35.91	39.99
Subsidize Renewables and Natural Gas	4.78	0.31	9.76	14.50	1.72	0.51	0.27	0.05	1.79	1.95	35.64	40.24

Source: RFF

Figure 27: Projected Emissions by Type by Scenario

Scenario	SO2 Emissions (k tons)	NOx Emissions (k tons)	Hg Emissions (tons)	CO2 Emissions (M tons)	CO2 Emissions Coal (M tons)	CO2 Emissions Ex NGCC (M tons)	CO2 Emissions New NGCC (M tons)	CO2 Emissions Steam O/G (M tons)	CO2 Emissions CT (M tons)	CO2 Emissions Other (M tons)
Baseline Scenario										
No New Set Aside	4.09	12.44	1.20	13.35	8.58	0.07	2.95	0.05	0.15	1.54
Scenarios With 2.5% Cap Reduction										
No New Set Aside	3.98	12.28	1.19	12.98	8.20	0.05	2.97	0.05	0.16	1.55
Auction	4.05	12.32	1.20	12.60	8.45	0.05	2.37	0.06	0.16	1.51
Auction Proceeds to Energy Efficiency	4.02	12.28	1.20	12.55	8.34	0.06	2.43	0.06	0.16	1.51
Subsidize Natural Gas	3.45	11.68	1.19	12.68	6.30	0.17	4.43	0.06	0.17	1.55
Subsidize Renewable	4.01	12.25	1.19	12.40	8.29	0.07	2.31	0.05	0.16	1.52
Subsidize Renewables and Natural Gas	3.48	11.66	1.19	12.15	6.41	0.16	3.82	0.07	0.18	1.53
Subsidize Natural Gas, Renewables, and Coal	4.26	12.69	1.20	13.83	9.21	0.07	2.81	0.05	0.17	1.53
Scenarios With 5% Cap Reduction										
No New Set Aside	3.73	11.92	1.19	12.10	7.31	0.07	2.98	0.05	0.17	1.53
Auction Proceeds to Energy Efficiency	3.98	12.21	1.19	12.29	8.18	0.07	2.32	0.05	0.17	1.51
Subsidize Natural Gas	3.13	11.20	1.19	11.45	5.17	0.15	4.36	0.05	0.18	1.55
Subsidize Renewable	3.88	12.05	1.19	11.89	7.82	0.05	2.28	0.05	0.17	1.52
Subsidize Renewables and Natural Gas	3.15	11.18	1.19	11.16	5.22	0.15	4.02	0.05	0.18	1.55

Source: RFF

Figure 28: Projected RGGI Impacts by Type by Scenario

Scenario	RGGI Allowance Price ($/ton)	RGGI Covered Emissions (M tons)	RGGI End-of-year Bank (M tons)	RGGI Allowances Issued (M tons)	RGGI Safety Valve Allowances (M tons)
Baseline Scenario					
No New Set Aside	9.49	78.84	7.69	77.68	0.00
Scenarios With 2.5% Cap Reduction					
No New Set Aside	11.74	73.43	42.06	67.90	0.00
Auction	11.61	73.06	43.57	67.90	0.00
Auction Proceeds to Energy Efficiency	11.65	73.00	46.19	67.90	0.00
Subsidize Natural Gas	11.72	72.32	43.72	67.90	0.00
Subsidize Renewable	11.33	73.02	45.83	67.90	0.00
Subsidize Renewables and Natural Gas	11.65	72.25	40.79	67.90	0.00
Subsidize Natural Gas, Renewables, and Coal	12.29	73.03	48.97	67.90	0.00
Scenarios With 5% Cap Reduction					
No New Set Aside	13.11	68.07	87.93	58.13	0.00
Auction Proceeds to Energy Efficiency	12.94	68.87	91.73	58.13	0.00
Subsidize Natural Gas	13.08	66.91	85.34	58.13	0.00
Subsidize Renewable	12.96	68.61	93.27	58.13	0.00
Subsidize Renewables and Natural Gas	12.84	66.75	86.42	58.13	0.00

