Multi-Pollutant Planning Exercise for Maryland

A Weight-of-Evidence Approach for the Maryland State Implementation Plan for Ozone and the Greenhouse Gas Reduction Act Plan Update

Prepared by
NESCAUM

May 20, 2015

Members of Northeast States for Coordinated Air Use Management

Arthur Marin, Executive Director
Northeast States for Coordinated Air Use Management

Anne Gobin, Bureau Chief
Connecticut Department of Energy and Environmental Protection, Bureau of Air Management

Marc Cone, Bureau Director
Maine Department of Environmental Protection, Bureau of Air Quality

Christine Kirby, Division Director
Massachusetts Department of Environmental Protection, Bureau of Waste Prevention

Craig Wright, Director
New Hampshire Department of Environmental Services, Air Resources Division

William O'Sullivan, Director
New Jersey Department of Environmental Protection, Office of Air Quality Management

David Shaw, Director
New York Department of Environmental Conservation, Division of Air Resources

Douglas L. McVay, Chief
Rhode Island Department of Environmental Management, Office of Air Resources

Heidi Hales, Director
Vermont Department of Environmental Conservation, Air Quality & Climate Division

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A WEIGHT-OF-EVIDENCE APPROACH FOR THE STATE IMPLEMENTATION PLAN FOR OZONE AND THE GREENHOUSE GAS REDUCTION ACT PLAN UPDATE

Project Managers

Paul Miller, NESCAUM
Leah Weiss, NESCAUM

Principal Contributors

Executive Summary: Paul Miller, NESCAUM

Chapter 1: Leah Weiss, NESCAUM

Chapter 2: Leah Weiss, NESCAUM

Chapter 3: Jason Rudokas, NESCAUM
Timothy Canty, University of Maryland College Park
Leiran Biton, NESCAUM
Susan Steward, Regional Economic Studies Institute (RESI) of Towson University

Chapter 4: Paul Miller, NESCAUM

Chapter 5: Paul Miller, NESCAUM

Appendix A: Jason Rudokas, NESCAUM

Appendix B: Jason Rudokas, NESCAUM

Appendix C: Timothy Canty, University of Maryland College Park

Appendix D: Leiran Biton, NESCAUM

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NESCAUM is an association of the eight northeastern states' air pollution control programs. NESCAUM provides technical guidance and policy advice to its member states.

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Abbreviations and Acronyms

BenMAP: Environmental Benefits Mapping and Analysis Program

bVMT: Billion vehicle miles traveled

bn-lum-yr: Billion lumens per year

CAFE: Corporate Average Fuel Economy

CMAQ: Community Multi-scale Air Quality model

CNG: Compressed natural gas

CO_2: Carbon dioxide

E85: A fuel blend of 85 percent ethanol and 15 percent gasoline

EPA: U.S. Environmental Protection Agency

GGRA: Greenhouse Gas Emissions Reduction Act

GHG: Greenhouse gas

Hg: Mercury

kT: Kiloton

LPG: Liquefied petroleum gas

MDE: Maryland Department of the Environment

MDOT: Maryland Department of Transportation

MEA: Maryland Energy Administration

MMBtu: Million British Thermal Units

MPAF: Multi-pollutant Policy Analysis Framework

mpg: Miles per gallon

MSW: Municipal solid waste

NAAQS: National Ambient Air Quality Standard

NE-MARKAL: Northeast version of the Market Allocation model

NESCAUM: Northeast States for Coordinated Air Use Management

NO_2: Nitrogen dioxide

NO_X: Oxides of nitrogen

$PM_{2.5}$: Fine particulate matter (particles less than 2.5 microns in diameter)

REMI: Regional Economic Models, Inc.

RGGI: Regional Greenhouse Gas Initiative

RPS: Renewable Portfolio Standard

SO_2: Sulfur dioxide

SIP: State Implementation Plan

tBTU: Trillion British Thermal Units

tcfm-hr: Trillion cubic feet per meter per hour

VMT: Vehicle miles traveled

VOCs: Volatile organic compounds

Executive Summary

ES1. Maryland Context for Multi-pollutant Planning

This report presents the findings of a multi-pollutant planning exercise the Maryland Department of the Environment (MDE) initiated in April 2013. The goals are to continue to build capacity in Maryland to conduct multi-pollutant planning and analyses as well as inform Maryland's 2012 Greenhouse Gas Emissions Reduction Act (GGRA) Plan Progress Report. The GGRA Plan of 2012's Progress Report is due in 2015.

The 2012 GGRA Plan seeks to achieve a 25 percent statewide reduction in greenhouse gas (GHG) emissions by 2020, while also spurring job creation and helping improve the economy. In the multi-pollutant planning context, it is part of a "multi-pollutant" planning approach for selecting and analyzing control programs to address multiple public health and environmental goals. The 2012 GGRA Plan will not only help reduce emissions of GHGs, but will also help Maryland meet its mandates to: (1) further clean up the Chesapeake Bay; (2) meet and maintain National Ambient Air Quality Standards for ground-level ozone, fine particles, sulfur dioxide, and nitrogen dioxide; and (3) meet federal and state requirements to further reduce regional haze as well as air emissions of mercury and other air toxics.

Maryland also intends to use a multi-pollutant framework to look at all pollutants whenever a single pollutant State Implementation Plan (SIP) is being developed. Therefore, this exercise is also a part of Maryland's preliminary effort to establish credit for energy efficiency and renewable energy (EE/RE) programs as part of its ozone SIP. To that end, it feeds into a larger effort in Maryland to better address some of the uncertainties associated with the SIP process through an expanded weight-of-evidence (WOE) approach.

ES2. Multi-Pollutant Policy Analysis Framework

The planning exercise presented in this report employed the Multi-pollutant Policy Analysis Framework (MPAF), which consists of the following model components to provide a broad view of climate and air quality program impacts:

1. NE-MARKAL, a Northeast version of the MARKet ALlocation (MARKAL) model, an energy model that is widely used in Europe. EPA has a nine-region national version of this model, called US9r;
2. Regional Economic Models, Inc. (REMI), a 12-state model that evaluates the effects of policies and programs on the economies of local regions;
3. EPA's Community Multi-scale Air Quality (CMAQ) model, which assesses future air quality impacts arising from changes in air emissions due to a set of policies and programs;

4. EPA's Environmental Benefits Mapping and Analysis Program (BenMAP), which estimates health impacts and associated monetized values resulting from changes in ambient air pollution.

Two meta-scenarios, an initial and an enhanced, were developed in collaboration with MDE and other Maryland state agencies, which were then analyzed through the MPAF. Each meta-scenario combined a suite of selected policies into a single NE-MARKAL run that captured their interactive effects. The initial meta-scenario was comprised of selected policies as they were defined in the GGRA Plan of 2012. The enhanced meta-scenario was comprised of a combination of individual policies, some of which had enhanced goals defined either in the GGRA Plan or by MDE. Note that enhanced policies not based on the GGRA Plan are for analytical exercise purposes only, and may not reflect current Maryland policy.

ES3. Multi-Pollutant Impact of GGRA Policies

The multi-pollutant planning exercise demonstrated that the selected GGRA policies collectively made positive contributions to near-term air quality outcomes, including the 2020 GGRA climate target. The analysis also indicated that further reductions in CO_2 emissions are needed to meet a hypothetical 80 percent reduction goal by 2050. In order to meet longer-term emission reduction goals, more measures involving the transportation sector would need to be considered. Climate sensitivity analyses undertaken as an extension of the meta-scenarios analyses found that in 2050, the combination of the most aggressive modeled GGRA policies alone lowered Maryland's reference case 2050 GHG emissions from almost 90 million tons of CO_2 to about 46 million tons (other GHGs were not considered in these analyses). This is still about 30 million tons short of a 2050 80 percent GHG reduction target of 17 million tons (relative to 2006 emissions). Of the 46 million tons, about 35 million tons comes from the transportation sector. This is not surprising, as the sensitivity analyses focused on more aggressive options for renewable energy and energy efficiency, while more aggressive transportation policies were not considered.

The GGRA measures in the two meta-scenarios also led to projected emission reductions in nitrogen oxides (NO_X) and sulfur dioxide (SO_2), key precursor pollutants for the criteria pollutants ozone (NO_X) and $PM_{2.5}$ (NO_X and SO_2) over the modeling timeframe through 2023. Cumulatively over this time period, the initial meta-scenario projected reductions of 63,000 tons of NO_X and 399,000 tons of SO_2 in Maryland. Larger reductions were seen for the enhanced meta-scenario, with 70,000 tons of NO_X and 492,000 tons of SO_2 reduced.

ES4. GGRA Contributions to Maryland's Ozone State Implementation Plan Reductions

A selected set of GGRA measures that were included in an ozone sensitivity analysis demonstrated promise for achieving additional NO_X reductions relevant to Maryland's ozone SIP timelines (2017 to 2023). These NO_X reductions go beyond current ozone SIP baseline projections and enforceable control strategies, thus they provide the technical basis for an expanded weight-of-evidence demonstration of reasonably foreseeable NO_X reductions in excess of those attributable to traditional ozone SIP measures.

The estimated additional NO_X reductions from the GGRA measures are in the range of 1,200 to 1,600 tons in the year 2017, which is Maryland's ozone attainment deadline for the 0.075 ppb ozone NAAQS (current NAAQS at the time of this analysis). Additional NO_X reductions in the range of 2,200 to 2,600 annual tons are projected for the year 2023, which is relevant to maintaining the current ozone NAAQS, as well as achieving a possible future revised ozone NAAQS. By way of comparison, the annual NO_X reductions projected under the ozone SIP sensitivity scenarios are somewhat less than, but comparable to, projected annual NO_X reductions from gasoline passenger vehicles in Maryland expected from implementation of EPA's Tier 3 motor vehicle program. The Tier 3 program represents one of the largest, if not the largest, measure in Maryland for reducing NO_X emissions in 2017 and beyond, and the results of the ozone sensitivity runs indicate the potential for additional NO_X reductions of a similar magnitude from the modeled GGRA policies.

ES5. Maryland's GGRA Measures Have Positive Air Quality, Health, and Economic Benefits

The projected GGRA emission changes estimated by NE-MARKAL were input into the Community Multi-scale Air Quality (CMAQ) model to evaluate their impacts on ambient air quality. The projected changes in emissions estimated by NE-MARKAL give rise to CMAQ-modeled air quality improvements for ozone and fine particulate matter ($PM_{2.5}$) in Maryland and in regions outside of the State, which in turn result in positive net health benefits in terms of avoided adverse health outcomes, including premature mortality. These avoided health incidences were quantified, along with their monetized benefits, using EPA's BenMAP tool coupled with the modeled air quality changes in ozone and $PM_{2.5}$ from CMAQ for each of the meta-scenarios.

As a result of the air quality changes attributable to the GGRA meta-scenarios, the BenMAP analysis found many reduced incidences of respiratory ailment, asthma attack, heart attack, hospital room visits, and lost work and school days. The monetary benefits of these public health improvements were driven largely by the reduced mortality, which includes (within Maryland) 43 to 100 avoided deaths per year due to reduced ozone and $PM_{2.5}$ under the initial meta-scenario, and 84 to 192 avoided deaths per year under the enhanced meta-scenario.

The monetized value of avoided mortality within Maryland ranges between $420 million to $850 million per year under the initial meta-scenario, and between $810 million to $1.6 billion per year under the enhanced meta-scenario, assuming a 3 percent discount rate for future health effects. With a 7 percent discount rate, the value is $320 million to $740 million per year under the initial meta-scenario, and $620 million to $1.4 billion under the enhanced meta-scenario.

The regional economic assessment using REMI found that overall, the GGRA measures as analyzed under the initial meta-scenario will benefit Maryland's economy with respect to jobs, wages, and real disposable income growth. However, the output and value added to Maryland's economy may decline given the large declines in demand for energy and maintenance associated with the electric power sector in the short term. Private, state, and households' continual structured investments in the economy toward GGRA goals under the enhanced meta-scenario mitigated some loss reported in the initial meta-scenario. Specifically, programs associated with increasing public transit helped to offset the later declines. The initial work creates construction jobs within the region, but the longer-term benefits associated with reduced motor fuel purchases and maintenance of private vehicles provide additional disposable income to households in the form of savings. Given this newly acquired disposable income, consumers are more likely to spend it locally, thereby creating additional induced impacts. Review of both scenarios indicates there will be a short-term negative impact incurred for implementation, but Maryland's economy benefits from nearly 20 additional years of increased jobs, wages, and output in the long-term.

1. INTRODUCTION

Historically, air pollution problems have been addressed on a pollutant-by-pollutant basis, whereby each pollutant or pollutant category of concern has required its own discrete planning effort. This approach has been fostered by media-specific federal and state statutes primarily designed to address the most serious pollution problems.

While states have made significant progress in reducing pollution over the years, there is a growing recognition that focusing on discrete pollutants or categories may not encompass the most effective strategies, or may lead to unintended results in other areas of the environment or economy. One critical aspect for more effective planning is the understanding of interactions between pollution sources. For example, motor vehicles, industrial facilities, and fossil-fuel power plants contribute not only to ground-level ozone, but also to fine particles, mercury and acid deposition, and climate change. As recognition increases that today's environmental, public health, energy, and economic challenges are increasingly intertwined, states are realizing the importance of moving to a more integrated, multi-pollutant, economy-wide approach.

1.1. Definition of Multi-pollutant Planning

Multi-pollutant planning is a process that identifies the air quality co-benefits of select policy options. By looking at multiple air quality goals concurrently and identifying potential control approaches and their environmental, public health, energy, and economic impacts together, a more complex set of policy questions emerges that can then be addressed. Multi-pollutant planning analysis should be able to help states assess unintended consequences of various policy options and identify the best policy mix and design, given the mandate to protect public health and the environment. If done appropriately, multi-pollutant planning should identify tradeoffs of implementing one policy over another, help states to set priorities and appropriate planning horizons, allow for more informed decisions about policy and program design, and ultimately provide regulatory certainty. As such, it has the potential to be a more economical way to address environmental and public health issues than traditional pollutant-by-pollutant approach.[1]

1.2. Context for Multi-pollutant Planning

Over the past 15 years, states have been exploring opportunities to integrate clean energy programs into their State Implementation Plans (SIPs) required by the federal Clean Air Act. These efforts have recently escalated due to increases in energy efficiency investments, the prioritization of energy security and climate change, and fiscal constraints. For air regulators, energy efficiency also offers new opportunities as the emission reductions needed to achieve clean air goals become more elusive.

The federal government has also been taking steps to encourage states to explore multi-pollutant planning approaches. In June 2007, the federal Clean Air Act Advisory Committee recommended that governments adopt a comprehensive statewide air quality planning process and move from a single- to a multi-pollutant approach in managing air

[1] Weiss, L., M. Manion, G. Kleiman, C. James, Building Momentum for Integrated Multipollutant Planning; Northeast States' Perspective. *EM*, May 2007, 25-29.

quality.[2] The U.S. Environmental Protection Agency (EPA) subsequently initiated pilot projects with three jurisdictions to explore ways to approach multi-pollutant planning by developing Air Quality Management Plans (AQMPs).[3] In July 2012, the EPA released its *Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs into State and Tribal Implementation Plans*. The document builds upon EPA's 2004 guidance on how states may account for energy efficiency (EE) and renewable energy (RE) programs in their SIPs.[4] The Roadmap identifies four pathways: (1) baseline emissions forecast; (2) control strategy quantification; (3) weight-of-evidence; and (4) innovative and emerging measures.[5]

Several states have been investigating and applying existing multi-pollutant planning analytical approaches to help advance the methodology. New York and Massachusetts undertook pilot projects to integrate energy and air quality planning by evaluating energy programs for criteria pollutant co-benefits and multi-sector interactions.[6,7] The city of Detroit, Michigan evaluated potential SIP strategies for ozone, fine particulates, and selected air toxics.[8]

Maryland has been involved in several multi-pollutant planning and analysis exercises in recent years. The Maryland Department of the Environment (MDE) has worked with NESCAUM on various preliminary multi-pollutant assessment exercises to become familiar with available tools. This work was conducted in collaboration with the Maryland Public Service Commission, the Maryland Energy Administration, and the Maryland Department of Natural Resources' Power Plant Research Project.[9] A subsequent exercise focused on greenhouse gas reductions and criteria pollutant co-benefits from a subset of policies contained in the Maryland Greenhouse Gas Reduction Act (GGRA) Plan of 2012.[10] The GGRA requires a state plan to reduce greenhouse gas emissions by 25 percent by 2020.

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[2] Recommendations to the Clean Air Act Advisory Committee: Air Quality Management Subcommittee. Phase II Recommendations, June 2007, available at: http://epa.gov/air/caaac/aqm/phase2finalrept2007.pdf.
[3] See: http://www.epa.gov/air/aqmp/.
[4] See: http://epa.gov/airquality/eere/pdfs/EEREmanual.pdf.
[5] The fourth pathway, innovative and emerging measures, was used as the basis for EPA's 2004 guidance on energy efficiency in SIPs. See: http://www.epa.gov/ttncaaa1/t1/memoranda/ereseerem_gd.pdf.
[6] NESCAUM, Applying the Multi-Pollutant Policy Analysis Framework to New York: An Integrated Approach to Future Air Quality Planning. Prepared for the New York State Energy Research and Development Authority, ST10600, May 2012. See: http://www.nescaum.org/documents/applying-the-multi-pollutant-policy-analysis-framework-to-new-york-an-integrated-approach-to-future-air-quality-planning/.
[7] NESCAUM, How Cost-Effective Energy Efficiency and Renewable Energy Projects Can Help Achieve Northeast Regional Air Quality Goals: An Integrated Assessment for the Commonwealth of Massachusetts, August 2010.
[8] Wesson, K., N. Fann, M. Morris, T. Fox, B. Hubbell, A multi-pollutant, risk-based approach to air quality management: Case study for Detroit, *Atmos Poll Res* 1 (2010), 296–304. See: http://www.atmospolres.com/articles/Volume1/issue4/APR-10-037.pdf.
[9] NESCAUM, Maryland Multi-Pollutant Project; Final NE-MARKAL Calibration for Maryland, March 2011.
[10] NESCAUM, A Multi-Pollutant Planning Approach for Maryland: A Weight-of-Evidence Analytical Exercise for the Maryland Greenhouse Gas Reduction Act Plan. Prepared for Maryland Department of the Environment, November 2012.

1.3. Project Goals

This report presents the findings of a multi-pollutant planning exercise MDE initiated in April 2013. The project's goals were to continue to build capacity in Maryland to conduct multi-pollutant planning and analyses as well as inform Maryland's ozone SIP and GGRA Plan Progress Report. Maryland's intention is to use a multi-pollutant framework to look at all pollutants whenever a single pollutant SIP is being developed. It is part of Maryland's preliminary effort to build credit for energy efficiency and renewable energy (EE/RE) programs into the ozone SIP. The requirement for Maryland to submit a SIP for attainment of the 2008 8-hour ozone NAAQS is currently suspended following EPA's determination that the Baltimore area has attained the 2008 8-hour ozone National Ambient Air Quality Standard (NAAQS). This proposed determination is based upon complete, quality-assured, and certified ambient air monitoring data that show the Baltimore area has monitored attainment for the 2012–2014 monitoring period. The multi-pollutant planning exercise is being conducted because this determination does not relieve Maryland from its obligation to submit a SIP if the Baltimore Area returns to non-attainment in the future.

This exercise is part of a larger effort in Maryland to better address some of the uncertainties associated with the SIP and attainment demonstration process, specifically the modeling and future year projections. The uncertainty analysis is currently captured in the SIP process through a weight-of-evidence (WOE) approach. In this context, EPA views WOE as "a supplemental analysis to an attainment demonstration in cases where a jurisdiction is not predicted to attain an air quality standard based on air quality modeling." EPA recommends this as an option to account for EE/RE policies and programs "where a state, tribal or local agency wants to claim emissions benefit that will potentially affect air quality in the attainment year, but where modeling the impacts of the policy or program is either too resource intensive or not feasible for other reasons and/or the jurisdiction is not interested in SIP/TIP credit."[11]

MDE's position is that EPA's approach is a limited construct, and that explicit analyses of uncertainty should be a mandatory element of all SIPs. It hopes that EPA considers this effort more broadly as an "expanded WOE" approach, as it goes beyond what is included in EPA guidance and more explicitly addresses all of the inherent uncertainties of a SIP.

[11] U.S. EPA, Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs into State and Tribal Implementation Plans, July 2012, pp. 14–15.

2. MULTI-POLLUTANT PLANNING IN MARYLAND

2.1. Assessing Co-Benefits of EE/RE Programs in Maryland

Since the early 1990s, the MDE has been developing SIPs for ground level ozone, fine particles, and other air pollutants that have led to many regulatory programs to meet Clean Air Act requirements. High profile state regulatory initiatives have included the Maryland Healthy Air Act, which targets power plants, the Maryland Clean Car Program, aimed at mobile source emissions, and numerous point, area, and mobile source control programs developed regionally through the Ozone Transport Commission.

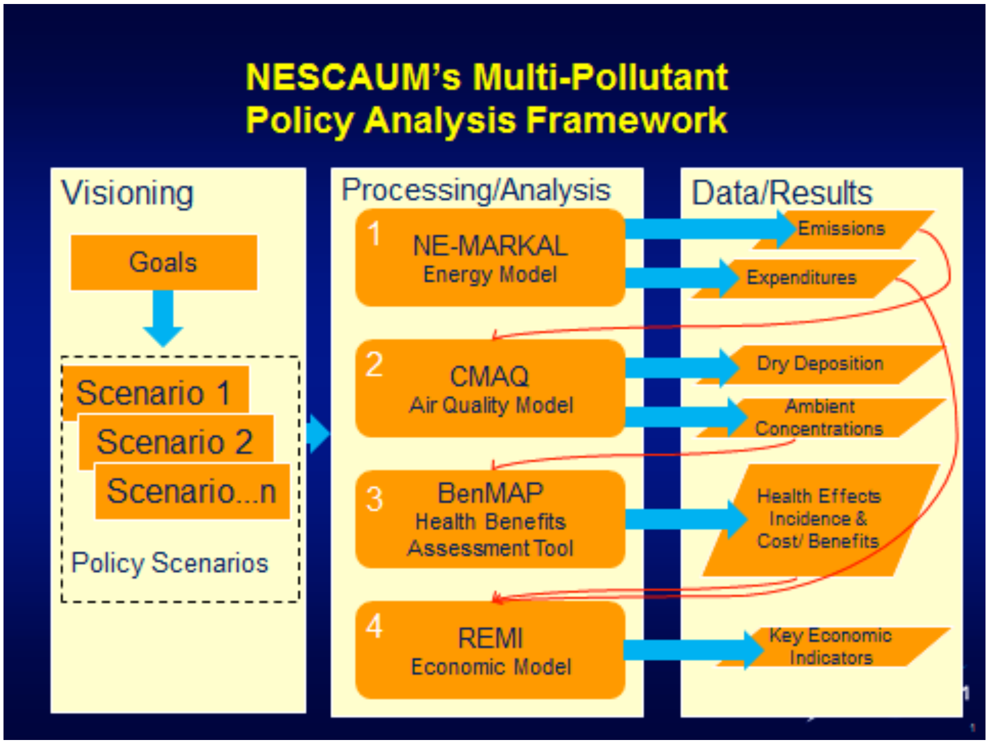
Despite Maryland's efforts, it remains a continuing challenge to attain and maintain the ozone and fine particle National Ambient Air Quality Standards (NAAQS). The State is pursuing efforts on two primary fronts: (1) targeting air pollution that is transported in-state from upwind sources; and (2) implementing effective non-traditional control programs to further reduce local emissions in lieu of traditional command-and-control regulatory drivers. This project examines how one of those non-traditional areas, energy efficiency and renewable energy (EE/RE) programs, can help clean the air and be included and credited within the SIP context. The EE/RE programs are drawn from the GGRA Reduction Act Plan.[12]

2.2. The Multi-Pollutant Framework

Maryland's approach to multi-pollutant planning is to reduce emissions through an integrated process that maximizes the co-benefits of reduction policies. This process allows for multi-sector analysis and estimates environmental, public health, economic and energy benefits of policies designed to reduce criteria pollutants, air toxics, and greenhouse gases. The approach, developed by the Northeast States for Coordinated Air Use Management (NESCAUM), is the Multi-pollutant Policy Analysis Framework (MPAF). The MPAF consists of three broad areas of activity: visioning, processing and analysis, and data/results assessment. The process is illustrated in Figure 2-1**.**

[12] Maryland's Greenhouse Gas Reduction Act Plan, October 2013. See: http://climatechange.maryland.gov/publications/greenhouse-gas-emissions-reduction-act-plan/.

Figure 2-1. NESCAUM's Multi-Pollutant Policy Analysis Framework



The framework brings together a series of assessment models, tools, and databases that connect through their data inputs or outputs. The models include:

1. NE-MARKAL, a Northeast version of the MARKet ALlocation (MARKAL) model, an energy model that is widely used in Europe. EPA has a nine-region national version of this model, called US9r;
2. Regional Economic Models, Inc. (REMI), a 12-state model that evaluates the effects of policies and programs on the economies of local regions;
3. EPA's Community Multi-scale Air Quality (CMAQ) model, which assesses future air quality impacts arising from changes in air emissions due to a set of policies and programs;
4. EPA's Environmental Benefits Mapping and Analysis Program (BenMAP), which estimates health impacts and associated monetized values resulting from changes in ambient air pollution.

The centerpiece of the framework is the NE-MARKAL model, an economy-wide energy model that that encompasses the entire energy infrastructure of the Northeast. It is capable of modeling all energy demand and supply in the transportation, commercial, industrial, residential, and power generation sectors to calculate least-cost combinations of energy technologies for achieving a prescribed pollution reduction goal. The model covers 11 states plus the District of Columbia,[13] and characterizes electricity generation, transportation, and the industrial, residential and commercial building sectors over a 30- to 50-year time horizon.

The MPAF allows the user to input the outputs of NE-MARKAL (which are changes in emissions across sectors) into other models that, in turn, can provide output data on potential air quality impacts (through CMAQ) and health benefits (using BenMAP). NE-MARKAL also provides inputs to the REMI economic model, which estimates economic metrics, such as gross state product, jobs, and household disposable income. Such complementary analyses have not been traditionally available to air quality planners.

The MPAF models can also help policymakers evaluate the relative importance of various policies and programs over others by assessing cross-sector impacts (e.g., how transportation programs may affect power plant emissions). It provides data on technology evolution for modeled programs (e.g., how many and what type of electric vehicles would be needed to achieve a certain emissions reduction goal). This type of specific information on program characteristics can be very helpful to state agencies in designing future regulatory programs.

For more information on the models within MPAF, see Appendices A through E.

2.3. Multi-Pollutant Planning Process

Starting in May 2013, MDE worked with NESCAUM, Towson University's Regional Economic Studies Institute, and the University of Maryland at College Park to conduct a multi-pollutant analysis with updated assumptions from the Greenhouse Gas Reduction Act Plan of 2012. This effort took approximately 18 months, which is consistent with other SIP planning and analytical exercises.

A subset of policies listed in the GGRA Plan was analyzed that were best suited to the NE-MARKAL model capabilities, specifically programs that affect the power generation and motor vehicle sectors as well as residential and commercial energy efficiency. The policies selected by MDE were:

- Regional Greenhouse Gas Initiative
- Maryland Renewable Portfolio Standard Program
- EmPOWER Maryland Energy Conservation Program
- Main Street Initiatives
- Energy Efficiency for Affordable Housing
- Maryland Clean Car Program
- Corporate Average Fuel Economy Standards for Model Years 2008 through 2011 for Light-duty Passenger Cars and Trucks
- Fuel Efficiency for Medium-and Heavy-duty Trucks
- Public Transportation and Intercity Transportation Initiatives

[13] The jurisdictions covered in the NE-MARKAL model include: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.

- Gasoline Tax
- Federal Tier 3 Motor Vehicle Emission and Fuel Standards
- Building and Trade Codes

NESCAUM characterized, quality assured, and simulated the policies in the NE-MARKAL energy model. The data derived from NE-MARKAL simulations were then used as inputs to other MPAF models: University of Maryland College Park processed and incorporated NE-MARKAL outputs into the CMAQ model to assess air quality impacts of the selected policies; NESCAUM input the CMAQ results into BenMAP to assess health impacts associated with the policies. The Regional Economic Studies Institute of Towson University used selected outputs from NE-MARKAL to examine economic effects using the REMI model.

Two key GGRA Plan policies—Leadership by Example and Maximum Achievable Control Technology Standards for Boilers (Boiler MACT)—were not analyzed in NE-MARKAL but were incorporated into the other MPAF analyses. Additional refined simulations, called sensitivity analyses, were also conducted using NE-MARKAL to further inform the analysis.

2.4. Context and Caveats

In the context of using multi-pollutant analyses to support the ozone SIP and GGRA Plan in a weight-of-evidence approach, there are inherent limitations, as is typical in most modeling systems. The following focuses on the NE-MARKAL model, as it is an energy model that is new to air quality planners, and serves as the centerpiece of the MPAF. Notwithstanding its limitations, NE-MARKAL and the full complement of the MPAF models provide a set of tools for decision-makers to assess the relative benefits of environmental policies and programs at a high level of detail at the state level.

The NE-MARKAL model is not an energy forecasting tool. It is designed to explore implications of implementing possible future energy policies and programs collectively (referred to as a meta-scenario). The NE-MARKAL modeling relies on a calibrated “reference case” against which those possible future energy policies are tested and compared. The reference case is not a prediction of future events absent major policy changes. Rather, it reflects one projection based on reasonable assumptions about energy and air emissions trends in Maryland. A simulation modeled by NE-MARKAL explores the projected changes arising from a given energy policy relative to the reference case. When modeled, these simulations are influenced by changes to the reference assumptions and other system constraints that reflect various policy choices.

Each modeled simulation projects technology shifts, costs, and emissions. The results are shaped by the data bases used and the assumptions or constraints placed on the model. The assumptions used in calibrating the reference case for the analyses are based on what the MDE and the Maryland Energy Administration agreed to as the most likely plausible future outcome at a specified point in time. NESCAUM compared the initial NE-MARKAL reference case energy consumption trends, by sector, to the U.S. Department of Energy’s (DOE’s) Annual Energy Outlook (AEO) 2012 forecast, and made appropriate updates and refinements. The simulations run for this exercise examined how various system constraints, representing policies and programs, would change that plausible future outcome in response to those changes.

Another important caveat in applying these tools is that the modeling results are constrained by the underlying data. In some cases, the limitations are inherent to the availability of data. In other cases, they may be due to the quality of the data. Understanding such limitations is important in terms of placing the results in context. Details on how the policies and meta-scenario were constrained and simulated in NE-MARKAL are presented in Appendix A.

The technology shifts projected by the model do not reflect individual or societal behavior associated with risk aversion or consumer preferences. To address these issues, the model can be constrained in a manner to more realistically represent future technology trends. Input by experts knowledgeable in such trends is important to ensure that the modeled assumptions and constraints are reasonable and appropriate for purposes of a given policy analysis.

In the NE-MARKAL framework, the decision-making objective is to minimize the total discounted cost of the energy system over the modeling horizon. Its strength is in exploring the relative cost effectiveness of meeting various policy goals, such as limits on carbon dioxide (CO_2) emissions from power generation or performance requirements on vehicles, based on total system cost. Total system cost is an internal accounting and decision-making criteria used within the NE-MARKAL modeling framework to choose between the alternative portfolios of energy sources and technologies represented in the NE-MARKAL database. The total system cost in the NE-MARKAL framework includes the following components:

- Annualized investments in technologies;
- Fixed and variable operations and maintenance of technologies;
- Cost of energy imports and domestic energy production;
- Revenue from energy exports;
- Energy costs;
- Taxes and subsidies associated with energy sources, technologies, and emissions.

NE-MARKAL does not directly estimate macroeconomic effects of introducing various programs, but within the MPAF, certain components of the projected optimized total system costs and savings can be used as inputs into the regional economic model.

3. THE MULTI-POLLUTANT WEIGHT-OF-EVIDENCE EXCERCISE

3.1. Energy Use and Emissions Changes: NE-MARKAL Results

3.1.1. Introduction

This section presents the NE-MARKAL energy use and emissions modeling results for the multi-pollutant exercise. Working with MDE staff, NESCAUM populated the NE-MARKAL model with Maryland-specific data as appropriate and then calibrated the model through sensitivity analyses and quality assurance/quality control efforts. NESCAUM and MDE then identified and developed policies that were modeled within two meta-scenarios. Appendix A details the core input assumptions for the NE-MARKAL model, how the specific policies and meta-scenarios were developed, and the data sets on which the policies were based.

3.1.2. Approach

NE-MARKAL is the Northeast-specific version of the economy-wide MARKet ALlocation (MARKAL) energy systems model, representing the energy infrastructure of the northeastern U.S. NE-MARKAL models energy demand and supply in the power generation, commercial, industrial, residential, and transportation sectors. NE-MARKAL currently includes the six New England states, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Washington, D.C. Key inputs to the model include energy demand, emission factors for GHGs and criteria air pollutants, and the operational and economic characteristics of all technologies critical to characterizing energy supply and demand.

In the NE-MARKAL modeling framework, the energy infrastructure is configured to meet estimated energy demand using the most cost-effective technologies and fuel sources. The model can be configured to represent enforceable requirements as well as incentives, such as energy efficiency programs, carbon mitigation strategies, and vehicle performance standards. The NE-MARKAL model currently begins in 2005 and models state and regional energy decision-making out to 2053 in three year time increments. For the core GGRA analysis, the modeling timeframe ranged between the years 2008 and 2023. For the climate sensitivity analysis, however, the timeframe was extended to 2050. Modeled outcomes from NE-MARKAL include: GHG and criteria pollutant emissions, energy consumption, and a variety of cost metrics.

For this analysis, the reference case NE-MARKAL energy calibration was accomplished in two phases. The first phase focused on aligning energy consumption in NE-MARKAL with observed historical trends between 2005 and 2011. This phase was executed by fixing NE-MARKAL energy consumption trends by sector and fuel type to Maryland-specific data reported in the EIA State Energy Data System (SEDS). The second phase focused on developing future NE-MARKAL reference case energy consumption trends by sector and fuel type. The first step in the second phase was to develop a set of benchmark future energy consumption trends that NE-MARKAL could be calibrated to. The benchmark energy consumption trends were constructed by applying AEO 2012 energy consumption growth rates by sector and fuel for the 2011-2023 period to the SEDS data used in the first phase of the energy calibration. Having established the benchmark energy consumption trends, a series of soft constraints were created in NE-MARKAL to ensure that the model's reference case energy consumption trends matched the main features of the AEO 2012 reference case. A detailed presentation of the energy calibration is found in section A.4.

There are a number of important caveats to keep in mind when assessing modeled NE-MARKAL results. (1) NE-MARKAL is best suited for "what-if" exploratory analyses of climate and air quality policies that probe a variety of possible technological and resource outcomes; the modeled results do not represent simulation-based forecasts of future energy, technology, and emissions trends. (2) NE-MARKAL is focused on a region's energy infrastructure and as such is best suited to assess policies aimed at technology and resource choices in this domain. The model is not well suited, for example, to assess policies aimed at land-use, agriculture, or waste management practices. (3) The electricity sector in NE-MARKAL uses a simplified load duration curve representation that breaks a typical year into six aggregate time-slices. This precludes analysis of policies aimed at affecting peak-generation resources and other scenarios aimed at shifting short-term load.

3.1.3. Policy and Meta-scenario Descriptions

As a first step, NESCAUM worked with MDE to select policies for analysis from the GGRA Plan of 2012 that were of key interest from a policy perspective and were most appropriate for characterizing in the NE-MARKAL model. The next step was to characterize the selected policies in NE-MARKAL and appropriately calibrate them. After the policies were finalized, two meta-scenarios were developed and analyzed.

The multi-pollutant analysis was based on an initial and an enhanced meta-scenario. Each meta-scenario combined all of the selected policies into a single NE-MARKAL run that captured their interactive effects. The initial meta-scenario was comprised of selected policies as they were defined in the GGRA Plan of 2012. The enhanced meta-scenario was comprised of a combination of individual policies, some of which had enhanced goals defined either in the GGRA Plan or by MDE. Initial and enhanced policy definitions were provided either in the GGRA Plan or by MDE.

Table 3-1 summarizes the initial and enhanced meta-scenarios, and Table 3-2 summarizes which policies are contained in the two meta-scenarios, with "I" denoting initial policies and "E" denoting enhanced policies. The scenarios highlighted in blue font, collectively referred to as the transportation bundle, remained at initial levels in both the initial and enhanced meta-scenarios.

Table 3-1. Initial and Enhanced Policy Definitions

Policy	Definition
RGGI	• **Initial GGRA**: model the RGGI cap before the updated model rule. • **Enhanced GGRA**: model the 91 MT updated model rule cap (using scenario: 91cap alt bank MR).
EmPOWER Maryland	• **Initial GGRA**: reduce MD per capita total electricity consumption 15% by 2015 relative to 2007; represented as an energy efficiency program. • **Enhanced GGRA**: expand energy efficiency to include natural gas
MD RPS	• **Initial GGRA**: require 20% qualified renewable generation regionally by 2022--only solar required in-state; the rest can come from the region. • **Enhanced GGRA**: require 25% qualified renewable generation regionally by 2020. • **For both scenarios**: (1) Tier 2 hydro to remain constant at 2.5% until 2018, and then sunset; (2) 2% solar by 2020.
Main Street Initiatives	• **Initial GGRA**: defined using the analysis of the low potential for energy efficiency provided by MDE. • **Enhanced GGRA**: defined using the analysis of the high potential for energy efficiency provided by MDE
Energy Efficiency for Affordable Housing	• **Initial GGRA**: Use methodology on pp. 115-116 of the GGRA Plan at $6,500 per retrofit. • **Enhanced GGRA**: Use methodology on pp. 115-116 of the GGRA Plan at $5,268 per retrofit.
CAFE Model Year 2008-2011	• **Initial GGRA**: NHTSA's pre-existing 2008-2011 fuel efficiency standards of 20.5 mpg. • No enhanced scenario.

Table 3-1. Continued

Policy	Definition
MD Clean Cars Program	• **Initial GGRA**: For model years 2012-2025: assume passenger fleet achieves most recent CAFE standards (~54.5 mpg by 2025). • No enhanced scenario.
National Fuel Efficiency and Emissions Standards for Medium- and Heavy-Duty Trucks	• **Initial GGRA**: EPA/NHTSA standards for model years 2012-2016 for medium- and heavy-duty trucks. • Standard does not sunset after 2016. • No enhanced scenario.
Public Transportation and Intercity Transportation Initiatives	• **Initial GGRA**: Assume 2.3% of Maryland's passenger vehicle fleet will be composed of BEVs and PHEVs by 2020. • No enhanced scenario
Building and Trade Codes	• **Initial GGRA**: Commercial and residential buildings to increase energy efficiency by 15%, starting in 2012. • No enhanced scenario.
Gas Tax	• **Initial GGRA**: Based on the documentation sent by MDOT, apply a gas tax of $0.27 per gallon. • **Enhanced GGRA**: Based on the documentation sent by MDOT, apply a gas tax of $1.20 per gallon.
Tier 3	• **Initial GGRA:** Adopt new SO2, NOx, and PM standards for motor gasoline beginning in 2017. • No enhanced scenario.

Table 3-2. Meta-scenario Definitions

	Scenario Definitions	
Policy	**Initial Meta-scenario**	**Enhanced Meta-scenario**
Regional Greenhouse Gas Initiative	I	E
Maryland Renewable Portfolio Standard	I	E
EmPOWER Maryland	I	E
Main Street	I	E
Energy Efficiency for Affordable Housing	I	E
Maryland Clean Cars	I	I
CAFE 2008-2011	I	I
Fuel Efficiency for Medium and Heavy Duty Trucks	I	I
Public Transportation and Intercity Transportation Initiatives	I	I
Tier 3 Vehicle and Emission Standards	I	I
Gas Tax	I	E
Building and Trade Codes	I	I

3.1.4. Modeled Energy Use Changes

NE-MARKAL modeling results were generated in three-year time intervals, from 2008 to 2023. All meta-scenario results should be considered relative to the reference case. In the figures, "tBTU" stands for trillion British Thermal Units, "LPG" refers to liquefied petroleum gas, and "E85" is a fuel blend comprised of 85 percent ethanol and 15 percent gasoline. For this analysis, "biomass" refers to dedicated biomass-electric generating plants; it does not include disaggregated wood burning for residential heating or in outdoor wood-fired boilers.

Buildings Sector

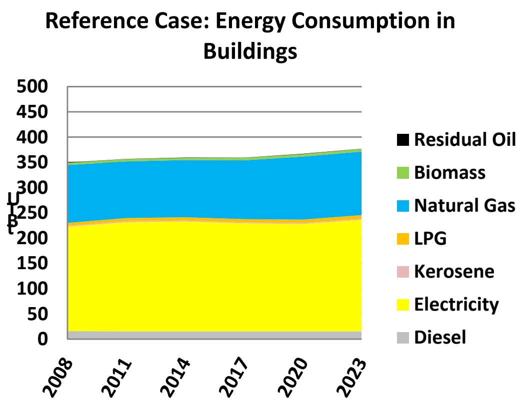
The results of the buildings sector are presented first, as they help establish the energy efficiency-related basis for some of the load reduction and fuel switching that is observed in the power sector (presented in the next section).

In this analysis, the buildings sector refers collectively to residential and commercial buildings. The individual GGRA Plan policies targeted at the buildings sector are: EmPOWER Maryland, Main Street, Energy Efficiency for Affordable Housing, and Building and Trade Codes. These policies are intended to increase adoption of energy efficient technologies and practices in residential and commercial buildings, and most of them are aimed at electrical end-uses.

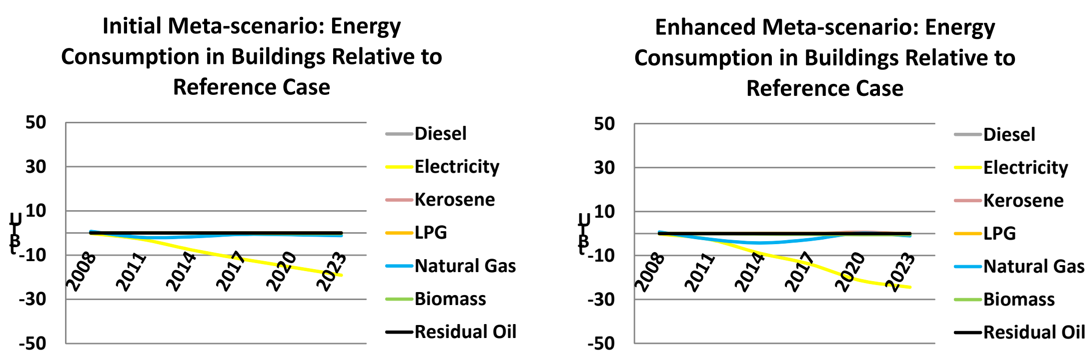
In the initial meta-scenario, only the Energy Efficiency for Affordable Housing policy is aimed at residential natural gas efficiency. Natural gas efficiency plays a larger role in the enhanced meta-scenario, as the EmPOWER Maryland policy was expanded in that context to include greater potential for natural gas efficiency in heating applications.

Figure 3-1 summarizes the buildings sector energy consumption trends in the reference case and in each of the meta-scenarios relative to the reference case. The chart in the upper left presents the reference case energy consumption trends by fuel type. The bottom two charts show changes in energy consumption relative to the reference case for each meta-scenario. The table in the upper right summarizes the cumulative change in energy consumption relative to the reference case for each meta-scenario.

Figure 3-1. Buildings Sector Energy Results



Cummulative Change 2008-2023 (tBTU)	Initial	Enhanced
Diesel	-2	-5
Electricity	-170	-214
Kerosene	-1	0
LPG	0	0
Natural Gas	-17	-30
Biomass	-2	-5
Residual Oil	0	0
Total	-192	-254
Total % Diff	-2.9%	-3.9%



In both the initial and enhanced meta-scenarios, there is a decline in overall electricity consumption in buildings. Relative to the reference case, cumulative electricity consumption declines by 4.4 percent and 5.6 percent, respectively. The electrical energy efficiency targets in the EmPOWER Maryland scenario are the primary drivers of the decreases, although each of the other buildings-related policies included in the meta-scenarios also have small electrical efficiency components.

A secondary result, observed in both meta-scenarios, is a smaller decline in natural gas consumption relative to electricity. In the initial meta-scenario, cumulative natural gas consumption decreases by 0.8 percent, and in the enhanced meta-scenario, cumulative natural gas consumption in buildings decreases by 1.4 percent. There are also smaller decreases in energy consumption for other fossil fuels. The smaller decreases for other fuels are associated with components of the Main Street Initiative that focus on heating and end-use efficiency (rather than the electrical or other fuel-specific efficiency provisions of the policy).