Source: RFF

Figure 29: Projected Non-renewable Energy Source Price and Consumption by Scenario

Scenario	Delivered Natural Gas Price ($/MMBtu)	Fuel Consumption Nat Gas (Tbtu)	Delivered Coal Price ($/MMBtu)	Fuel Consumption Coal (TBtu)
Baseline Scenario				
No New Set Aside	5.84	54.26	2.55	80.13
Scenarios With 2.5% Cap Reduction				
No New Set Aside	5.83	54.49	2.55	76.52
Auction	5.83	44.19	2.55	78.90
Auction Proceeds to Energy Efficiency	5.82	45.37	2.55	77.83
Subsidize Natural Gas	5.88	81.68	2.55	58.80
Subsidize Renewable	5.83	43.55	2.55	77.38
Subsidize Renewables and Natural Gas	5.89	71.30	2.55	59.78
Subsidize Natural Gas, Renewables, and Coal	5.82	52.20	2.55	85.93
Scenarios With 5% Cap Reduction				
No New Set Aside	5.83	55.13	2.55	68.23
Auction Proceeds to Energy Efficiency	5.82	43.92	2.55	76.33
Subsidize Natural Gas	5.90	80.29	2.55	48.25
Subsidize Renewable	5.83	42.97	2.55	73.04
Subsidize Renewables and Natural Gas	5.89	74.36	2.55	48.75

Source: RFF

Figure 30: Maryland Reprogrammed Allowances Subsidy by Scenario

Scenario	MD Reprogrammed Allowances Subsidy ($/MWh)
Baseline Scenario	
No New Set Aside	0.00
Scenarios With 2.5% Cap Reduction	
No New Set Aside	0.00
Auction	0.00
Auction Proceeds to Energy Efficiency	0.00
Subsidize Natural Gas	5.12
Subsidize Renewable	19.02
Subsidize Renewables and Natural Gas	5.02
Subsidize Natural Gas, Renewables, and Coal	3.89
Scenarios With 5% Cap Reduction	
No New Set Aside	0.00
Auction Proceeds to Energy Efficiency	0.00
Subsidize Natural Gas	5.31
Subsidize Renewable	13.67
Subsidize Renewables and Natural Gas	4.83

Source: RFF

A.2 Allowance Allocation

Figure 31: Effects of 2025 Allowance Allocation (in M tons) by Scenario

Scenario	No Power Market Effects	Bill Assistance	Subsidy to New Renewables	Subsidy to New NGCC Subsidy	Energy Efficiency	Subsidy to New Renewables and All Gas	Subsidy to New Renewables and All Gas and Coal	Total
Baseline Scenario								
No New Set Aside	3.0	6.9	2.8	1.9	2.8	0.0	0.0	17.3
Scenarios With 2.5% Cap Reduction								
No New Set Aside	2.8	5.8	2.3	1.9	2.3	0.0	0.0	15.1
Auction	3.0	6.8	2.7	0.0	2.7	0.0	0.0	15.1
Auction Proceeds to Energy Efficiency	2.5	4.3	1.7	0.0	6.6	0.0	0.0	15.1
Subsidize Natural Gas	2.5	4.3	1.7	4.9	1.7	0.0	0.0	15.1
Subsidize Renewable	2.5	4.3	6.6	0.0	1.7	0.0	0.0	15.1
Subsidize Renewables and Natural Gas	2.5	4.3	1.7	0.0	1.7	4.9	0.0	15.1
Subsidize Natural Gas, Renewables, and Coal	2.5	4.3	1.7	0.0	1.7	0.0	4.9	15.1
Scenarios With 5% Cap Reduction								
No New Set Aside	2.5	4.7	1.9	1.9	1.9	0.0	0.0	12.9
Auction Proceeds to Energy Efficiency	2.3	3.4	1.4	0.0	5.8	0.0	0.0	12.9
Subsidize Natural Gas	2.3	3.4	1.4	4.5	1.4	0.0	0.0	12.9
Subsidize Renewable	2.3	3.4	5.8	0.0	1.4	0.0	0.0	12.9
Subsidize Renewables and Natural Gas	2.3	3.4	1.4	0.0	1.4	4.5	0.0	12.9