On an overall net energy basis, modeled energy consumption decreases in buildings by 2.9 percent in the initial meta-scenario and by 3.9 percent in the enhanced meta-scenario.

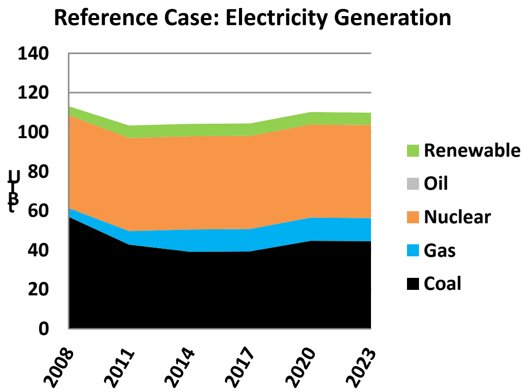
Power Sector

The GGRA Plan policies targeted at the power sector that were included in this analysis are the Regional Greenhouse Gas Initiative (RGGI) and the Maryland Renewable Portfolio Standard (RPS). The buildings sector policies that act to reduce electricity consumption through efficiency targets also have a significant impact on power sector outcomes. Generally, the load reductions associated with energy efficiency account for the largest impacts on power sector electricity generation trends in both the initial and enhanced meta-scenarios. The in-state impacts of the RPS are modest, based on the estimated in-state potential for renewable development. However, the impacts of renewable development on electricity generation trends are noticeably different in the initial and enhanced meta-scenarios. The RGGI policy is binding only in the enhanced meta-scenario, as slower-than-expected macro-economic trends and low natural gas prices have the combined effect of keeping the reference case CO_2 levels below the RGGI cap level that was modeled in the initial meta-scenario.

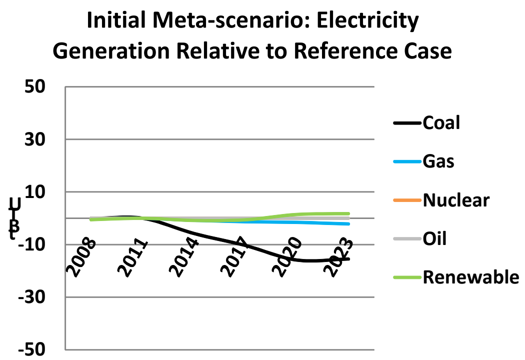
Figure 3-2 summarizes the power sector electricity generation trends in the reference case and in each of the meta-scenarios relative to the reference case. The chart in the upper left presents the reference case electricity generation by fuel type. The bottom two charts show changes in electricity generation (relative to the reference case) for each of the meta-scenarios. The table in the upper right summarizes the cumulative change in electricity generation relative to the reference case for each meta-scenario by fuel type.

In the initial and enhanced meta-scenarios, there is a switch away from coal-fired generation. Relative to the reference case, cumulative electricity generation from coal declines by 17.8 and 23.4 percent, respectively. These declines are primarily associated with the load reduction impacts of the energy efficiency targets that were modeled in the buildings sector. Efficiency-related load reduction has a smaller impact on natural gas generation trends in the initial meta-scenario that is directionally consistent with coal. In the enhanced meta-scenario, natural gas generation declines more aggressively in the later modeling years, as the RPS policy becomes more stringent and requires a larger share of in state-renewable development, relative to other fossil fuels. On an overall net energy basis, modeled electricity generation decreases by 8.1 percent in the initial meta-scenario and by 10.6 percent in the enhanced meta-scenario.

Figure 3-2. Power Sector Electricity Generation Energy Results



Cummulative Change 2008-2023 (tBTU)	Initial	Enhanced
Coal	-143	-188
Gas	-18	-45
Nuclear	0	0
Oil	0	0
Renewable	4	27
Total	-157	-205
Total % Diff	-8.1%	-10.6%



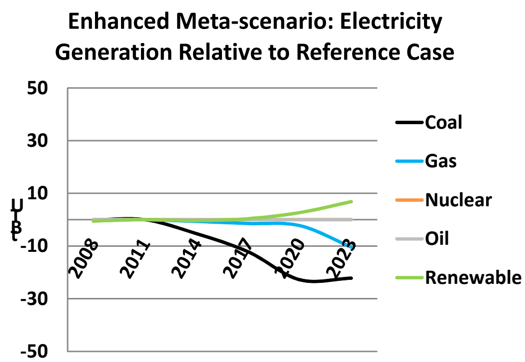
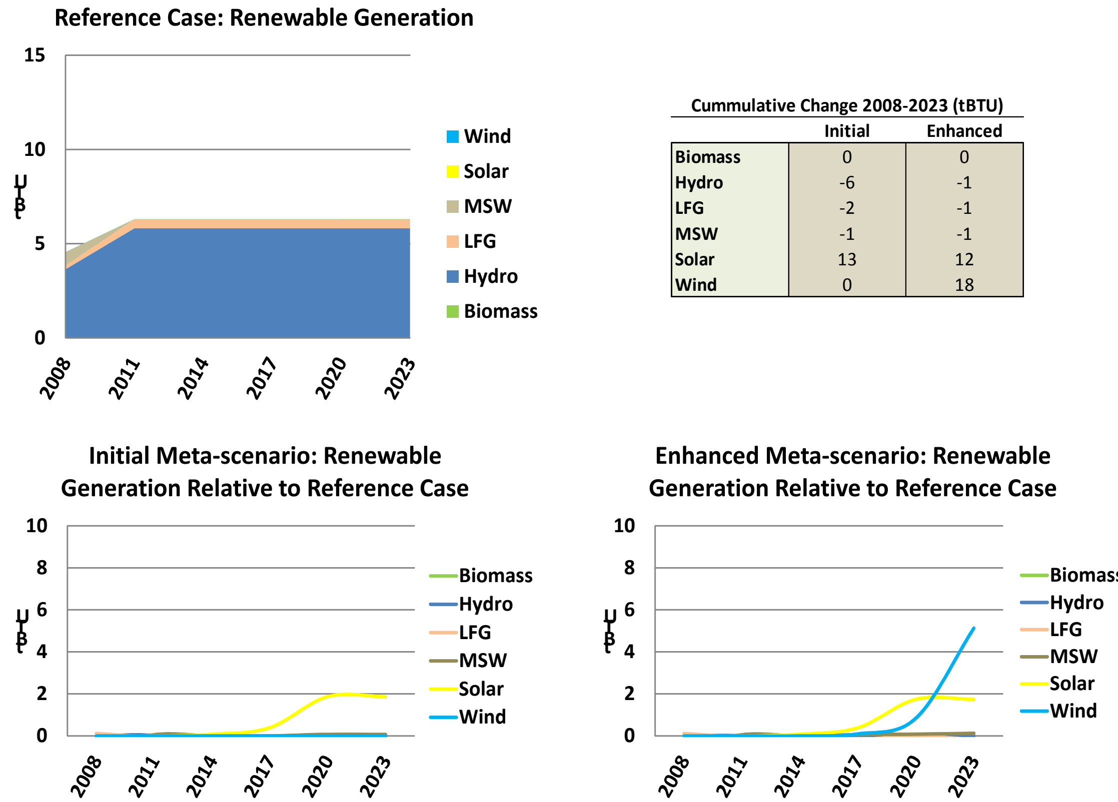


Figure 3-3 summarizes in-state renewable power generation by resource type. The chart in the upper left presents the reference case renewable electricity generation by resource type. The bottom two charts present changes in renewable electricity generation relative to the reference case for each of the meta-scenarios. The table in the upper right summarizes the cumulative change in renewable electricity generation relative to the reference case for each meta-scenario.

Figure 3-3 highlights the impact of the Maryland RPS on in-state renewable generation. Estimates for in-state renewable potential were derived from sources provided by the MDE and Maryland Energy Administration (MEA).[14] In the initial meta-scenario, the only aspect of the RPS that necessitates increased deployment of renewable technologies is the state solar carve-out. The solar carve-out requires that 2 percent of total generation comes from solar photovoltaic sources by 2020. This requirement remained the same for both the initial and enhanced meta-scenarios. In the enhanced meta-scenario, the cumulative in-state development of wind resources increased by 6 tBTU, which is roughly equivalent to 200 megawatts. This is a result of increasing both the RPS requirement to 25 percent renewable generation by 2020 and in-state potential for wind development from 2.3 percent to 3.5 percent by 2020.

[14] Personal communication from Christopher Beck, MDE, on April 1, 2014.

Figure 3-3. Renewable Generation Energy Results



Cummulative Change 2008-2023 (tBTU)

	Initial	Enhanced
Biomass	0	0
Hydro	-6	-1
LFG	-2	-1
MSW	-1	-1
Solar	13	12
Wind	0	18

Transportation Sector

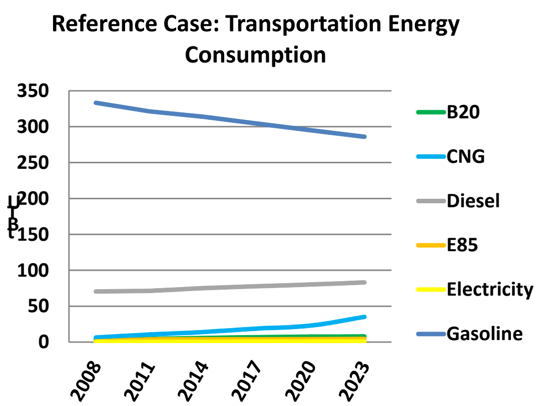
The GGRA Plan policies targeted at the transportation sector and included in this analysis are: Maryland Clean Cars, Corporate Average Fuel Economy standards for model years 2008 through 2011 for light-duty passenger cars and trucks (CAFE 2008–2011), Fuel Efficiency for Medium and Heavy-Duty Trucks, Public Transportation and Intercity Transportation Initiatives, Tier 3 Motor Vehicle Emission and Fuel Standards, and Maryland State Gas Tax. Of these policies, only the Gas Tax was modified for the enhanced the meta-scenarios; the other policies remained constant for both meta-scenarios.

Figure 3-4 summarizes the transportation sector energy consumption trends in the reference case and in each of the meta-scenarios relative to the reference case. The chart in the upper left presents the reference case energy consumption by fuel type. The bottom two charts present changes in energy consumption relative to the reference case for each of the meta-scenarios. The table in the upper right summarizes the cumulative change in energy consumption relative to the reference case for each meta-scenario.

Both the initial and enhanced meta-scenarios show a decline in overall motor gasoline consumption relative to the reference case by 1.6 and 2.1 percent, respectively. The advanced 54.5 miles per gallon (mpg) CAFE target in the Maryland Clean Cars policy is the primary driver of the decreases in gasoline consumption in both meta-scenarios.

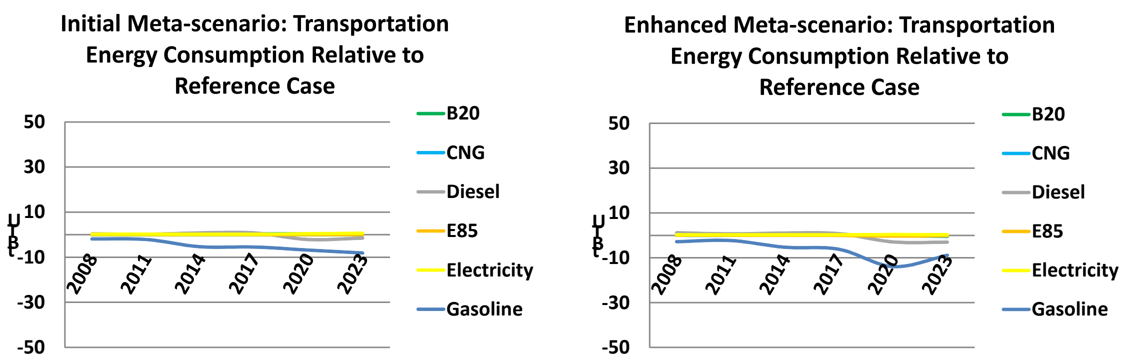
Another observed result is an increase in transportation electricity consumption in both meta-scenarios. The Public Transportation and Intercity Transportation Initiatives assume that 2.3 percent of Maryland's passenger vehicle fleet will be comprised of battery electric vehicles and plug-in hybrid electric vehicles by 2020. The Maryland State Gas Tax has an additional incremental effect in the enhanced meta-scenario, causing cumulative gasoline consumption to decrease by an additional 9 tBTU. On an overall net energy basis, modeled transportation energy consumption decreases by 1.1 percent in the initial meta-scenario and by 1.6 percent in the enhanced meta-scenario.

Figure 3-4. Transportation Sector Energy Results



Cummulative Change 2008-2023 (tBTU)

	Initial	Enhanced
B20	0	0
CNG	4	1
Diesel	-5	-7
E85	0	-2
Electricity	6	5
Gasoline	-90	-118
Total	-85	-121
Total % Diff	-1.1%	-1.6%



3.1.5. Modeled Emissions Changes

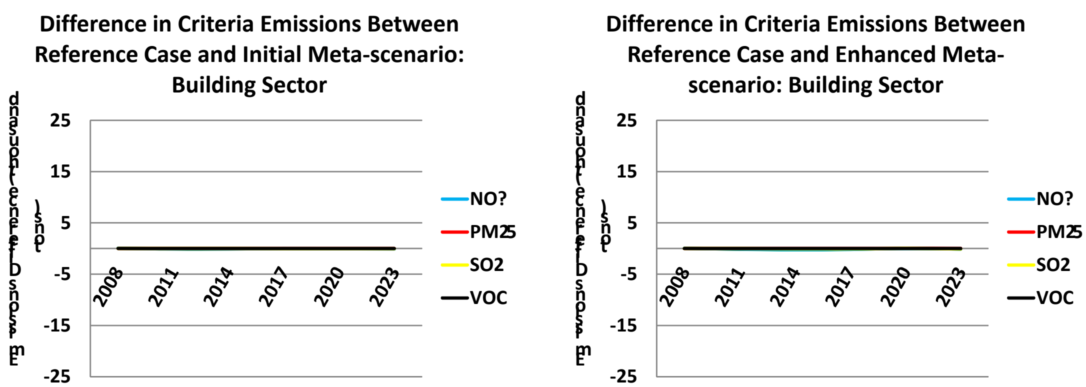
This section describes the modeled emissions changes across energy sectors from each of the meta-scenarios. Emissions indicators included nitrogen oxides (NO_X), fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), and volatile organic compounds (VOCs) for criteria pollutants, and CO_2 for greenhouse gases. The criteria pollutant carbon monoxide (CO) was included for the transportation sector only. NE-MARKAL modeling results were generated from 2008 to 2023. All meta-scenario results should be considered relative to the reference case. For this analysis, "biomass" refers to dedicated biomass-electric generating plants; it does not include disaggregated wood burning for residential heating or in outdoor wood-fired boilers.

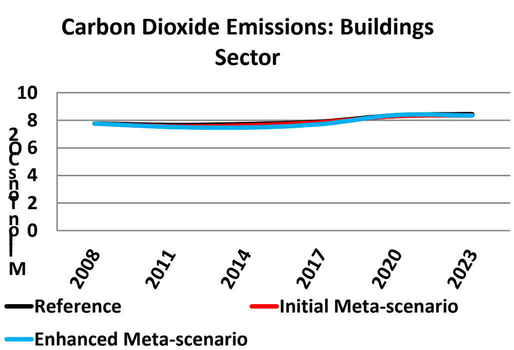
Buildings Sector

Figure 3-5 summarizes the modeled buildings sector emissions trends for each meta-scenario relative to the reference case. The top two charts present changes in criteria emissions relative to the reference case for the two meta-scenarios. The bottom left chart presents CO_2 emissions trends for the reference case and the meta-scenario. The table in the lower right summarizes cumulative changes in all emissions indicators relative to the reference case for each meta-scenario.

There are few observed emissions changes in the buildings sector for either meta-scenario. The primary energy-related effect of the modeled buildings sector policies was to reduce electricity demand through energy efficiency and conservation, which does not have direct emissions implications in the buildings sector, per se. In the enhanced meta-scenario, where natural gas efficiency is expanded, small decreases are observed in CO_2 and NO_X.

Figure 3-5. Building Sector Emissions Results





Cummulative Change 2008-2023 (kt)

	Initial	Enhanced
CO2*	-1	-2
NO?	-1	-2
PM25	0	0
SO2	0	-1
VOC	0	0

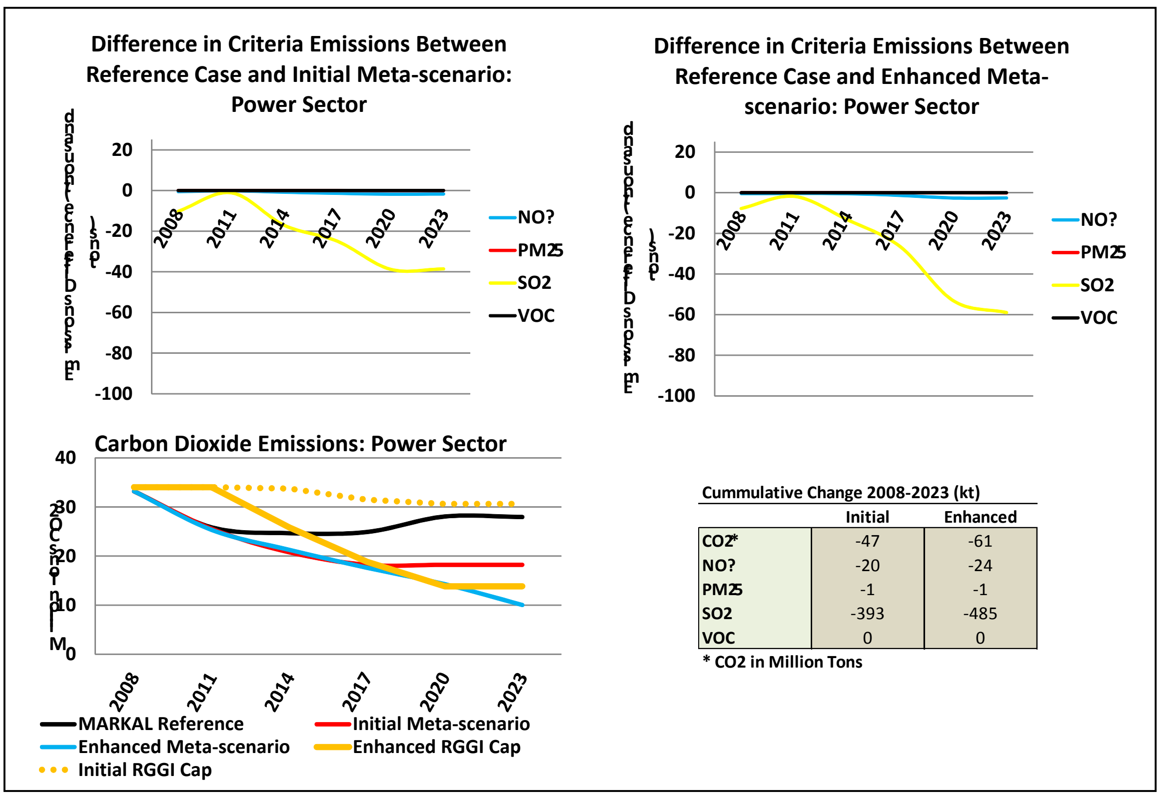
* CO2 in Million Tons

Power Sector

Figure 3-6 summarizes the modeled power sector emissions trends for the meta-scenarios relative to the reference case. The top charts examine changes in criteria emissions. The bottom left chart presents modeled CO_2 emissions trends in the reference case and for the meta-scenarios; the initial and enhanced RGGI caps are displayed as dotted and unbroken yellow lines, respectively, to provide reference. The table in the lower right summarizes the cumulative change in all emissions indicators relative to the reference case for the two meta-scenarios.

There is a significant reduction in SO_2 emissions for both meta-scenarios. Relative to the reference case, cumulative SO_2 emissions decline by 131,000 tons by 2023 in the initial meta-scenario and by 162,000 tons by 2023 in the enhanced meta-scenario. These effects are likely due to efficiency-related load reductions induced by the suite of building efficiency measures in the EmPOWER Maryland policy playing a large role in driving coal-fired generation down. In the enhanced meta-scenario, RGGI plays a role, albeit modest, in driving coal generation down further; this is seen in the additional SO_2 and CO_2 reductions. The significant decline in coal-fired generation also has a marked impact on CO_2 emissions. Relative to the reference case, cumulative CO_2 emissions decline by 16 million tons in the initial meta-scenario and by 20 million tons in the enhanced meta-scenario. The RPS policy plays a role in driving natural gas generation down in each meta-scenario, as renewable targets shift the generation mixes towards wind and solar generation. However, relative to the efficiency-related changes in coal generation, changes in natural gas generation in each meta-scenario have marginal impacts on climate and criteria pollutant emissions.

Figure 3-6. Power Sector Emissions Results



Cummulative Change 2008-2023 (kt)

	Initial	Enhanced
CO2*	-47	-61
NO?	-20	-24
PM25	-1	-1
SO2	-393	-485
VOC	0	0

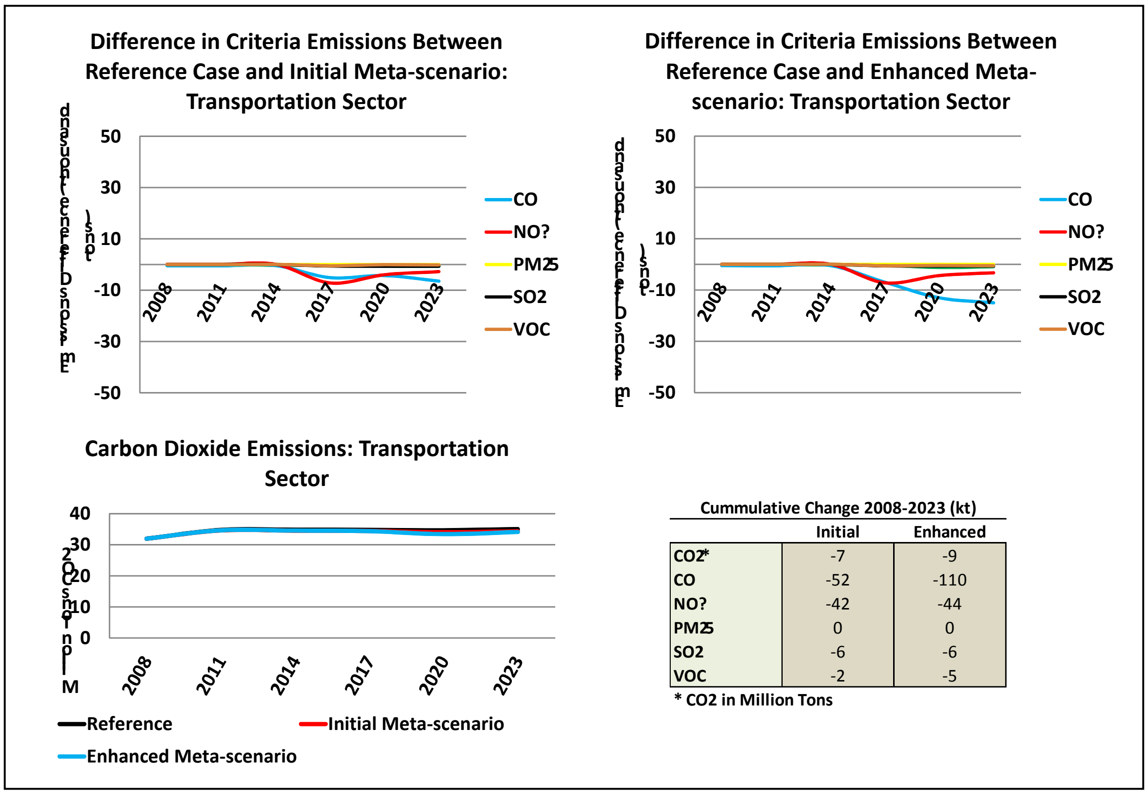
* CO2 in Million Tons

Transportation Sector

Figure 3-7 summarizes the modeled transportation sector emissions trends for the meta-scenarios relative to the reference case. The top two charts show changes in criteria emissions, and the chart on the bottom left presents CO_2 emissions trends. The table on the lower right summarizes cumulative changes in all emissions indicators.