Source: RFF

Figure 32: Effects of 2020-2030 Allowance Allocation (in M tons) by Scenario

Scenario	No Power Market Effects	Bill Assistance	Subsidy to New Renewables	Subsidy to New NGCC Subsidy	Energy Efficiency	Subsidy to New Renewables and All Gas	Subsidy to New Renewables and All Gas and Coal	Total
Baseline Scenario								
No New Set Aside	32.6	73.2	29.3	21.0	29.3	0.0	0.0	185.3
Scenarios With 2.5% Cap Reduction								
No New Set Aside	30.2	61.2	24.5	21.0	24.5	0.0	0.0	161.4
Auction	32.3	71.7	28.7	0.0	28.7	0.0	0.0	161.4
Auction Proceeds to Energy Efficiency	27.0	45.1	18.0	0.0	71.3	0.0	0.0	161.4
Subsidize Natural Gas	27.0	45.1	18.0	53.3	18.0	0.0	0.0	161.4
Subsidize Renewable	27.0	45.1	71.3	0.0	18.0	0.0	0.0	161.4
Subsidize Renewables and Natural Gas	27.0	45.1	18.0	0.0	18.0	53.3	0.0	161.4
Subsidize Natural Gas, Renewables, and Coal	27.0	45.1	18.0	0.0	18.0	0.0	53.3	161.4
Scenarios With 5% Cap Reduction								
No New Set Aside	28.0	49.0	19.6	21.3	19.6	0.0	0.0	137.5
Auction Proceeds to Energy Efficiency	25.2	35.3	14.1	0.0	62.9	0.0	0.0	137.5
Subsidize Natural Gas	25.2	35.3	14.1	48.8	14.1	0.0	0.0	137.5
Subsidize Renewable	25.2	35.3	62.9	0.0	14.1	0.0	0.0	137.5
Subsidize Renewables and Natural Gas	25.2	35.3	14.1	0.0	14.1	48.8	0.0	137.5

Source: RFF

A.3 CO_2 Emissions

Figure 33: CO_2 Emissions Reductions by Geography by Scenario

Scenario	RGGI States			Ring States	Total		
	CO2 Emissions 2020-2030 (M tons)	**Reduction from BL (M tons)**	**% Reduction from BL**	**CO2 Emissions 2020-2030 (M tons)**	**CO2 Emissions 2020-2030 (M tons)**	**Reduction from BL (M tons)**	**% Reduction from BL**
Baseline Scenario							
No New Set Aside	1045			3483	4528		
Scenarios With 2.5% Cap Reduction							
No New Set Aside	985	60.1	5.7%	3498	4484	44.6	4.3%
Auction	983	62.2	6.0%	3497	4480	48.1	4.6%
Auction Proceeds to Energy Efficiency	984	61.2	5.9%	3493	4477	51.0	4.9%
Subsidize Natural Gas	985	60.3	5.8%	3482	4467	60.8	5.8%
Subsidize Renewable	984	60.9	5.8%	3490	4474	54.3	5.2%
Subsidize Renewables and Natural Gas	984	61.2	5.9%	3486	4470	57.8	5.5%
Subsidize Natural Gas, Renewables, and Coal	992	53.0	5.1%	3488	4480	48.0	4.6%
Scenarios With 5% Cap Reduction							
No New Set Aside	935	110.3	10.6%	3520	4455	73.2	7.0%
Auction Proceeds to Energy Efficiency	938	107.3	10.3%	3523	4461	67.4	6.4%
Subsidize Natural Gas	932	113.5	10.9%	3513	4445	83.2	8.0%
Subsidize Renewable	935	110.0	10.5%	3516	4451	77.1	7.4%
Subsidize Renewables and Natural Gas	933	111.8	10.7%	3516	4449	78.9	7.6%