With the exception of CO, overall cumulative changes in criteria emissions are similar for both meta-scenarios. The largest cumulative change in criteria pollutant emissions is observed for NO_X, which decreases by 14 million tons in the initial meta-scenario and 15 million tons in the enhanced meta-scenario by 2023. Both $PM_{2.5}$ and SO_2 emissions decline by the same amount in each of the meta-scenarios. The primary drivers for these criteria emissions changes are the Tier III Vehicle and Emissions Standards and the advanced 54.5 mpg CAFE targets in the Maryland Clean Cars policy, (which are defined identically in the initial and enhanced meta-scenarios). The Maryland Gas Tax enhancements (introduced in the enhanced meta-scenario), drives the incremental differences between the initial and enhanced scenarios for both criteria emissions and CO_2.

Figure 3-7. Transportation Sector Emissions Results



Cummulative Change 2008-2023 (kt)

	Initial	Enhanced
CO2*	-7	-9
CO	-52	-110
NO?	-42	-44
PM25	0	0
SO2	-6	-6
VOC	-2	-5

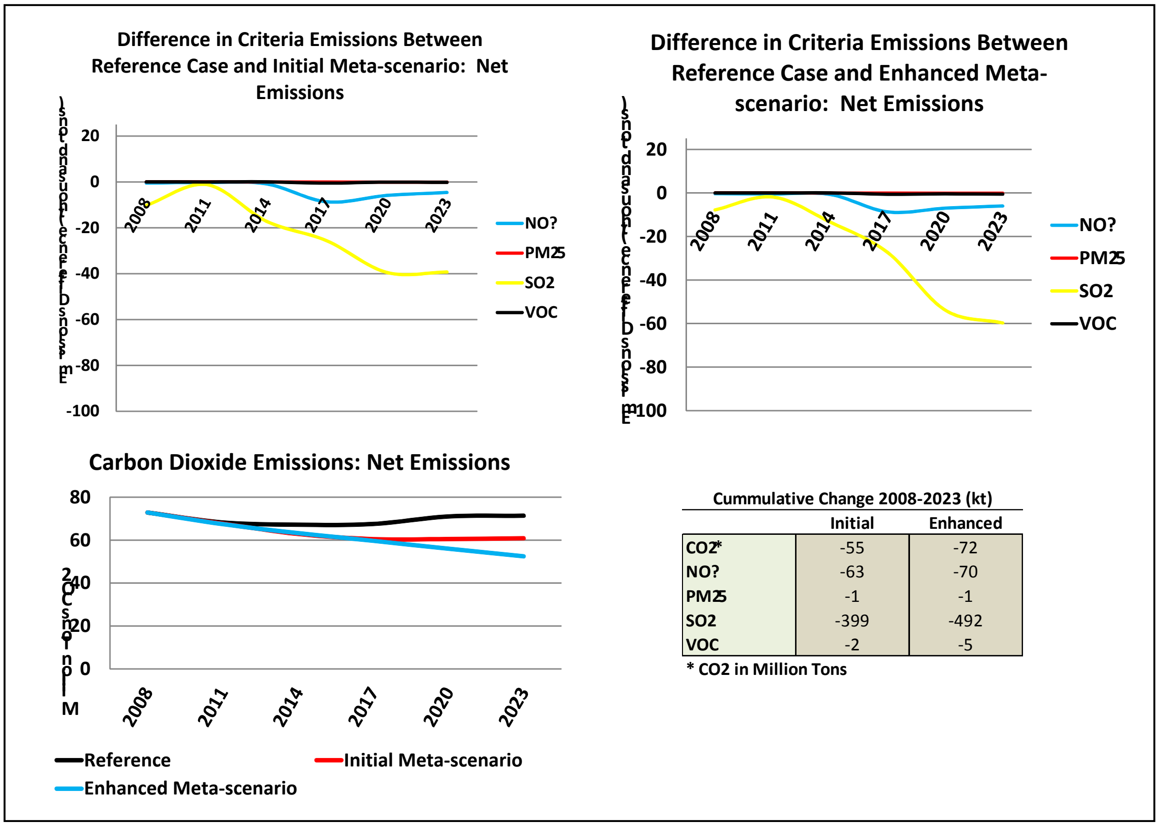
* CO2 in Million Tons

Net Emissions

Figure 3-8 summarizes the modeled net emissions trends for each meta-scenario relative to the reference case. The top two charts examine changes in criteria emissions and the chart on the bottom left presents CO_2 emissions trends. Finally, the table in the lower right summarizes the cumulative change in net emissions for all emissions indicators relative to the reference case for each meta-scenario.

Changes in net emissions are the sum of emissions changes from the power, buildings and transportation sectors of the NE-MARKAL model. As a result, the trends in Figure 3-8 follow directly from the emissions trends presented in Figure 3-5 through Figure 3-7. On a cumulative basis, the largest observed changes in criteria emissions are in SO_2 and NO_X. Relative to the reference case, SO_2 emissions decline by 133,000 tons in the initial meta-scenario and by 164,000 tons in the enhanced meta-scenario by 2023. NO_X emissions decline by 21,000 tons in the initial meta-scenario, and by 23,000 tons in the enhanced meta-scenario by 2023. The cumulative change in VOCs and $PM_{2.5}$ relative to the reference is less than 1.25 percent in each meta-scenario. Cumulative CO_2 emissions decline by 18 million tons in the initial meta-scenario, and by 24 million tons in the enhanced meta-scenario.

Figure 3-8. Net Emissions Results



3.1.6. Sensitivity Analyses

NESCAUM conducted two sensitivity analyses after completing the core GGRA modeling exercise. The first sensitivity analysis was designed to examine the GGRA policies specifically in the context of Maryland's current SIP planning work. The second sensitivity analysis was designed to assess the GGRA scenarios in the context of long-term climate planning targets. The rest of this section describes each of the sensitivity analyses.

Ozone Sensitivity

This section presents the ozone SIP sensitivity analysis conducted to inform the weight-of-evidence planning approach Maryland is exploring to account for NO_X reductions tied to policies such as energy efficiency, renewable energy, and market-based carbon reduction schemes that are not fully accounted for in ozone SIP strategies. For example, state renewable portfolio standards are mostly incorporated into AEO projections used in SIPs, but the full range of state-based measures, especially energy efficiency programs, are typically not included. In addition, the AEO2012 projection (the most recent projection available at the time of this analysis) did not include the revised carbon dioxide cap for the power sector in states participating in the Regional Greenhouse Gas Initiative (RGGI), which includes Maryland. Following a 2012 program review, the RGGI member states implemented a revised cap of 91 million short tons in 2014, which then declines 2.5 percent annually from 2015 to 2020.[15]

A new round of NE-MARKAL modeling was designed to highlight the benefits of GGRA policies from the Maryland GGRA Plan that focus specifically on projected NO_X emission reductions over a timeframe relevant to current ozone attainment planning. To this end, a new reference case was developed along with two additional "ozone SIP sensitivity" scenarios that incorporate GGRA policies beyond AEO projections used in setting the ozone SIP baseline. This provides a more robust estimate of NO_X emission reductions reasonably expected from Maryland's GGRA policies that are not included as control measures in the ozone SIP. The ozone SIP sensitivity analysis serves as an expanded weight-of-evidence method to estimate additional NO_X reductions that will contribute to future ozone air quality improvements beyond what is expected to be achieved through enforceable SIP measures. The ozone SIP sensitivity scenarios are described in more detail in the next sub-section.

The GGRA modeling conducted using the NE-MARKAL MPAF was designed around a policy neutral reference case meant to demonstrate how Maryland would benefit from implementing selected GGRA policies. Benefits were demonstrated by comparing the policy neutral reference case results to an initial meta-scenario, which represented each policy as described in Maryland's GGRA policy documentation, and an enhanced meta-scenario, which examined more ambitious goals for selected policies characterized in the initial meta-scenario.[16] This scenario modeling framework was not well suited to examine the weight-of-evidence benefits of the GGRA policies in the context of ozone SIP planning. NESCAUM worked closely with MDE staff to construct a new reference case and ozone sensitivity scenarios that were more closely aligned with the aim of demonstrating the weight-of-evidence impacts of the GGRA policies selected for the analysis. Table 3-3 presents how the ozone SIP reference case was constructed and also defines each of the weight-of-evidence ozone SIP sensitivity scenarios.

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[15] Regional Greenhouse Gas Initiative, *The RGGI CO2 Cap,* http://www.rggi.org/design/overview/cap (accessed December 15, 2014).

[16] The policy neutral reference case and the initial and enhanced meta-scenarios were described in earlier sections.

Table 3-3. Ozone SIP Scenario Definitions

Policy	Reference O3 SIP	2 EE/RE alternative strategies (I & E)
Regional Greenhouse Gas Initiative	None	E
MD Renewable Portfolio Standard	I	E
EmPOWER Maryland	None	I & E
Main Street Initiatives	None	I & E
Energy Efficiency for Affordable Housing	None	I & E
MD Clean Cars Program	***I***	***I***
Corporate Average Fuel Economy 2008-2011	***I***	***I***
Fuel Efficiency and Emissions Standards for Medium- and Heavy-Duty Trucks	***I***	***I***
Public Transportation and Intercity Transportation Initiatives	***I***	***I***
Tier 3 Motor Vehicle Emission and Fuel Standards	***I***	***I***
Gas Tax	2014 tax $0.27/gal	2014 tax $0.27/gal
Building and Trade Codes	None	I

Table 3-4 summarizes the NE-MARKAL modeling results for the ozone SIP sensitivity scenarios. Results are focused on changes in NO_X emissions to highlight the ozone impacts of each weight-of-evidence sensitivity defined in Table 3-3.[17] Table 3-4 presents the 3-year annual average change in NO_X emissions for each of the ozone SIP sensitivities. The annual average is centered on the middle year of the three-year intervals projected by NE-MARKAL (i.e., 2017, 2020, 2023).

[17] A full set on NE-MARKAL modeling results for the ozone SIP sensitivity analysis is in the file: *MD MultiP_NE-MARKAL Output Template - O3 Sensitivity (11-5-2014).xls*.

Table 3-4. Annual Average Decrease in NO_X Emissions Relative to Ozone SIP Reference Case Centered on 2017, 2020, and 2023 (thousand tons)

Sector	Initial			Enhanced		
	2017	2020	2023	2017	2020	2023
Electricity	-1.3	-2.5	-2.2	-1.3	-2.5	-2.3
Buildings	0.2	0.2	0.1	-0.2	-0.2	-0.2
Transportation	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Total	-1.2	-2.4	-2.2	-1.6	-2.8	-2.6

The total modeled annual decreases in the initial sensitivity scenario are associated with the enhanced Regional Greenhouse Gas Initiative (RGGI) cap,[18] the enhanced Renewable Portfolio Standard (RPS),[19] and the initial energy efficiency programs. By far, the largest reductions of NO_X emissions occur in the electricity sector and are associated with the state RPS and the enhanced RGGI cap. There is a marginal increase in building sector NO_X emissions driven primarily by a small increase in natural gas consumption, and this increase is offset by a marginal decrease transportation sector NO_X. The initial sensitivity scenario energy efficiency assumptions do not include a natural gas efficiency component; as a result in the later years there is a small electricity price-driven fuel switch away from electricity towards natural gas.

The additional NO_X reductions (about 400 tons annually) in the enhanced sensitivity scenario relative to the initial scenario are associated with modeling the energy efficiency programs with enhanced efficiency potential assumptions. The largest reductions continue to occur in the electricity sector and are associated, as previously noted, with the state RPS and the enhanced RGGI cap.

Climate Sensitivity

This section presents the climate sensitivity analysis. Unlike the ozone SIP sensitivity analysis, which focused on near-term air quality planning concerns, the primary focus of the climate sensitivity analysis is to examine the long-term climate implications of the multi-pollutant planning approach Maryland is using.

The climate sensitivity analysis focused on longer term emissions trends beyond the original GGRA planning exercise, which estimated emissions trends over the 2008-2023 timeframe. In this analysis, emissions trends were estimated out to the year 2050 (based on the 3-year steps of the NE-MARKAL outputs). The goals of the climate sensitivity analysis were to examine both the long-term emissions implications of the original GGRA scenarios and also to assess the climate response to a set of more aggressive renewable energy and energy efficiency scenarios based on the original core GGRA scenarios. In addition to the renewable energy and efficiency sensitivities, the analysis also examined how electricity sector trends in the context of

[18] The AEO 2012 projection used for this analysis does not include the revised RGGI cap for 2020, therefore we include it in the sensitivity scenarios. The U.S. DOE Energy Information Administration is including the revised RGGI cap in AEO 2014.
[19] The initial Maryland RPS is part of the AEO 2012 projection, hence it is included in the reference case rather than the ozone sensitivity scenarios.

these sensitivities would be affected by imposing a carbon price and adjusting downward the investment cost for solar technologies.

The climate sensitivity analysis is based on the NE-MARKAL database and modeling framework developed for both the core GGRA analysis and the ozone SIP sensitivity. For the climate sensitivity, all of the individual GGRA scenarios were extended out to 2050, and then new extended initial and enhanced meta-scenarios were run over the extended timeframe. The climate sensitivities were only layered on top of the extended enhanced meta-scenario – the initial meta-scenario was not the most logical choice as a basis for examining more aggressive renewable and energy efficiency scenarios. The reference case for the climate sensitivities was the same policy neutral scenario used for the original GGRA analysis. Table 3-5 lists and describes each of the scenarios assessed as part of the climate sensitivity analysis. The analysis considered three sensitivities around the RPS, two sensitivities around the EmPOWER Maryland goals and an additional three sensitivities that looked at the combined effects of the RPS and EmPOWER Maryland sensitivities while also examining the role of carbon pricing and alternate solar investment costs.

Table 3-5. Climate Sensitivity Scenario Definitions

Scenario	Description
GGRA Sensitivity Reference Case	Original policy neutral reference case
Enhanced - Meta Scenario	Original definition of enhanced meta-scenario with all policy components extended to 2050
RPS 1	Enhanced + 16.4% RPS by 2050
RPS 2	Enhanced + 50% RPS by 2050
RPS 3	Enhanced + 50% RPS by 2050 + (Alternate Solar Investment Cost)
EmpMD 1	Enhanced + 30% reduction in per-capita electricity consumption by 2050.
EmpMD 2	Enhanced + 30% reduction in per-capita electricity consumption by 2050 + Triple natural gas efficiency potential by 2030 and hold constant out to 2050.
Combined Scen	Enhanced + RPS3 (Alternate Solar Investment Cost) + EmpMD 2
Combined Scen 2	Enhanced + RPS3 (Original Solar Investment Cost) + EmpMD 2 + Carbon Tax
Combined Scen 3	Enhanced + RPS3 (Alternate Solar Investment Cost) + EmpMD 2 + Carbon Tax

The climate sensitivities were primarily focused on adjusting policies and assumptions germane to the electricity sector, as such the results presented below focus on how the sensitivities affected electricity sector outcomes. NESCAUM has provided MDE a full set of climate sensitivity results covering all sectors and pollutants in an Excel workbook.

Figure 3-9 presents the cumulative change in electricity generation for each sensitivity scenario relative to the reference case. The key differences between the scenarios are the total decline in coal generation and the total addition of new renewable generating resources. The stringency of the RPS is the key driver of these differences. The Enhanced, RPS 1, EmPOWER Maryland 1 and EmPOWER Maryland 2 scenarios have similar 2050 RPS targets and thus lead to qualitatively similar levels of renewables and coal retirements. The two EmPOWER Maryland scenarios are focused on energy efficiency and have the effect of decreasing electricity load requirements, which accounts for the overall lower levels of new renewables in these two scenarios. RPS scenarios 2 and 3 and all of the combined scenarios have a renewable target of 50 percent by 2050, and thus lead to similar electricity sector outcomes. The combined scenarios also each include the EmPOWER Maryland efficiency targets and as such are also faced with lower levels of electricity load – again this explains the slightly smaller level of renewable deployment relative to RPS scenarios 2 and 3. Combined scenarios 2 and 3 also each apply a carbon tax in the power sector starting at $20/ton in 2015 and increasing to $200/ton in 2035. In each of these scenarios, coal-fired power plants are entirely phased out by 2029.

Figure 3-9. Cumulative (2008-2050) Change in Electricity Generation Relative to the Reference Case

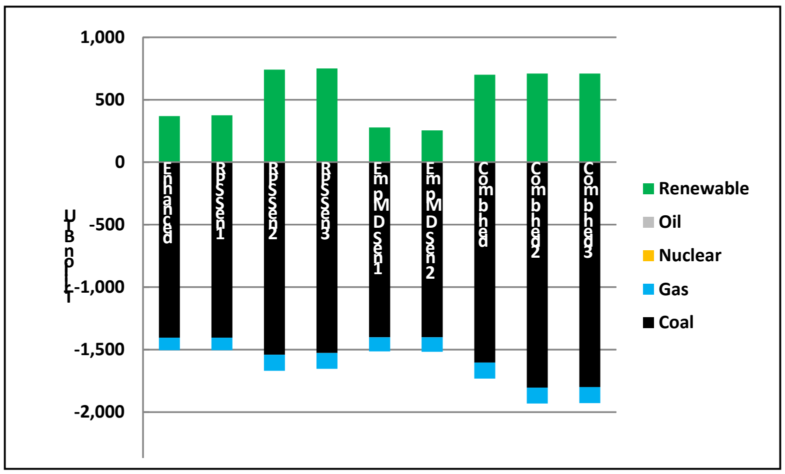


Figure 3-10 presents the cumulative change in renewable electricity generation for each sensitivity scenario relative to the reference case. The key differences between these scenarios are the overall level of renewable energy generation and the share of solar generation relative to wind. The drivers for the overall level of renewable generation are the stringency of the RPS in 2050 and the inclusion of the load mitigating effects of the EmPOWER Maryland efficiency scenarios – these effects were described above. The primary driver of new solar generation relative to wind is the assumption made about the investment cost of new utility scale solar projects. The RPS 3, Combined, and Combined 3 scenarios each assume an alternative lower investment cost for new solar plants. In these scenarios, solar energy displaces some of the market for new wind turbines. The rationale for looking at an alternative solar investment cost was to provide a cost trajectory for solar projects that is more in line with recent historical trends and the future expectations of industry experts.

Figure 3-10. Cumulative (2008-2050) Change in Renewable Electricity Generation Relative to the Reference Case

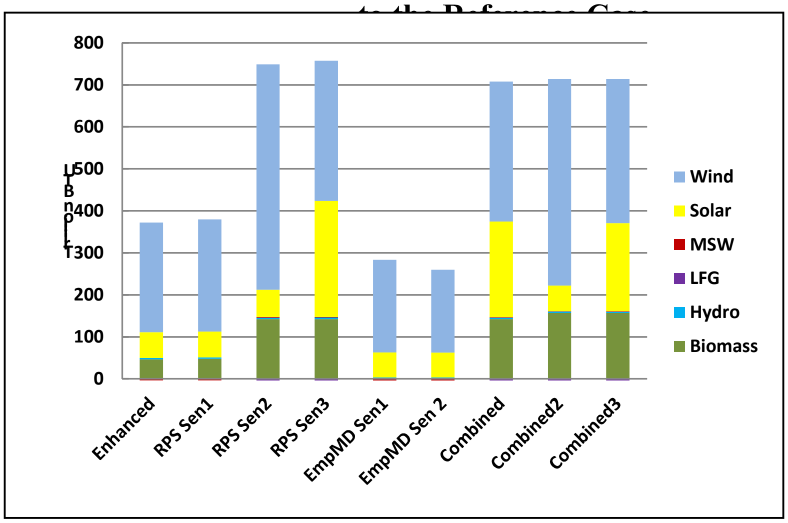
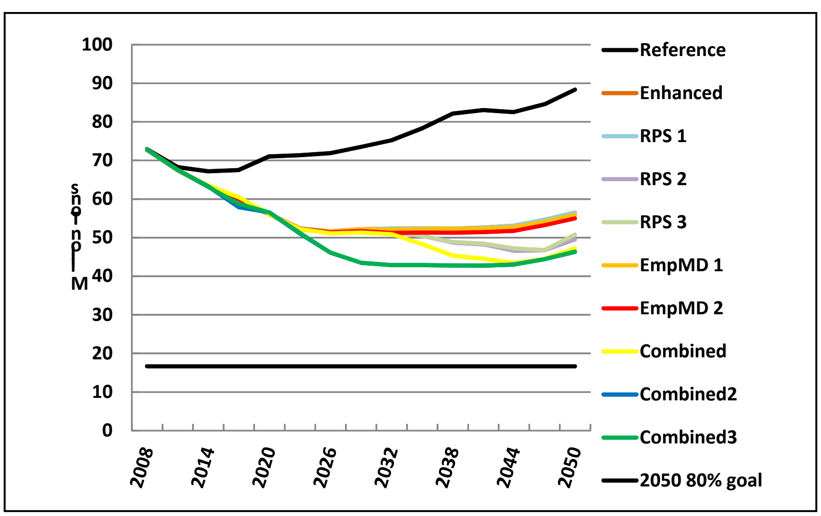


Figure 3-11 presents total carbon dioxide trends across all sectors in Maryland for each of the modeled climate sensitivity scenarios. The chart also includes a reference line that represents a hypothetical Maryland-specific 80 percent CO_2 reduction by 2050 relative to the 2005 Maryland reference case emissions. The greatest modeled CO_2 reductions in 2050 relative to the reference case are realized by adopting the suite of GGRA policies represented by the Combined 3 scenario; these reductions amount to 42 million tons of CO_2. The enhanced meta-scenario reductions alone accounts for 32 million tons of CO_2 in 2050. These reduction outcomes highlight that taken together, the climate sensitivity scenarios will at most achieve a further 10 million tons of CO_2 reductions beyond the enhanced meta-scenario and that even under the most aggressive sensitivity, Combined 3, CO_2 emissions are 30 million tons above the hypothetical 80 percent reduction goal in 2050 previously mentioned. The dominant share of those remaining emissions is from the transportation sector.

Figure 3-11. Total Carbon Dioxide Emissions by Sensitivity Scenario



3.1.7. NE-MARKAL Summary and Conclusions

The 2009 Maryland GGRA calls for a 25 percent reduction in GHGs from 2006 levels by 2020. The multi-pollutant planning exercise demonstrated that the GGRA policies collectively made positive contributions to near-term air quality outcomes, including the 2020 GGRA climate target. Figure 3-12 presents the net CO_2 trends for all sectors and includes a dashed line indicating the 2020 GGRA target. The climate sensitivity analyses indicate that in order to meet a hypothetical 80 percent GHG emissions reduction target by 2050, additional mitigation measures not considered in this analysis would be needed, primarily for the transportation sector.

Figure 3-12. Net Change in Carbon Dioxide, All Sectors

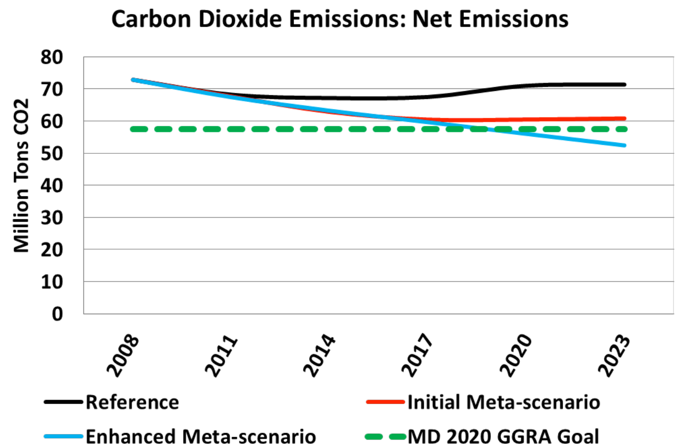


Table 3-6 presents the cumulative 2008-2023 change in air emissions across all sectors for the initial and enhanced meta-scenarios. Over this time period, the initial meta-scenario projected reductions of 63,000 tons of NO_X and 399,000 tons of SO_2 in Maryland. Larger reductions were seen for the enhanced meta-scenario, with 70,000 tons of NO_X and 492,000 tons of SO_2 reduced.

Table 3-6. Net Change in Emissions 2008-2023 (thousand tons), All Sectors

	Initial	Enhanced
NO_x	-63	-70
PM_{25}	-1	-1
SO_2	-399	-492
VOC	-2	-5

3.2. Modeled Air Quality Changes: CMAQ Results

Emissions projections from the NE-MARKAL model were used to develop inventory growth and control factors for air quality modeling simulations carried out with the Community Multi-Scale Air Quality modeling system (CMAQ, v4.7.1) model. CMAQ is a regulatory model used to quantify impacts of emissions reduction strategies on air quality and to create the information needed to run the BenMAP model. This model has been used extensively by states that are members of the Ozone Transport Commission (OTC) as part of state and regional planning efforts. Here, CMAQ simulations are performed at a 12 km × 12 km horizontal resolution and a 34 layer vertical grid from the surface to ~20 km with hourly output. The model domain spans most of the eastern United States, including all of New England and parts of southern Canada (Figure 3-13). Meteorological fields were calculated using the Weather Research Forecasting (WRF v3.1.1) model for year 2007 and processed for use in CMAQ by the Meteorological Chemistry Interface Processor (MCIP).

Figure 3-13. CMAQ Domain Boundary (thick black line)

The emissions used in this study are based off of inventories for year 2007 that were developed by the Mid-Atlantic Regional Air Management Association, Inc. (MARAMA) for use in OTC modeling efforts for SIP development. Since this project began, the OTC modeling participants have begun to use the 2011 model year as a foundation for SIP modeling. However, the final version of the 2011 emissions is still being developed. Emissions from biogenic sources are based on output from the Model of Emissions of Gases and Aerosols in Nature (MEGAN v2.04).[20] Emissions from on-road mobile sources were developed using the Motor Vehicle Emission Simulator (MOVES) while off–road emissions were supplied by the National Mobile Inventory Model (NMIM). Emission inventories and WRF/MCIP meteorology are merged and gridded using the Sparse Operator Kernel Emissions (SMOKE v3.1) model to generate the

[20] Guenther, A. B., Karl, T., Harley, P., Wiedinmyer, C., Palmer, P. I., and Geron, C.: Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature), Atmos. Chem. Phys., 6, 3181–3210, doi:10.5194/acp-6-3181-2006, 2006.

CMAQ ready emission fields. CMAQv4.7.1 uses the 2005 Carbon Bond (CB05) chemical mechanism.[21]

Recent studies have shed light on possible improvements to the standard CMAQ framework. A comparison of NO_X ($NO_X = NO + NO_2$) from emission inventories for 2011 to measurements taken during the NASA DISCOVER-AQ field mission highlights a potential overestimation of mobile NO_X.[22] The ratio of CO/NO_Y from observations was roughly a factor of two greater than the ratio based on the National Emissions Inventory data used in CMAQ. Model carbon monoxide (CO) is only ~15 percent greater than observed for this time period, indicative of a large overestimate of mobile NO_X emissions.[22]

Observations of tropospheric column NO_2 from the Ozone Monitoring Instrument (OMI) show that CMAQ overestimates urban NO_2 and underestimates rural NO_2 in the U.S. Northeast. The CB05 chemical mechanism represents all organic nitrate species, such as alkyl nitrates, as a single species called NTR.[21] In CB05, NTR is created by the breakdown of isoprene and isoprene products and is lost through photolytic and oxidation processes. The photolysis of NTR is based on isopropyl nitrate and produces NO_2 and HO_2, important precursors to surface O_3 formation.[23] Analysis of aircraft observations, however, indicates the speciation of NTR is not well described in CMAQ using CB05, with the most abundant species in this family being hydroxynitrates with lifetimes on order ~1 day or less.[24,25,26] With a lifetime of 10 days, NTR is a long term reservoir of NO_2 and CMAQ under-estimates both ozone production and the regional nature of ozone.[27]

Finally, recent updates to biogenic emissions models such as MEGAN and Biogenic Emission Inventory System (BEIS) lead to better representation of ozone precursors such as isoprene, the most reactive volatile organic compound in the mid-Atlantic region. The version of MEGAN used for this study is biased high based on comparison with aircraft observations of isoprene and comparison to tropospheric column formaldehyde (HCHO), a product of isoprene

[21] Yarwood, G., S. Rao, M. Yocke, and G. Z. Whitten, Updates to the Carbon Bond Chemical Mechanism: CB05, ENVIRON International Corp, 2005.
[22] Anderson, D.C., Loughner, C.P., Weinheimer, A., Diskin, D., Canty, T.P., Salawitch, R.J., Worden, H., Freid, A., Mikoviny, T., Wisthaler, A., and Dickerson, R.R.: Measured and modeled CO and NOy in DISCOVER-AQ: An evaluation of emissions and chemistry over the eastern US, Atmos. Environ., 96, 78–87, 2014.
[23] Yu, S. C., Mathur, R. Pleim, J., Pouliot, G., Wong, D., Eder, B., Schere, K., Gilliam, R., and Rao, S.T.,: Comparative evaluation of the impact of WRF-NMM and WRF-ARW meteorology on CMAQ simulations for O3 and related species during the 2006 TexAQS/GoMACCS campaign, Atmos. Poll. Res., 3(2), 149–162, doi:10.5094/APR.2012.015, 2012.
[24] Horowitz, L. W., Fiore, A. M., Milly, G. P., Cohen, R. C., Perring, A., Wooldridge, P. J., Hess, P. G., Emmons, L. K., and Lamarque, J.: Observational constraints on the chemistry of isoprene nitrates over the eastern United States, J. Geophys. Res., 112(12), D12S08, doi:10.1029/2006JD007747, 2007.
[25] Perring, A. E., Bertram, T. H., Wooldridge, P. J., Fried, A., Heikes, B. G., Dibb, J., Crounse, J. D., Wennberg, P. O., Blake, N. J., Blake, D. R., Brune, W. H., Singh, H. B., and Cohen, R. C.: Airborne observations of total RONO2: new constraints on the yield and lifetime of isoprene nitrates, Atmos. Chem. Phys., 9, 1451-1463, doi:10.5194/acp-9-1451-2009, 2009.
[26] Beaver, M.R., St. Clair, J.M., Paulot, E., Spencer, K.M., Crounse, J.M., LaFranchi, B.W., Min, K.E., Pusede, S.E., Woolridge, P.J., Cohen, R.C., Wennberg, P.O.: Importance of biogenic precursors to the budget of organic nitrates: observations of multifunctional organic nitrates by CIMS and TD-LIF during BEARPEX 2009, Atmos. Chem. Phys., 12(13), 5773-5785, 2012.
[27] Canty, T.P., Hembeck, L., Vinciguerra, T.P., Anderson, D.C., Goldberg, D.L., Carpenter, S.F., Allen, D.J., Loughner, C.P., Salawitch, R.J., and Dickerson, R.R.: Ozone and NOx chemistry in the eastern US: Evaluation of CMAQ/CB05 with satellite (OMI) data, Atmos. Chem. Phys. Dis., 2014.

oxidation. Improvements to isoprene emissions would lead to an overall decrease in ozone due to a decrease in the HO_2 and RO_2 ozone precursors.

In total, these issues highlight that the "off the shelf" version of CMAQ does not properly represent the regional nature of pollution episodes and the modeling scenarios presented in this study may underestimate improvement in downwind states.

Emissions for the year 2020 were created for the three different emissions scenarios defined through the NE-MARKAL analysis: reference case, initial meta-scenario, and enhanced meta-scenario. Emissions of NO_X, VOC, CO, SO_2, and $PM_{2.5}$ were projected using MARAMA's 2007 Level 3 emissions platform. The NE-MARKAL runs provided reduction values for the six New England states, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Washington, D.C. for each of the three scenarios. Compared to the reference case, the initial meta-scenario reduced area, point, and EGU emissions in Maryland as well as mobile emissions in the NE-MARKAL region. These reductions were further decreased for the enhanced meta-scenario, and EGU emissions from the other NE-MARKAL states were also decreased. For the rest of the modeling domain, 2018 emission projections were used. The tabulated state and outside region emissions changes for each of the three scenarios are given in Appendix C.

Full year CMAQ simulations were performed for each meta-scenario. Average maximum 8-hour ozone was calculated for the ozone season (April-October). Differences between the reference case and the two meta-scenarios are shown in Figure 3-14. Reductions in ozone precursors and particulate matter lead to modest changes in ozone, with the maximum benefit predicted by the enhanced meta-scenario of over 0.8 ppb centered on Maryland with further benefit in southeastern Pennsylvania, New Jersey, New York City, and Connecticut. A closer look at the Maryland region (Figure 3-15) shows widespread benefit over most of the State.

Figure 3-14. Difference between Average Maximum Daily 8-hour Average Ozone Calculated for the Initial and Enhanced Meta-scenarios and Reference Case

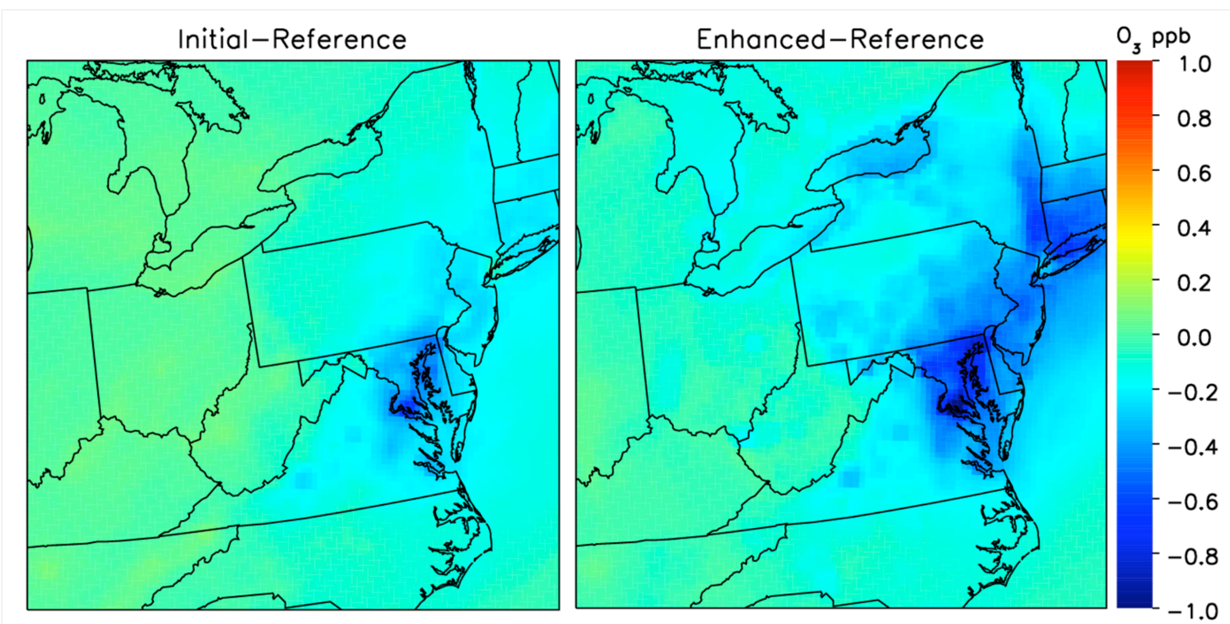
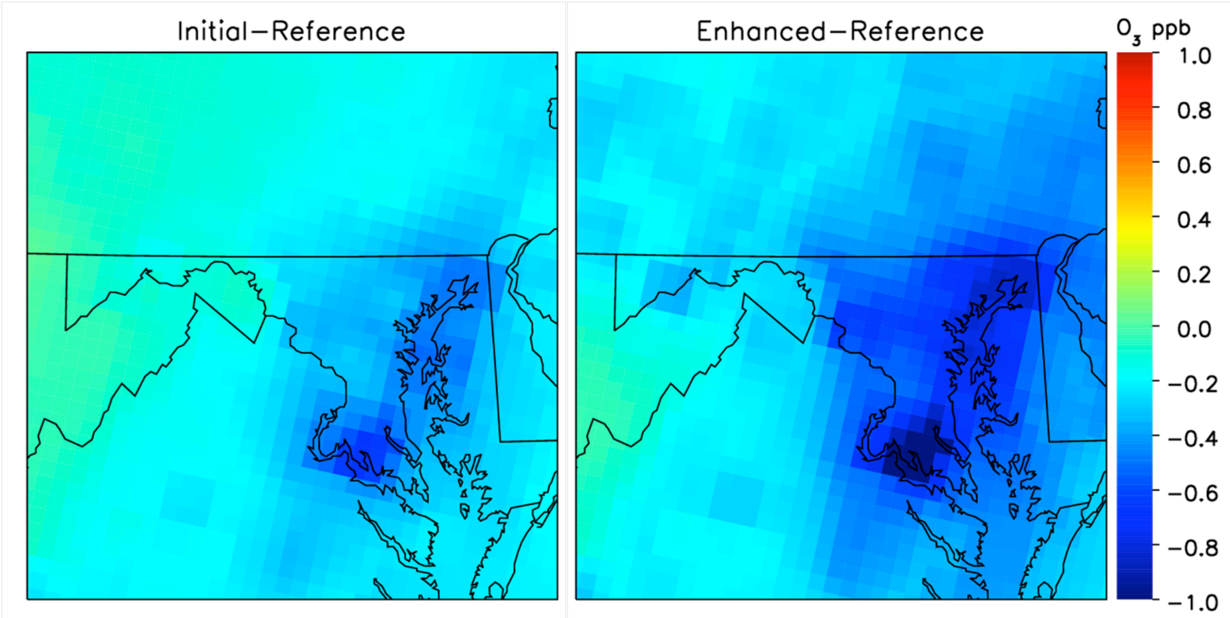


Figure 3-15. Difference between Average Maximum Daily 8-hour Average Ozone Calculated for the Initial and Enhanced Meta-scenarios and Reference Case for Maryland



The greatest reductions in particulate matter are centered in Maryland (Figure 3-16). The largest decreases in Maryland are found near Baltimore/Edgewood and in the vicinity of power plants within the State (Figure 3-17).

Figure 3-16. Difference between Average 24-hour Mean $PM_{2.5}$ Calculated for the Initial and Enhanced Meta-scenarios and Reference Case

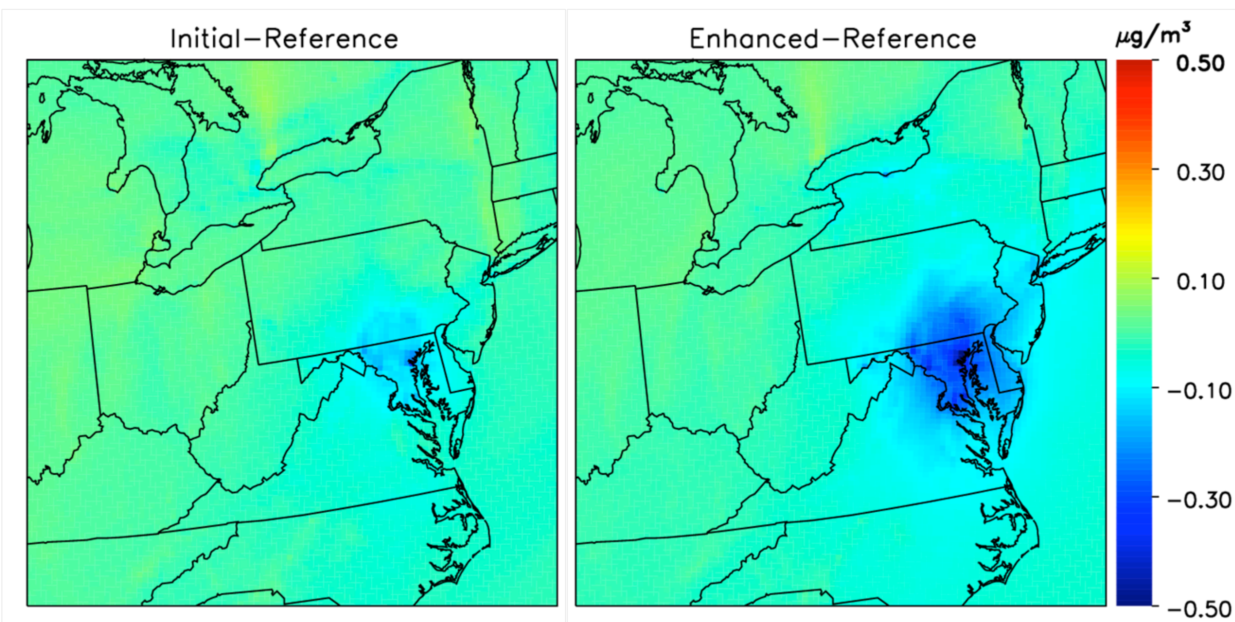
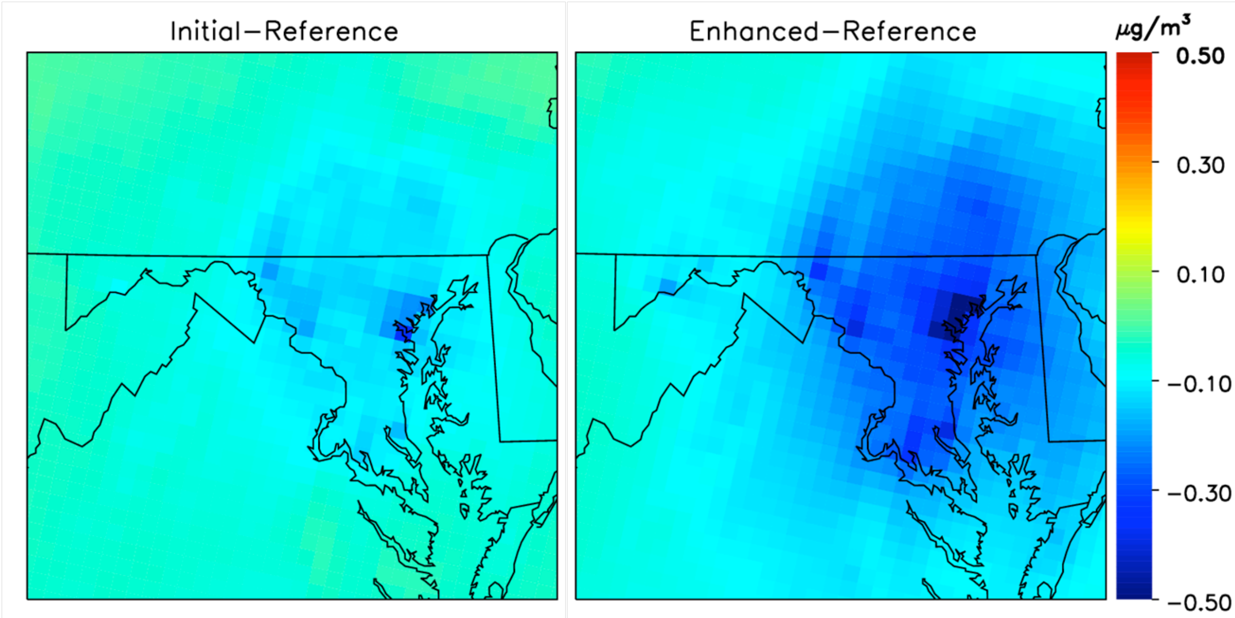


Figure 3-17. Difference between Average 24-hour Mean $PM_{2.5}$ Calculated for the Initial and Enhanced Meta-scenarios and Reference Case for Maryland



Decreases in SO_2 emissions are primarily seen around coal burning power plants in New York State, specifically the Kodak Park Plant near Rochester, and in Maryland in the enhanced meta-scenario (Figure 3-18). In Maryland, these decreases are most noticeable around city centers and power plants, such as those in western (Dickerson) and southern (Chalk Point) Maryland (Figure 3-19).