Source: RFF

A.4 NO_X Emissions

Figure 34: NO_X Emissions Reductions by Geography by Scenario

	RGGI States			Ring States	Total		
Scenario	**NOx Emissions 2020-2030 (k tons)**	**Reduction from BL (k tons)**	**% Reduction from BL**	**NOx Emissions 2020-2030 (k tons)**	**NOx Emissions 2020-2030 (k tons)**	**Reduction from BL (k tons)**	**% Reduction from BL**
Baseline Scenario							
No New Set Aside	887			2067	2954		
Scenarios With 2.5% Cap Reduction							
No New Set Aside	884	2.5	0.3%	2055	2939	15.0	1.7%
Auction	887	0.2	0.0%	2051	2938	16.2	1.8%
Auction Proceeds to Energy Efficiency	886	0.5	0.1%	2057	2943	10.8	1.2%
Subsidize Natural Gas	877	10.3	1.2%	2051	2928	26.5	3.0%
Subsidize Renewable	884	2.8	0.3%	2059	2943	11.4	1.3%
Subsidize Renewables and Natural Gas	882	4.8	0.5%	2046	2929	25.5	2.9%
Subsidize Natural Gas, Renewables, and Coal	892	-5.4	-0.6%	2048	2941	13.3	1.5%
Scenarios With 5% Cap Reduction							
No New Set Aside	883	3.6	0.4%	2053	2936	18.2	2.1%
Auction Proceeds to Energy Efficiency	885	2.2	0.3%	2059	2944	10.4	1.2%
Subsidize Natural Gas	876	11.4	1.3%	2051	2927	27.4	3.1%
Subsidize Renewable	887	0.4	0.0%	2057	2944	10.3	1.2%
Subsidize Renewables and Natural Gas	875	11.7	1.3%	2055	2930	23.9	2.7%

Source: RFF

A.5 SO_2 Emissions

Figure 35: SO_2 Emissions Reductions by Geography by Scenario – 2020 - 2030

	RGGI States			Ring States	Total		
Scenario	**SO2 Emissions (k tons)**	**Reduction from BL (k tons)**	**% Reduction from BL**	**SO2 Emissions (k tons)**	**SO2 Emissions (k tons)**	**Reduction from BL (k tons)**	**% Reduction from BL**
Baseline Scenario							
No New Set Aside	100			2204	2304		
Scenarios With 2.5% Cap Reduction							
No New Set Aside	97	2.8	2.8%	2196	2293	11.1	11.2%
Auction	99	0.9	1.0%	2197	2296	8.3	8.3%
Auction Proceeds to Energy Efficiency	99	1.2	1.2%	2194	2293	10.9	10.9%
Subsidize Natural Gas	94	6.1	6.1%	2195	2288	15.5	15.5%
Subsidize Renewable	98	1.7	1.7%	2201	2299	4.8	4.8%
Subsidize Renewables and Natural Gas	94	5.5	5.5%	2186	2280	23.5	23.5%
Subsidize Natural Gas, Renewables, and Coal	101	-1.1	-1.1%	2212	2313	-9.4	-9.4%
Scenarios With 5% Cap Reduction							
No New Set Aside	93	6.8	6.8%	2205	2298	6.3	6.3%
Auction Proceeds to Energy Efficiency	94	5.3	5.3%	2187	2281	22.5	22.6%
Subsidize Natural Gas	90	9.4	9.4%	2185	2275	28.6	28.7%
Subsidize Renewable	94	5.6	5.6%	2182	2276	27.4	27.5%
Subsidize Renewables and Natural Gas	90	9.3	9.3%	2188	2279	25.2	25.3%

Source: RFF

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