Figure 3-18. Difference between Average 1-hour Mean SO_2 Calculated for the Initial and Enhanced Meta-scenarios and Reference Case

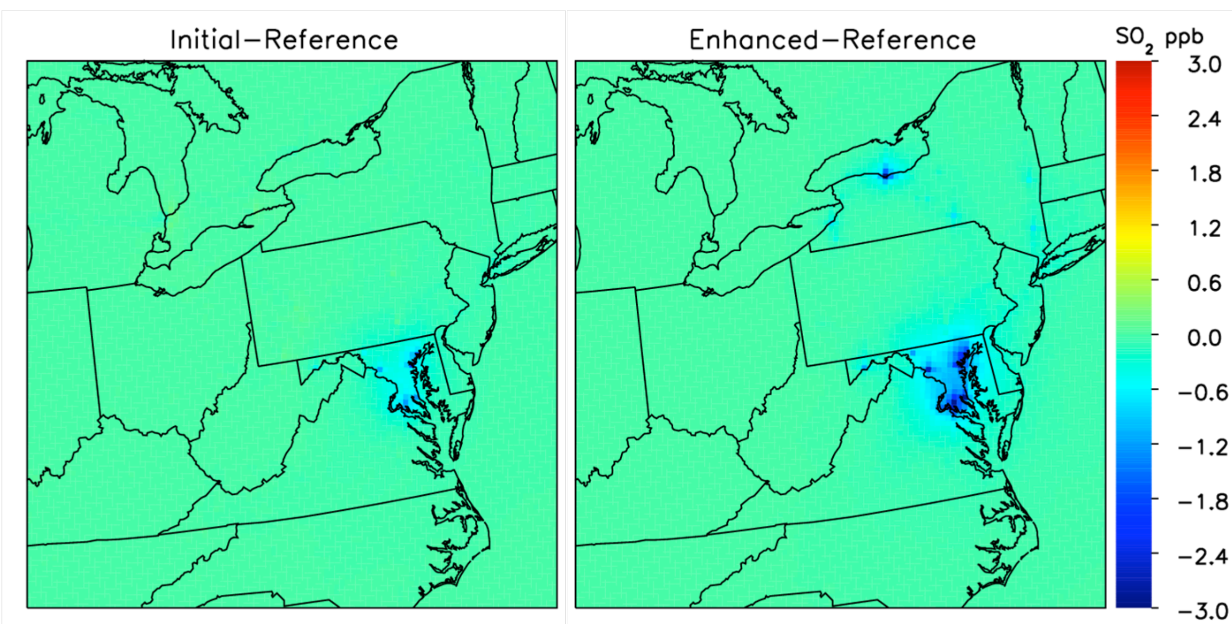
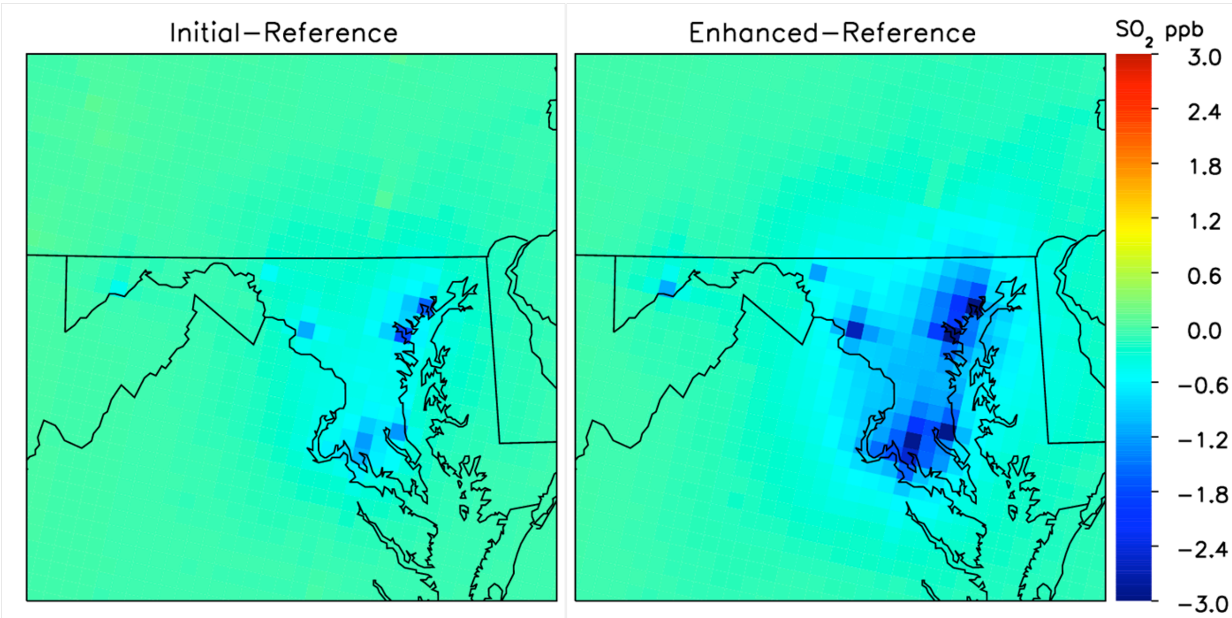


Figure 3-19. Difference between Average 1-hour Mean SO_2 Calculated for the Initial and Enhanced Meta-scenarios and Reference Case in Maryland



3.3. Modeled Health Benefits Assessment: BenMAP Results

The changes in ambient air quality values projected for the two meta-scenarios by the CMAQ model were used as inputs in the BenMAP model to estimate specific increases and decreases in incidences of air quality-related health effects. The BenMAP model was developed to assess the average benefits to a population from changes in ozone and $PM_{2.5}$ ambient air pollution levels. It provides quantitative and monetized estimates of the public health benefits of the GGRA programs that were simulated in NE-MARKAL and modeled in CMAQ. The changes in ambient air quality values projected for the initial and enhanced meta-scenarios by the CMAQ model were used as inputs in the BenMAP model to estimate specific increases and decreases in incidences of health effects. The same technology shifts that led to reductions in GHGs also reduced ozone and $PM_{2.5}$ over much of the Ozone Transport Region (OTR). The model indicated that there will be substantial public health benefits in Maryland and throughout the region due to the reduced incidence of adverse health impacts associated with ozone and $PM_{2.5}$.

Table 3-7 presents summary monetized results of the modeled health effects of implementing the initial meta-scenario in 2020 for $PM_{2.5}$ and ozone; Table 3-8 presents the analogous results for the enhanced meta-scenario. We present a range of monetary valuation results for premature mortality and various morbidity health endpoints. We present results using 3 percent and 7 percent discount rates for estimating future year health effects. Morbidity health endpoints are presented together rather than expressed individually. See Appendix D for more detailed information on the incidence and valuation methodology and results, including the 95th percentile confidence interval around a central point estimate. Monetary results are presented in millions of dollars.

Table 3-7. Summary Health Impact and Valuation Changes in 2020 from Reference Case to Initial Meta-scenario, Combined Ozone and $PM_{2.5}$ Results

Monetized total benefits (millions of 2010$)	*Maryland*	*OTR (excluding Maryland and Virginia)*	*Beyond OTR*	*Total*
Krewski et al. (2009) PM mortality and Bell et al. (2004) ozone mortality				
3% discount rate	$418	$2,080	$871	$2,951
7% discount rate	$321	$1,647	$674	$2,321
Lepeule et al. (2012) PM mortality and Levy et al. (2005) ozone mortality				
3% discount rate	$851	$4,382	$1,834	$6,216
7% discount rate	$742	$3,827	$1,613	$5,440
Total morbidity health effects (lower end estimate)				
3% discount rate	$6	$32	$15	$48
7% discount rate	$6	$32	$15	$47
Total morbidity health effects (upper end estimate)				
3% discount rate	$10	$53	$24	$77
7% discount rate	$10	$53	$24	$76

Notes: Values represent the central "point" estimate of health benefits (i.e., value saved from reduced incidence) attributable to the meta-scenario.

Table 3-8. Summary Health Impact and Valuation Changes in 2020 from Reference Case to Enhanced Meta-scenario, Combined Ozone and $PM_{2.5}$ Results

Monetized total benefits (millions of 2010$)	*Maryland*	*OTR (excluding Maryland and Virginia)*	*Beyond OTR*	*Total*
Krewski et al. (2009) PM mortality and Huang et al. (2005) ozone mortality				
3% discount rate	$811	$4,107	$1,214	$5,320
7% discount rate	$622	$3,217	$939	$4,156
Lepeule et al. (2012) PM mortality and Levy et al. (2005) ozone mortality				
3% discount rate	$1,631	$8,401	$2,492	$10,893
7% discount rate	$1,419	$7,275	$2,185	$9,459
Total morbidity health effects (lower end estimate)				
3% discount rate	$13	$57	$21	$78
7% discount rate	$12	$57	$21	$78
Total morbidity health effects (upper end estimate)				
3% discount rate	$20	$97	$30	$127
7% discount rate	$20	$96	$29	$125

Notes: Values represent the central "point" estimate of health benefits (i.e., value saved from reduced incidence) attributable to the meta-scenario.

Figure 3-20 and Figure 3-21 show the modeled distribution of upper-end estimates of changes in premature mortality incidence for Maryland and surrounding areas for $PM_{2.5}$ and ozone, respectively, for the initial meta-scenario. Figure 3-22 and Figure 3-23 show the analogous results for the enhanced meta-scenario. The incidence of adverse health effects (e.g., school loss days and other estimates of premature mortality) is expected to scale similarly with population levels for each grid cell, thus the resulting health benefits tend to accrue in the major population centers within the region of improved air quality (e.g., D.C., Baltimore, Philadelphia).

The CMAQ model predicts slightly higher ozone concentrations in New York City (and the immediate surrounding area) likely due to local NO_X scavenging of ozone in the model results. The atmospheric formation of ozone has a non-linear relationship with NO_X levels. Areas of high NO_X concentrations relative to VOCs, such as some urban cores, can suppress ozone levels because NO_X chemistry under these conditions tends to destroy (“scavenge”) ozone. The modeled ozone levels in these locations may increase incrementally as NO_X emissions decrease because NO_X scavenging decreases with decreasing NO_X emissions. Downwind from major emission centers, NO_X levels become lower relative to VOCs as the pollution plume ages, and the overall effect of NO_X on ozone formation switches from destruction to formation. As a result, the same decline in NO_X emissions leading to increased ozone nearby results in lower ozone in areas farther away, and these downwind areas typically experience the highest regional ozone concentrations. The aggregate magnitude of the health effects associated with the lower downwind ozone concentrations is greater than the adverse effect associated with reduced NO_X scavenging in urban cores like New York City.

The magnitude of the NO_X scavenging effect is also far lower than the health benefits arising from related $PM_{2.5}$ reductions. For ozone, the health effects are greater in the suburbs surrounding the cities, while for $PM_{2.5}$ the effects are highest in the city cores. The overall result of this analysis is that the major population areas within Maryland and in the OTR will experience substantial health benefits, while less populated areas see lower (but still substantial) decreases in health incidence.

Figure 3-20. Distribution of Upper End (Levy *et al.* 2005) Estimate of Premature Mortality in Maryland from Changes in Ozone Concentrations from Reference Case to Initial Meta-scenario

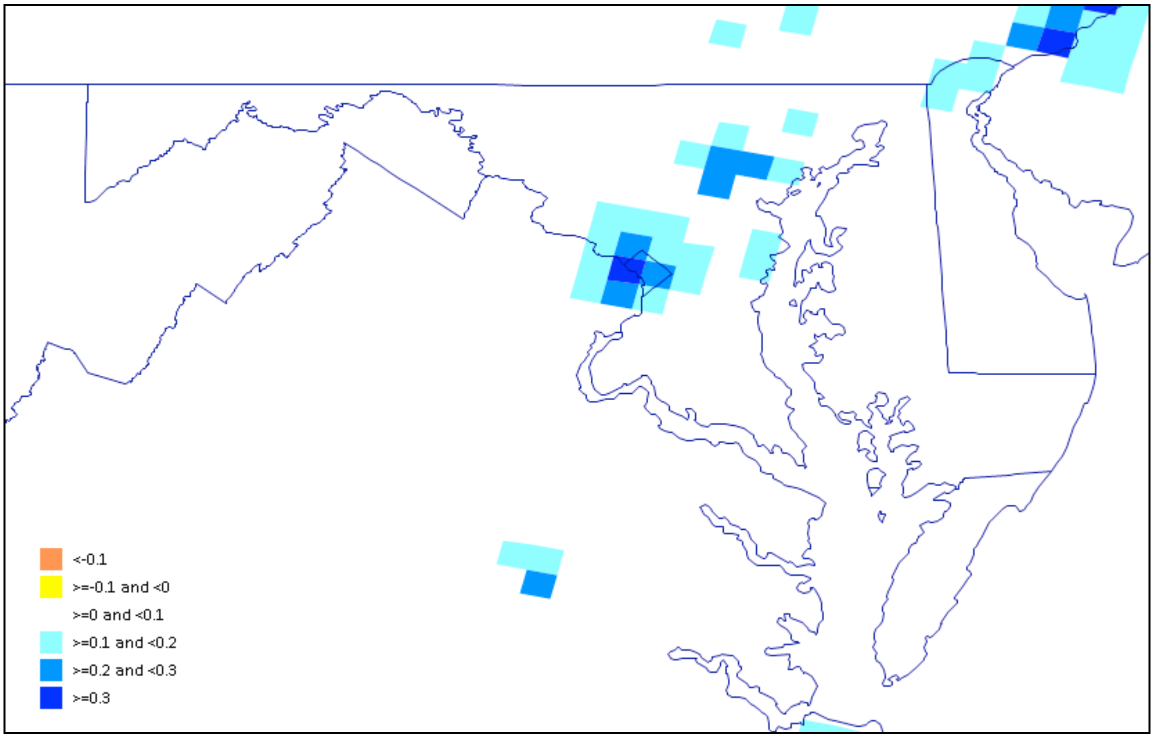


Figure 3-21. Distribution of Upper End (Lepeule *et al.* 2012) Estimate of Premature Mortality in Maryland from Changes in $PM_{2.5}$ Concentrations from Reference Case to Initial Meta-scenario

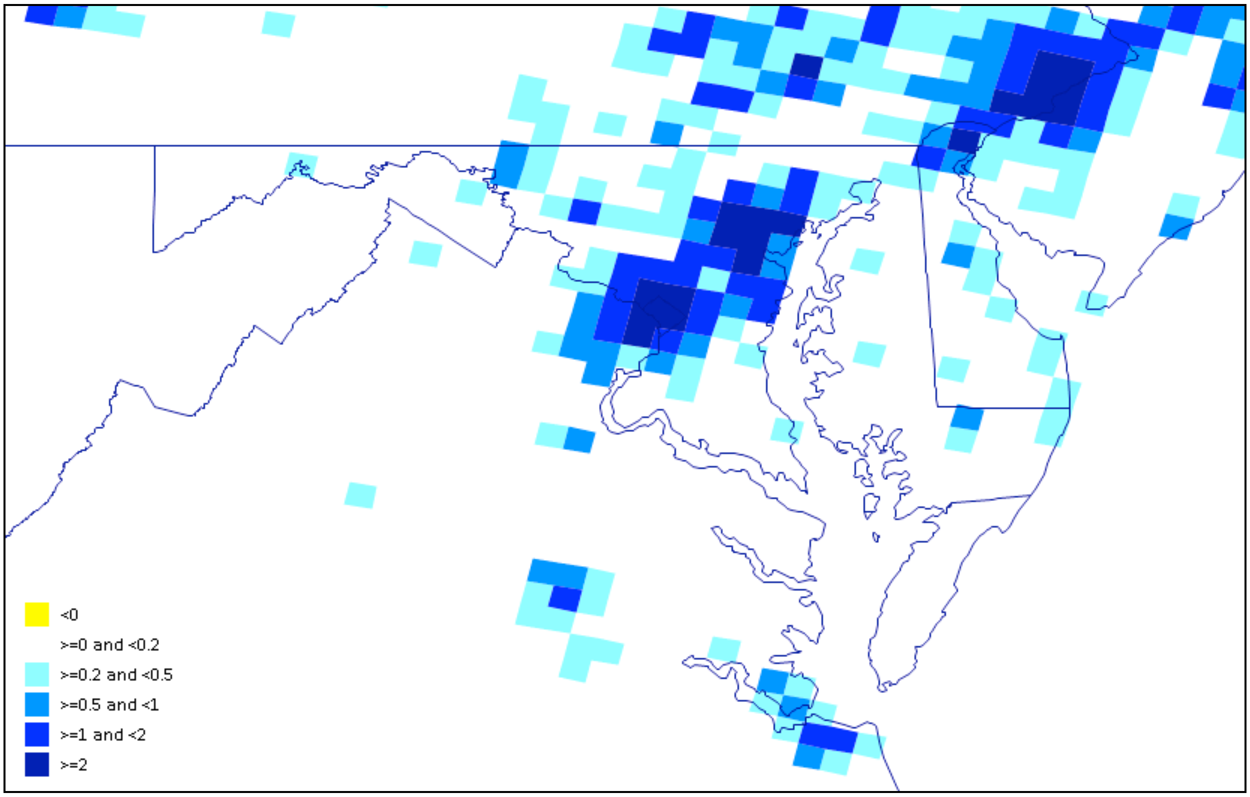


Figure 3-22. Distribution of Upper End (Levy *et al.* 2005) Estimate of Premature Mortality in Maryland from Changes in Ozone Concentrations from Reference Case to Enhanced Meta-scenario

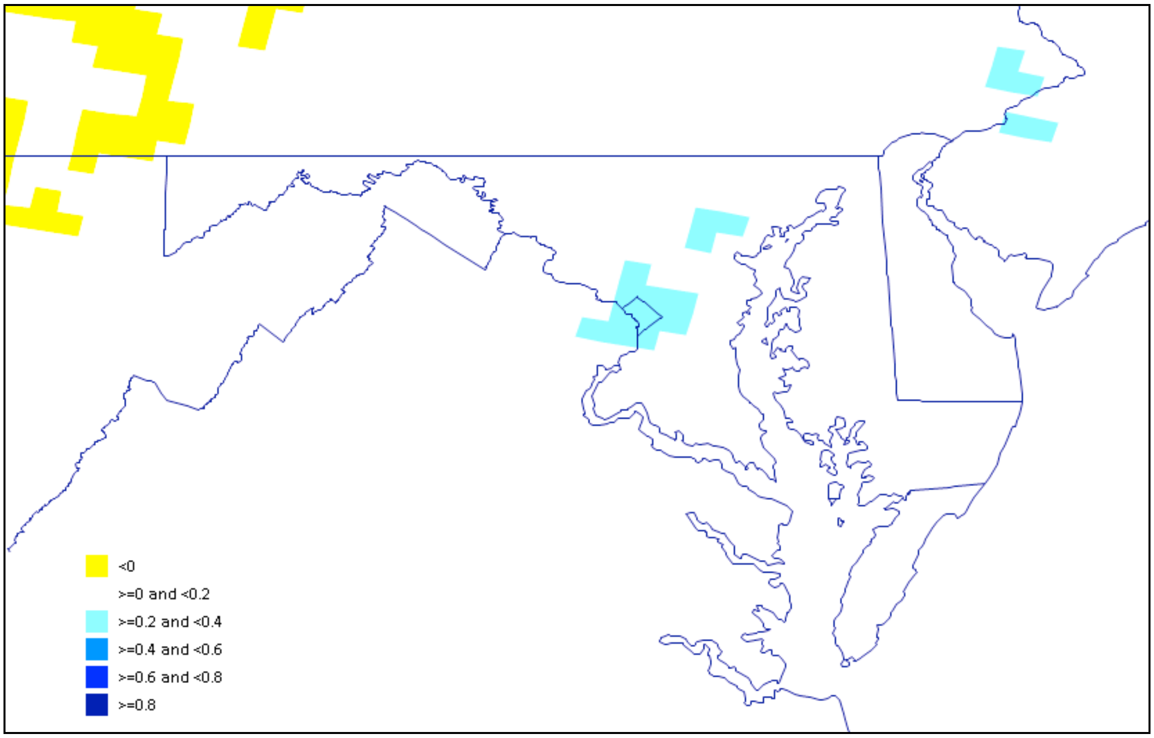
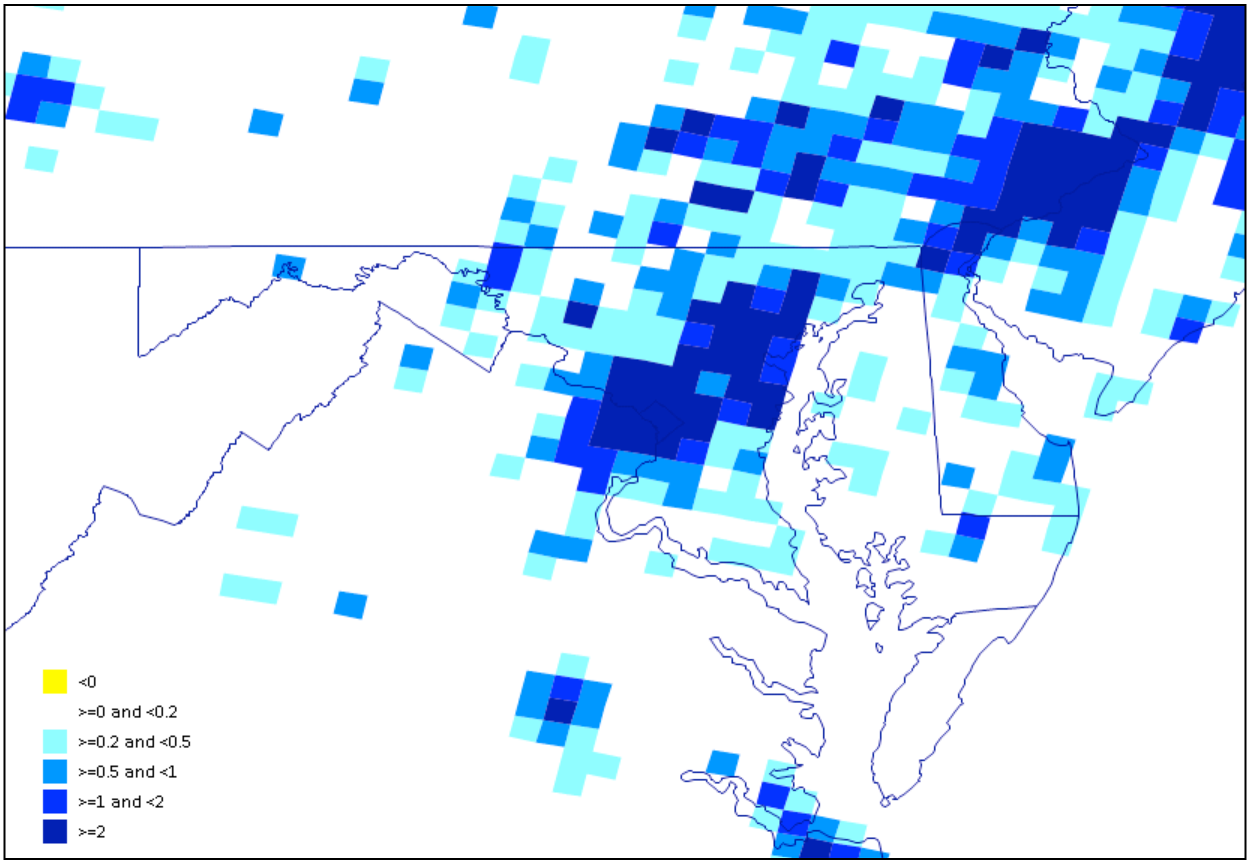


Figure 3-23. Distribution of Upper End (Lepeule *et al.* 2012) Estimate of Premature Mortality in Maryland from Changes in $PM_{2.5}$ Concentrations from Reference Case to Enhanced Meta-scenario



The net result of these modeled public health benefits include many reduced incidences of respiratory ailment, asthma attack, heart attack, hospital room visits, and lost work and school days. The monetary benefits of these public health improvements are driven largely by the reduced mortality, which includes (within Maryland) 43 to 100 avoided deaths per year due to reduced ozone and $PM_{2.5}$ under the initial meta-scenario, and 84 to 192 avoided deaths per year under the enhanced meta-scenario.

The monetized value of avoided mortality within Maryland ranges between $420 million to $850 million per year under the initial meta-scenario, and between $810 million to $1.6 billion per year under the enhanced meta-scenario, assuming a 3 percent discount rate for future health effects. With a 7 percent discount rate, the value is $320 million to $740 million per year under the initial meta-scenario, and $620 million to $1.4 billion under the enhanced meta-scenario. Substantial additional public health benefits are expected across the OTR and beyond. Appendix D presents additional detail on the BenMAP results.

3.4. Modeled Economic Assessment: REMI Results

3.4.1. Introduction

In this section, the Regional Economic Studies Institute (RESI) of Towson University describes the results of a regional economic assessment of the GGRA meta-scenarios using the Regional Economic Models, Inc. (REMI) PI+ model. The REMI PI+ model is a dynamic economic modeling framework based on general equilibrium theory. It is a peer-reviewed model for evaluating the effects of policy initiatives and similar changes on the economies of local regions. The model incorporates Bureau of Economic Analysis economic impact multipliers specific to Maryland. One area of focus with the REMI PI+ model is to discern trends in the energy, industrial, and commercial sectors' activity levels and employment in Maryland under the meta-scenarios. The REMI PI+ analysis examined the broader economic impacts, such as employment changes and gross state product impacts, of implementing Maryland's climate strategies.

RESI linked REMI PI+ to the NE-MARKAL results to generate estimates of economic impacts to Maryland associated with the various climate and air quality programs incorporated in the meta-scenarios. To calculate the potential economic benefits of the meta-scenarios, RESI used the REMI PI+ 1.6 version to provide an annual impact analysis associated with the NE-MARKAL results. RESI built a sophisticated model that is calibrated to the specific relationships between industrial sectors within the Maryland economy. The REMI PI+ model features the ability to capture price effects, wage changes, and behavioral effects through time. RESI set up the modeling inputs to ensure that no double-counting of costs and benefits occurred in the REMI PI+ model. The model has some unavoidable limitations, such as its use of Bureau of Economic Analysis data from 2012. Given these limitations, benefits in industries for future years may not be as significant as those for 2012 or may be slightly overstated.

This section presents REMI PI+ results for 2020 and 2050. The analysis uses 2020 as the year by which the measures are expected to be implemented. The full measure of their costs and benefits, however, will accrue over a longer period. Therefore, to provide more comprehensive long-term economic impacts in Maryland, RESI also provides REMI PI+ economic impacts in 2050 in this section.

3.4.2. Modeling Approach

To analyze the economic benefits of the GGRA meta-scenarios to Maryland, RESI first identified the industries that were most likely to be impacted. For most policies, RESI used cost data in terms of the outlay of funding necessary to achieve the results for a given policy that Maryland state agencies provided. RESI used NE-MARKAL results for fuel reductions in conjunction with their corresponding policies to gauge the changes in economic impacts. The only exception where RESI did not use data from Maryland agencies was Building and Trade Codes. Instead, RESI used technology costs from the NE-MARKAL model to estimate results. Analysis and data assumptions were carefully guided through discussions between NESCAUM, MDE, and RESI staff.

In addition to considering the potential costs and benefits associated with investments in new technology, the model also considered health benefits as a factor. Referencing the CMAQ air quality modeling results, RESI reviewed the potential increase in wages from employees who may have otherwise missed work for sick leave as well as the benefits of a potential decrease in the mortality rate associated with a decrease in air pollution exposure. Both prospects allow for Maryland's workforce to be healthier and often contribute to lower labor costs for employers through improved worker productivity over time.

RESI approached each policy with two key questions:

1. Who (industry-specific, commercial overall, or households) would benefit from this policy's indicated savings?
2. Who (private industry, government, or households) would be responsible for the costs of implementation?

To answer the first question, RESI discussed the NE-MARKAL results with NESCAUM to determine the potential benefits. Policies such as RGGI, EmPOWER Maryland, RPS, and Offshore Wind will likely bring benefits largely to the electrical distribution, generation, and transmission sectors.[28] Policies such as RGGI have a dual effect—electricity generators operating in the region incur costs, but the collected funds are used to promote energy efficiency initiatives such as EmPOWER. RESI determined that the largest benefits to Maryland came in the form of reduced energy consumption under programs (such as EmPOWER) that seek to minimize consumers' energy consumption. Consumers may include businesses or private households since EmPOWER includes business grants to help reduce regional businesses' energy use. Benefits to Maryland from Offshore Wind mostly come in the form of potential jobs associated with the maintenance of the wind turbines and transformers.

RESI determined all other policies' effects on consumer spending with respect to the policies' ultimate goal. For example, policies such as new transit projects seek to reduce household consumption of motor fuels; therefore, RESI considered this impact as a reduction to consumer spending for motor fuels. Although the gas tax is considered as a separate policy in the NE-MARKAL analysis, RESI included it within the transportation modeling as a method of funding for state transit programs. For more information regarding this assumption, please refer to Section 3.0 below.

The second question of who bears the implementation costs was more challenging to answer. Policies such as RGGI create a sharing of costs between the energy sectors (to purchase credits) and the government (to manage auctions). Overall, the costs are placed on the private sector, with Maryland investing RGGI auction proceeds back into the economy to fund programs aimed at increasing energy efficiency.[29] Funds collected by the private industry through RGGI auctions are used to incentivize private households and businesses to invest in energy reduction initiatives, such as weatherization or new

[28] Offshore wind is included in Maryland's Renewable Energy Portfolio Standard (RPS). Under the economic analysis, the initiative has been analyzed separately from the RPS, and, to avoid double-counting wind, was not considered in the analysis for RPS.
[29] "Private sector" refers to the business community not affiliated with government.

energy star appliances. RESI captured this reallocation of funding into the program to minimize consumer's costs in this analysis.

In other cases, such as EmPOWER Maryland, the private energy sector bears a share of the costs to provide incentives for energy efficiency measures. Households and commercial sectors seeking to implement these investments for future returns then take on further investment.

Table 3-9 describes a list of those policies that RESI determined would lead to benefits and costs by sector.

Table 3-9. Benefits and Costs Assignment by Policy for GGRA

Policy	Who takes on the cost?	Who would benefit?
RGGI	Producers of electric transmission, distribution, and generation	Producers of electric transmission, distribution, and generation; and, Households (through government investment)
RPS	Producers of electric transmission, distribution, and generation	Producers of electric transmission, distribution, and generation
EmPOWER MD	Producers of electric transmission, distribution, and generation; Households; and, commercial industries	Households and commercial industries
Main Street	Households and commercial industries	Households and commercial entities
EE Affordable	Household and commercial industries	Households and commercial industries
Public Transportation Projects	Government	Households
Building and Trade Codes	Households and commercial industries	Households and commercial industries

Source: RESI

RESI includes two different meta-scenarios associated with the GGRA:

1. The initial meta-scenario assessed the GGRA in Maryland's economy between 2010 and 2050. The reported totals are the additional benefits (costs) associated with implementation of the GGRA measures in the initial meta-scenario between 2010 and 2050.
2. The enhanced meta-scenario incorporated the policies under their enhanced greenhouse gas reduction criteria. Under this scenario, the policies would continue through 2050, but the reduction in GHG would be higher than under the initial meta-scenario.

3.4.3. Caveats to the Analysis

RESI determined the required investment and ongoing costs for the GGRA measures using Maryland-provided data and the NE-MARKAL results. The respective Maryland agencies' cost estimates may vary from the NE-MARKAL model's cost estimates. In some cases, agencies' cost estimates may be more reflective of the current costs incurred to complete tasks under a GGRA initiative, and costs may be over- or understated in the NE-MARKAL model as the NE-MARKAL does not take into account certain areas of specific contract costs.

Programs such as EmPOWER Maryland seek to reduce consumption of energy within Maryland. However, this aim may alter the number of renewable energy credits needed to meet the guidelines of the RPS. RPS could increase some costs in the energy sector by increasing the number of renewable energy credits (RECs). To mitigate for this potential effect, RESI created a "shadow price" based on the current value of renewable energy credits and Maryland's level of imported energy to date. This shadow price is captured as an indirect cost that is not necessarily borne from the direct generation of power but rather the indirect costs associated with compliance under RPS. These costs may be over- or understated depending on the inflation and actual purchases of renewable energy credits between 2010 and 2050. The level of energy consumption reduced through programs such as EmPOWER Maryland may also cause this indirect cost to be over- or understated within the model. For example, if the generated power needed in Maryland is less than that for the previous year, the percentage to meet the RPS of renewable energy would be less. This lower amount would then potentially lower the necessary RECs needed to meet the RPS goal.

NE-MARKAL analyzed Maryland's gas tax and its air quality benefits for the State of Maryland. Under RESI's analysis, the gas tax is a driver for providing funding to public transit programs. Therefore, the transfer of dollars spent on motor fuels by households affected by the tax to the government is balanced and offsets the State's total additional costs for transit programs. Given these assumptions, RESI could potentially double-count the jobs, output, and wages associated with the gas tax and overstate impacts associated with increased public transit programs if the tax were analyzed separately. Therefore, RESI included the gas tax as a cost to households and captured the transfer of funds through the state government into road construction programs under the "Public Transit Programs."

RESI highly encourages additional analysis of State-proposed programs and NE-MARKAL modeling results to better gauge the potential future economic impacts of the GGRA measures. Alternative methods for achieving the GGRA reductions may need to be considered to help decrease the costs associated with implementing the GGRA.

3.4.4. Results

Initial Meta-scenario

RESI's initial meta-scenario analysis reviews the GGRA measures and benefits or costs that may be associated with them. Figures 2 through 6 show the annual distribution between 2010 and 2050 for the GGRA measures as a whole in employment, wages, output, value added, and real disposable income. The key concept captured in Figures 2 through 6 is how economic stimulus is generated throughout the economy.

Each figure reports the direct, spinoff, and total impacts. A direct impact is an impact directly related to the operations of an industry. For example, if a construction firms hires 100 site workers to resurface a road, then there would be 100 new direct jobs. If this construction project requires the firm to purchase materials such as concrete, and the supplier hires 10 new delivery drivers to meet the increased product demand, then these 10 jobs are indirect jobs. Finally, as these 100 new direct employees and 10 new indirect employees have increased income as a result of this construction project, those employees may go out to eat more often. A local restaurant may need to increase staff by 5 employees to meet the new demand from the increased lunchtime crowds. This increase in the number of restaurant employees would be induced jobs. Therefore, the project would generate 100 new direct jobs, 10 new indirect jobs, and 5 new induced jobs for a total of 115 new jobs in the economy. It should be noted, however, that REMI PI+ does not differentiate between indirect and induced jobs. RESI reports these jobs as a combined “spinoff” effect in Table 3-10 through Table 3-14.

RESI evaluated the benefits and costs of the measures from implementation to 2020. However, the full impact of a program’s costs and benefits may accrue over a longer period. Therefore, to provide more comprehensive long-term economic impacts in Maryland, RESI extended the REMI PI+ analysis to 2050.

Table 3-10. Employment Benefits (Costs) for GGRA Initial Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	1,020.4	574.0	1,594.4
2015	696.0	391.5	1,087.5
2020	2,498.7	1,405.5	3,904.2
2025	1,499.2	843.3	2,342.5
2030	1,019.5	573.5	1,592.9
2035	407.8	229.4	637.2
2040	285.4	160.6	446.0
2045	141.6	79.6	221.2
2050	137.2	77.1	214.3

Sources: REMI PI+, RESI

Table 3-11. Wage Benefits (Costs) for GGRA Initial Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	$22,457,500	$12,092,500	$34,550,000
2015	-$10,102,950	-$5,440,050	-$15,543,000
2020	$80,720,900	$43,465,100	$124,186,000
2025	$44,999,500	$24,230,500	$69,230,000
2030	-$29,341,000	-$15,799,000	-$45,140,000
2035	-$13,019,500	-$7,010,500	-$20,030,000
2040	$8,560,500	$4,609,500	$13,170,000

2045	$12,480,000	$6,720,000	$19,200,000
2050	$18,193,500	$9,796,500	$27,990,000

Sources: REMI PI+, RESI

Table 3-12. Output Benefits (Costs) for GGRA Initial Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	-$924,950	-$498,050	-$1,423,000
2015	-$143,611,000	-$77,329,000	-$220,940,000
2020	-$4,325,750	-$2,329,250	-$6,655,000
2025	$6,110,000	$3,290,000	$9,400,000
2030	$17,810,000	$9,590,000	$27,400,000
2035	$18,070,000	$9,730,000	$27,800,000
2040	$17,433,000	$9,387,000	$26,820,000
2045	$19,532,500	$10,517,500	$30,050,000
2050	$19,623,500	$10,566,500	$30,190,000

Sources: REMI PI+, RESI

Table 3-13. Value Added Benefits (Costs) for GGRA Initial Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	-$22,033,050	-$11,863,950	-$33,897,000
2015	-$133,812,250	-$72,052,750	-$205,865,000
2020	-$75,143,250	-$40,461,750	-$115,605,000
2025	-$24,745,500	-$13,324,500	-$38,070,000
2030	$3,607,500	$1,942,500	$5,550,000
2035	$11,167,000	$6,013,000	$17,180,000
2040	$11,485,500	$6,184,500	$17,670,000
2045	$11,258,000	$6,062,000	$17,320,000
2050	$12,850,500	$6,919,500	$19,770,000

Sources: REMI, RESI

Table 3-14. Real Disposable Income Benefits (Costs) for GGRA Initial Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	$41,616,900	$22,409,100	$64,026,000
2015	$60,262,800	$32,449,200	$92,712,000
2020	$146,770,000	$79,030,000	$225,800,000
2025	$37,745,500	$20,324,500	$58,070,000
2030	$24,277,500	$13,072,500	$37,350,000
2035	$25,070,500	$13,499,500	$38,570,000
2040	$29,276,000	$15,764,000	$45,040,000
2045	$33,566,000	$18,074,000	$51,640,000
2050	$40,150,500	$21,619,500	$61,770,000

Sources: REMI, RESI

Overall, the GGRA measures as analyzed under the initial meta-scenario will benefit Maryland's economy with respect to jobs, wages, and real disposable income growth. However, the output and value added to Maryland's economy may decline given the large declines in demand for energy and maintenance associated with the electric power sector in the short term. The movement from labor-intensive industries, such as fuel extraction and dealers, to more high-skilled capital-intensive industries, such as engineering and research, will continue into 2020. The spinoff employment (which includes indirect and induced employment associated with the policies) would represent the loss of some low-skilled employment in the industries associated with extraction and service.

Traditional retail sector jobs, such as gasoline station employees, would be displaced as the economy begins to shift consumption patterns from fossil fuel-based energy technologies toward less fossil fuel-intensive technologies, such as plug-in electric vehicles. Suppliers and businesses associated with these products would need to seek alternative methods to stay competitive.

Enhanced Meta-scenario

RESI analyzed the enhanced meta-scenario of the GGRA for benefits or costs that may be associated with implementation of the enhanced measures. The enhanced meta-scenario analyzes the impacts from the enhanced versions of EmPOWER Maryland and the Public Transportation programs. A major difference between the initial meta-scenario and the enhanced meta-scenario is the increased investment in the Public Transportation Programs.[30] The enhanced version of the Public Transportation Programs includes full funding of projects such as the Red and Purple Lines. Table 3-15 through Table 3-19 show the annual distribution between 2010 and 2050 for the GGRA as a whole in employment, wages, output, value added, and real disposable income.

Table 3-15. Employment Benefits (Costs) for GGRA Enhanced Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	1,350.4	759.6	2,110.0
2015	2,013.7	1,132.7	3,146.5
2020	2,296.6	1,291.9	3,588.5
2025	1,607.6	904.3	2,512.0
2030	1,045.0	587.8	1,632.8
2035	574.7	323.3	898.0
2040	373.6	210.1	583.7
2045	176.3	99.2	275.5
2050	170.8	96.1	267.0

Sources: REMI PI+, RESI

[30] Some transportation programs as slated for delayed construction and may not begin full operation until after 2020. Furthermore, some transit programs are still contingent on funding, or additional funding. The meta-scenarios account for these programs being funded, such as the Red Line and Purple Line.

Table 3-16. Wage Benefits (Costs) for GGRA Enhanced Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	$41,860,000	$22,540,000	$64,400,000
2015	$71,838,000	$38,682,000	$110,520,000
2020	$63,895,000	$34,405,000	$98,300,000
2025	$39,344,500	$21,185,500	$60,530,000
2030	-$15,561,000	-$8,379,000	-$23,940,000
2035	$2,821,000	$1,519,000	$4,340,000
2040	$10,861,500	$5,848,500	$16,710,000
2045	$15,730,000	$8,470,000	$24,200,000
2050	$23,894,000	$12,866,000	$36,760,000

Sources: REMI PI+, RESI

Table 3-17. Output Benefits (Costs) for GGRA Enhanced Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	$48,275,500	$25,994,500	$74,270,000
2015	$33,501,000	$18,039,000	$51,540,000
2020	-$36,471,500	-$19,638,500	-$56,110,000
2025	-$52,058,500	-$28,031,500	-$80,090,000
2030	$7,150,000	$3,850,000	$11,000,000
2035	$22,067,500	$11,882,500	$33,950,000
2040	$22,691,500	$12,218,500	$34,910,000
2045	$22,087,000	$11,893,000	$33,980,000
2050	$26,175,500	$14,094,500	$40,270,000

Sources: REMI PI+, RESI

Table 3-18. Value Added Benefits (Costs) for GGRA Enhanced Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	$8,281,000	$4,459,000	$12,740,000
2015	-$34,203,000	-$18,417,000	-$52,620,000
2020	-$94,334,500	-$50,795,500	-$145,130,000
2025	-$32,708,000	-$17,612,000	-$50,320,000
2030	$4,329,000	$2,331,000	$6,660,000
2035	$13,916,500	$7,493,500	$21,410,000
2040	$14,475,500	$7,794,500	$22,270,000
2045	$14,274,000	$7,686,000	$21,960,000
2050	$17,153,500	$9,236,500	$26,390,000

Sources: REMI, RESI

Table 3-19. Real Disposable Income Benefits (Costs) for GGRA Enhanced Meta-scenario, 2010–2050

Year	Direct	Spinoff	Total
2010	$58,181,500	$31,328,500	$89,510,000
2015	$133,718,000	$72,002,000	$205,720,000
2020	$141,258,000	$76,062,000	$217,320,000
2025	$150,163,000	$80,857,000	$231,020,000
2030	$77,837,500	$41,912,500	$119,750,000
2035	$36,855,000	$19,845,000	$56,700,000
2040	$39,754,000	$21,406,000	$61,160,000
2045	$44,830,500	$24,139,500	$68,970,000
2050	$55,783,000	$30,037,000	$85,820,000

Sources: REMI, RESI

Private, state, and households' continual structured investments in the economy toward GGRA goals under the enhanced meta-scenario mitigated some loss reported in the initial meta-scenario. Specifically, programs associated with increasing public transit helped to offset the later declines. The initial work creates construction jobs within the region, but the longer benefits associated with reduced motor fuel purchases and maintenance of private vehicles provide additional disposable income to households in the form of savings. Given this newly acquired disposable income, consumers are more likely to spend it locally, thereby creating additional induced impacts. Overall, the benefits with regard to value added and real disposable income are evident in Table 3-18 and Table 3-19. Review of both scenarios indicates there will be a short-term negative impact incurred for implementation, but Maryland's economy benefits from nearly 20 additional years of increased jobs, wages, and output in the long-term.

4. PLACING THE ANALYSIS IN CONTEXT

4.1. Maryland Climate Context

The 2012 Greenhouse Gas Emissions Reduction Act (GGRA) Plan seeks to achieve a 25 percent statewide reduction in greenhouse gas (GHG) emissions by 2020, while also spurring job creation and helping improve the economy.[31] In the multi-pollutant planning context, it is part of a "multi-pollutant" planning approach for selecting and analyzing control programs to address multiple public health and environmental goals. The 2012 GGRA Plan will not only help reduce emissions of GHGs, but will also help Maryland to: (1) further clean up the Chesapeake Bay; (2) meet and maintain the NAAQS for ground-level ozone, fine particles, sulfur dioxide, and nitrogen dioxide; and (3) meet federal and state requirements to further reduce regional haze as well as mercury and other air toxics.

There are some critical linkages between GHGs and other air pollutants. First, studies have indicated that climate change, if unaddressed, could result in increased ozone and fine particle levels, or reduce the effectiveness of current pollution control strategies ("climate penalty").[32] Second, many programs that are designed to lower GHG emissions, such as energy efficiency programs, may also reduce emissions of nitrogen oxides, sulfur dioxide, mercury, other toxic metals, diesel exhaust, and black carbon.[33] Third, some policies that are designed to lower GHG emissions, when otherwise unconstrained, may result in increases in other air pollutant emissions.[34] Working on

[31] For more on Maryland's GGRA Plan, *see* "Climate Change Maryland," State of Maryland, http://climatechange.maryland.gov/publications/greenhouse-gas-emissions-reduction-act-plan/ (accessed September 30, 2014).

[32] *See, e.g.,* Trail, M., A.P. Tsimpidi, P. Liu, K. Tsigaridis, J. Rudokas, P. Miller, A. Nenes, Y. Hu, and A.G. Russell, "Sensitivity of Air Quality to Potential Future Climate Change and Emissions in the United States and Major Cities," *Atmospheric Environment*, **94** 552-563 (2014), doi:10.1016/j.atmosenv.2014.05.079; Rasmussen, D.J., J. Hu, A. Mahmud, and M.J. Kleeman, "The Ozone−Climate Penalty: Past, Present, and Future," *Environmental Science & Technology*, **47** 14258−14266 (2013), doi:10.1021/es403446m; Dawson, J.P., P.N. Racherla, B.H. Lynn, P.J. Adams, and S.N. Pandis, "Impacts of Climate Change on Regional and Urban Air Quality in the Eastern United States: Role of Meteorology," *Journal of Geophysical Research*, **114** D05308 (2009), doi:10.1029/2008JD009849; Jacob, D.J. and D.A. Winner, "Effect of Climate Change on Air Quality," *Atmospheric Environment*, **43** 51-63 (2009), doi:10.1016/j.atmosenv.2008.09.051; Tagaris, E., K. Manomaiphiboon, K. Liao, L.R. Leung, J. Woo, S. He, P. Amar, and A.G. Russell, "Impacts of Global Climate Change and Emissions on Regional Ozone and Fine Particulate Matter Concentrations over the United States," *Journal of Geophysical Research*, **112** D14312 (2007), doi:10.1029/2006JD008262.

[33] *See, e.g.,* Thompson, T.M., S. Rausch, R.K. Saari, and N.E. Selin, "A Systems Approach to Evaluating the Air Quality Co-benefits of US Carbon Policies," *Nature Climate Change* (published online August 24, 2014), doi:10.1038/NCLIMATE2342.

[34] *See, e.g.,* Babaee, S., A.S. Nagpure, and J.F. DeCarolis, "How Much Do Electric Drive Vehicles Matter to Future U.S. Emissions?," *Environmental Science & Technology*, **48** 1382-1390 (2014), doi:10.1021/es4045677; Driscoll, C.T, J. Buonocore, S. Reid, H. Fakhraei, and K.F. Lambert, "Co-benefits of Carbon Standards Part 1: Air Pollution Changes under Different 111d Options for Existing Power Plants," Syracuse University, Syracuse, NY and Harvard University, Cambridge, MA (2014), 34 pp, http://eng-cs.syr.edu/carboncobenefits (accessed October 1, 2014).

climate, energy, criteria pollutant, and toxics issues together helps maximize benefits while also ensuring that any adverse effects are minimized.

The multi-pollutant planning exercise demonstrated that the GGRA policies collectively made positive contributions to near-term air quality outcomes, including the 2020 GGRA climate target.

The analysis also indicated that further reductions in CO_2 emissions are needed to meet a hypothetical 80 percent reduction goal by 2050. In order to meet longer-term emission reduction goals, more measures involving the transportation sector would need to be considered. The climate sensitivity analyses found that in 2050, the combination of the most aggressive modeled GGRA policies alone lowered Maryland's reference case 2050 GHG emissions from almost 90 million tons[35] to about 46 million tons. This is still about 30 million tons short of a 2050 80 percent GHG reduction target of 17 million tons (relative to 2006 emissions). Of the 46 million tons, about 35 million tons comes from the transportation sector. This is not surprising, as the sensitivity analyses focused on more aggressive options for RE and EE, while more aggressive transportation policies were not considered.

The decreases in NO_X and SO_2 emissions occurring under the GGRA meta-scenarios resulted in modeled ozone and $PM_{2.5}$ air quality improvements. Using CMAQ, average maximum 8-hour ozone was calculated for the ozone season (April-October). Reductions in ozone precursors and particulate matter lead to modest changes in ozone, with the maximum benefit predicted by the enhanced meta-scenario of over 0.8 ppb centered on Maryland with further benefit in southeastern Pennsylvania, New Jersey, New York City, and Connecticut. The greatest reductions in particulate matter in Maryland are found near Baltimore/Edgewood and in the vicinity of power plants within the State. Decreases in SO_2 emissions in Maryland are most noticeable around city centers and power plants, such as those in western (Dickerson) and southern (Chalk Point) Maryland.

The modeled reductions in air pollution arising from the GGRA measures were input into the BenMAP model to estimate specific increases and decreases in incidences of health effects. BenMAP found positive net health benefits from the modeled changes in air quality in terms of avoided adverse health outcomes, including premature mortality. Within Maryland, BenMAP estimated 43 to 100 avoided deaths per year due to reduced ozone and $PM_{2.5}$ under the initial meta-scenario, and 84 to 192 avoided deaths per year under the enhanced meta-scenario.

The monetized value of avoided mortality within Maryland ranges between $420 million to $850 million per year under the initial meta-scenario, and between $810 million to $1.6 billion per year under the enhanced meta-scenario, assuming a 3 percent discount rate for future health effects. With a 7 percent discount rate, the value is $320 million to $740 million per year under the initial meta-scenario, and $620 million to $1.4 billion under the enhanced meta-scenario.

The regional economic assessment using REMI found that overall, the GGRA measures as analyzed under the initial meta-scenario will benefit Maryland's economy

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[35] Amounts reflect carbon dioxide only. Other GHGs were not considered in the analysis.

with respect to jobs, wages, and real disposable income growth. However, the output and value added to Maryland's economy may decline given the large declines in demand for energy and maintenance associated with the electric power sector in the short term. Private, state, and households' continual structured investments in the economy toward GGRA goals under the enhanced meta-scenario mitigated some loss reported in the initial meta-scenario. Specifically, programs associated with increasing public transit helped to offset the later declines. The initial work creates construction jobs within the region, but the longer benefits associated with reduced motor fuel purchases and maintenance of private vehicles provide additional disposable income to households in the form of savings. Given this newly acquired disposable income, consumers are more likely to spend it locally, thereby creating additional induced impacts. Review of both scenarios indicates there will be a short-term negative impact incurred for implementation, but Maryland's economy benefits from nearly 20 additional years of increased jobs, wages, and output in the long-term.

4.2. Maryland Ozone SIP Context

The Maryland GGRA Plan includes a number of policies that provide a basis for incorporating these as alternative (non-traditional) control strategies in the Maryland ozone SIP. In the context of ozone, the precursor pollutant of interest is NO_X, which has a large regional impact on ozone formation across the eastern United States. GGRA policies involving energy efficiency and renewable energy to reduce GHGs can also reduce ozone-forming NO_X emissions when displacing fossil fuel combustion. For example, reductions in NO_X emissions from the electric power sector under the NO_X SIP Call have successfully reduced ozone levels in Maryland and across the eastern United States since the inception of the program during the 1990s.

In July 2012, the U.S. EPA released its *Roadmap for Incorporating Energy Efficiency and Renewable Energy Policies and Programs into State and Tribal Implementation Plans* (hereinafter "Roadmap").[36] With its Roadmap, the EPA is encouraging states to consider incorporating energy efficiency and renewable energy programs into their SIPs. The EPA recognizes that states have adopted and are continuing to pursue a range of energy efficiency and renewable energy programs that can reduce SIP-relevant pollutant emissions, such as NO_X. In addition, the EPA recognizes that with strengthened air quality standards occurring over time, energy efficiency and renewable energy measures can help states find the greater emission reductions they need to achieve the standards.

The Roadmap builds upon EPA's 2004 guidance on how states may account for energy efficiency and renewable energy programs in their SIPs.[37] The Roadmap clarifies how states might include these programs in SIPs as emerging and voluntary measures, or using three other pathways: (1) baseline emissions forecast; (2) control strategy quantification; and (3) weight-of-evidence. As described earlier, the Ozone Transport Commission asked EPA to modify the weight-of-evidence pathway to include a robust

[36] U.S. EPA. *Roadmap for Incorporating EE/RE in SIPs/TIPs*, USEPA OAQPS, Research Triangle Park, NC, EPA-456/D-12-001a (July 2012). Available at http://epa.gov/airquality/eere/pdfs/EEREmanual.pdf.
[37] U.S. EPA, *Incorporating Emerging and Voluntary Measures in a State Implementation Plan (SIP)* (September 2004). Available at http://www.epa.gov/ttncaaa1/t1/memoranda/ereseerem_gd.pdf.

technical approach that combines traditional air quality modeling with less traditional assessment tools. [38] This is the approach being used by Maryland in its ozone SIP as it seeks to obtain the multi-pollutant benefits from the energy efficiency and renewable energy policies in its GGRA Plan.

The ozone SIP sensitivity analysis presented in section 3.1.6 provides an expanded weight-of-evidence approach for projecting total NO_X reductions from GGRA measures not currently captured in SIP baseline forecasts or in ozone control strategies. These are estimated to be in the range of 1,200 to 1,600 tons in 2017, which is Maryland's ozone attainment deadline for the 0.075 ppb ozone NAAQS (current NAAQS at the time of this analysis). Additional NO_X reductions in the range of 2,200 to 2,600 tons are projected in 2023, which is relevant to maintaining the current ozone NAAQS, as well as achieving a possible future revised ozone NAAQS, as EPA proposed at the end of 2014.[39]

To give context for these the projected annual NO_X emission reductions from Maryland's GGRA policies, NESCAUM previously estimated state-level NO_X reductions from the introduction of low sulfur gasoline (10 parts per million sulfur) under the EPA's then potential Tier 3 rule for gasoline-powered vehicles. Assuming an introduction year of 2017, NESCAUM estimated a 5,000 ton annual NO_X reduction in Maryland.[40] The NO_X reductions projected under the ozone SIP sensitivity scenarios in the range of 1,200 to 2,600 tons of NO_X indicate the potential for additional NO_X reductions somewhat less than, but comparable to, projected Tier 3 reductions in Maryland. The Tier 3 program represents one of the largest, if not the largest, measure in Maryland for reducing NO_X emissions in 2017 and beyond, and the results of the ozone sensitivity runs indicate the potential for additional NO_X reductions of a similar magnitude from the modeled GGRA policies.

[38] *OTC Recommendations: Expanded Weight-of-Evidence (WOE) for Attainment Demonstrations*, OTC letter to C. Wayland and S. Mathias, U.S. EPA Office of Air Quality Planning and Standards (June 17, 2011). Available at http://www.otcair.org/upload/Interest/Modeling/OTC%20Expanded%20Weight-of-Evidence%20Letter%20and%20Recommendation.pdf (accessed September 19, 2014).
[39] *National Ambient Air Quality Standards for Ozone*, 79 Fed. Reg. 75234-75411 (December 17, 2014).
[40] NESCAUM White Paper, *Assessment of Clean Gasoline in the Northeast and Mid-Atlantic States*, NESCAUM (Boston, MA) November 21, 2011 (Table 4-2), available at http://www.nescaum.org/documents/nescaum-tier-3-low-s-gasoline-20111121.pdf.

5. SUMMARY

The 2009 Maryland Greenhouse Gas Emissions Reduction Act (GGRA) calls for a 25 percent reduction in GHGs from 2006 levels by 2020. A multi-pollutant analysis using the Multi-pollutant Policy Analysis Framework (MPAF) provides insight on a range of potential air quality, energy, and economic impacts arising from GHG mitigation programs undertaken in response to the GGRA. Through the MPAF integrated process, this analysis has provided insight to the Maryland Department of the Environment (MDE) on potential co-benefits these reduction measures can have in achieving the State's climate and air quality goals.

The MPAF consists of the following model components to provide a broad view of climate and air quality program impacts:

5. NE-MARKAL, a Northeast version of the MARKet ALlocation (MARKAL) model, an energy model that is widely used in Europe. EPA has a nine-region national version of this model, called US9r;
6. Regional Economic Models, Inc. (REMI), a 12-state model that evaluates the effects of policies and programs on the economies of local regions;
7. EPA's Community Multi-scale Air Quality (CMAQ) model, which assesses future air quality changes for a set of policies and programs;
8. EPA's Environmental Benefits Mapping and Analysis Program (BenMAP), which estimates health impacts and associated monetized values resulting from changes in ambient air pollution.

NESCAUM worked with MDE to select policies for analysis from the GGRA Plan of 2012 that were of key interest from a policy perspective and were most appropriate for characterizing in the NE-MARKAL model. After selecting the policies, the next step was to characterize and calibrate them within NE-MARKAL.

Two meta-scenarios, an initial and an enhanced, were developed and analyzed through the MPAF. Each meta-scenario combined all of the selected policies into a single NE-MARKAL run that captured their interactive effects. The initial meta-scenario was comprised of selected policies as they were defined in the GGRA Plan of 2012. The enhanced meta-scenario was comprised of a combination of individual policies, some of which had enhanced goals defined either in the GGRA Plan or by MDE. Initial and enhanced policy definitions were provided either in the GGRA Plan or by MDE. Note that enhanced policies not based on the GGRA Plan are for analytical exercise purposes only, and may not reflect current Maryland policy.

The multi-pollutant planning exercise demonstrated that the GGRA policies collectively made positive contributions to near-term air quality outcomes, including the 2020 GGRA climate target..

The analysis also indicated that further reductions in CO_2 emissions are needed to meet a hypothetical 80 percent reduction goal by 2050. In order to meet longer-term emission reduction goals, more measures involving the transportation sector would need to be considered. Climate sensitivity analyses undertaken as an extension of the meta-scenarios analyses found that in 2050, the combination of the most aggressive modeled GGRA policies alone lowered Maryland's reference case 2050 GHG emissions from almost 90 million tons of CO_2 to about 46 million tons (other GHGs were not considered in these analyses). This is still about 30 million tons short of a 2050 80 percent GHG reduction target of 17 million tons (relative to 2006 emissions). Of the 46 million tons, about 35 million tons comes from the transportation sector. This is not surprising, as the sensitivity analyses focused on more aggressive options for renewable energy and energy efficiency, while more aggressive transportation policies were not considered.

The GGRA measures in the two meta-scenarios also led to projected emission reductions in NO_X and SO_2, key precursor pollutants for the criteria pollutants ozone (NO_X) and $PM_{2.5}$ (NO_X and SO_2) over the modeling timeframe through 2023. Cumulatively over this time period, the initial meta-scenario projected reductions of 63,000 tons of NO_X and 399,000 tons of SO_2 in Maryland. Larger reductions were seen for the enhanced meta-scenario, with 70,000 tons of NO_X and 492,000 tons of SO_2 reduced.

A selected set of GGRA measures that were included in an ozone SIP sensitivity analysis demonstrated promise for achieving additional NO_X reductions relevant to Maryland's ozone SIP timelines (2017 to 2023). These NO_X reductions go beyond current ozone SIP baseline projections and enforceable control strategies, thus they provide the technical basis for an expanded weight-of-evidence demonstration of reasonably foreseeable NO_X reductions in excess of those attributable to traditional ozone SIP measures.

The estimated additional NO_X reductions from the GGRA measures are in the range of 1,200 to 1,600 tons in the year 2017, which is Maryland's ozone attainment deadline for the 0.075 ppb ozone NAAQS (current NAAQS at the time of this analysis). Additional NO_X reductions in the range of 2,200 to 2,600 annual tons are projected for the year 2023, which is relevant to maintaining the current ozone NAAQS, as well as achieving a possible future revised ozone NAAQS. By way of comparison, the annual NO_X reductions projected under the ozone SIP sensitivity scenarios are somewhat less than, but comparable to, projected annual NO_X reductions from gasoline passenger vehicles in Maryland expected from implementation of EPA's Tier 3 motor vehicle program. The Tier 3 program represents one of the largest, if not the largest, measure in Maryland for reducing NO_X emissions in 2017 and beyond, and the results of the ozone sensitivity runs indicate the potential for additional NO_X reductions of a similar magnitude from the modeled GGRA policies.

The projected changes in emissions estimated by NE-MARKAL give rise to modeled air quality improvements for ozone and $PM_{2.5}$ in Maryland and in regions outside of the State. In the enhanced meta-scenario, CMAQ projected a maximum ozone reduction benefit of over 0.8 ppb centered on Maryland with further benefit in southeastern Pennsylvania, New Jersey, New York City, and Connecticut. The greatest reductions in particulate matter in Maryland are found near Baltimore/Edgewood and in the vicinity of power plants within the State. Decreases in SO_2 emissions in Maryland are most noticeable around city centers and power plants, such as those in western (Dickerson) and southern (Chalk Point) Maryland.

The improvements in modeled ozone and $PM_{2.5}$ air quality give rise to positive net health benefits in terms of avoided adverse health outcomes, including premature mortality. These avoided health incidences were quantified, along with their monetized benefits, using EPA's BenMAP tool coupled with the modeled air quality changes in ozone and $PM_{2.5}$ from CMAQ for each of the meta-scenarios.

As a result of the air quality changes attributable to the GGRA meta-scenarios, the BenMAP analysis found many reduced incidences of respiratory ailment, asthma attack, heart attack, hospital room visits, and lost work and school days. The monetary benefits of these public health improvements were driven largely by the reduced mortality, which includes (within Maryland) 43 to 100 avoided deaths per year due to reduced ozone and $PM_{2.5}$ under the initial meta-scenario, and 84 to 192 avoided deaths per year under the enhanced meta-scenario.

The monetized value of avoided mortality within Maryland ranges between $420 million to $850 million per year under the initial meta-scenario, and between $810 million to $1.6 billion per year under the enhanced meta-scenario, assuming a 3 percent discount rate for future health effects. With a 7 percent discount rate, the value is $320 million to $740 million per year under the initial meta-scenario, and $620 million to $1.4 billion under the enhanced meta-scenario.

The regional economic assessment using REMI found that overall, the GGRA measures as analyzed under the initial meta-scenario will benefit Maryland's economy with respect to jobs, wages, and real disposable income growth. However, the output and value added to Maryland's economy may decline given the large declines in demand for energy and maintenance associated with the electric power sector in the short term. Private, state, and households' continual structured investments in the economy toward GGRA goals under the enhanced meta-scenario mitigated some loss reported in the initial meta-scenario. Specifically, programs associated with increasing public transit helped to offset the later declines. The initial work creates construction jobs within the region, but the longer benefits associated with reduced motor fuel purchases and maintenance of private vehicles provide additional disposable income to households in the form of savings. Given this newly acquired disposable income, consumers are more likely to spend it locally, thereby creating additional induced impacts. Review of both scenarios indicates there will be a short-term negative impact incurred for implementation, but Maryland's economy benefits from nearly 20 additional years of increased jobs, wages, and output in the long-term.

Appendix A: NE-MARKAL Input Assumptions, Scenario Descriptions, and Methodology

A.1. Introduction

Appendix A describes the core database input assumptions for the Northeast version of the MARKet ALlocation (NE-MARKAL) model[41] and reviews the specific scenarios and data developed for the Maryland weight-of-evidence planning exercise. We introduce the model, describe basic NE-MARKAL data structures and input assumptions—including tables with key data elements that constitute a typical MARKAL energy model—and document the Maryland-specific weight-of-evidence reference case calibration. We then define each strategy simulation run for the weight-of-evidence multi-pollutant exercise in terms of its specific NE-MARKAL modeling representation. It is important to note that while the timeframe for the GGRA analysis was 2008-2023 and the timeframe for the sensitivity analysis was 2008-2050, the full NE-MARKAL database is specified over the 2005-2053 timeframe. All tables and charts in this section will cover the 2005-2053 timeframe. In addition, all cost data were deflated to 2005 dollars to be consistent with the NE-MARKAL database, which was normalized across all sectors and technologies to a 2005 dollar basis.

A.2. The NE-MARKAL Model

NE-MARKAL is an economy-wide model that encompasses the entire energy infrastructure of the Northeast; it is capable of modeling all energy demand and supply in the transportation, commercial, industrial, residential, and power generation sectors.[42] The model contains highly-detailed depictions of energy technologies and their associated economic factors, such that each generated technology combination is based on the relative costs of the various energy technology options and constraints on the energy system.

As a linear programming model that optimizes outcomes based on cost, NE-MARKAL's strength is in exploring the relative cost-effectiveness of meeting various policy goals, such as limits on CO_2 emissions from power generation or minimum performance requirements on vehicles. NE-MARKAL is not a computable general equilibrium model that generates estimates of economy-wide price and welfare effects (i.e., gains or losses of producer and consumer surplus) associated with introducing various policies. It is, however, one of the few models of its kind that considers all energy-consuming sectors and characterizes energy use, emissions of GHGs and criteria air pollutants, technology deployment, and costs at a high level of detail. This formulation provides a powerful tool for decision-makers to assess the relative benefits of environmental policies, viewed individually or collectively.

In the NE-MARKAL modeling framework, the energy infrastructure is configured to meet the estimated demand for energy using the most cost-effective technologies and fuel sources. The model can be configured to represent enforceable

[41] For information on the MARKAL model, *see* Loulou, R., G. Goldstein, and K. Noble, The MARKAL Family of Models, Energy Technology Systems Analysis Programme (ETSAP), October 2004. See www.etsap.org.
[42] NE-MARKAL currently includes the six New England states, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Washington, D.C., and focuses primarily on the power generation, transportation, and buildings sectors.

requirements as well as incentives, such as energy efficiency programs, carbon mitigation strategies, and vehicle performance standards. The NE-MARKAL model currently begins in 2005 and models state and regional energy decision-making out to 2053 in three year time increments. For the core GGRA analysis, the modeling timeframe ranged between the years 2008 and 2023. For the climate sensitivity analysis, however, the timeframe was extended to 2050. Modeled outcomes from NE-MARKAL include: GHG and criteria pollutant emissions, energy consumption, and a variety of cost metrics.

There are a number of important caveats to keep in mind when assessing modeled NE-MARKAL results. (1) NE-MARKAL is best suited for "what-if" exploratory analysis of climate and air quality policies that probes a variety of possible technological and resource outcomes; the modeled results do not represent simulation-based forecasts of future energy, technology, and emissions trends. (2) NE-MARKAL is focused on a region's energy infrastructure and as such is best suited to assess policies aimed at technology and resource choices in this domain. The model, for example, is not well suited to assess policies aimed at land-use, agriculture, or waste management practices. (3) The electricity sector in NE-MARKAL uses a simplified load duration curve representation which breaks a typical year into 6 aggregate time-slices. This precludes analysis of policies aimed at affecting peak-generation resources and other scenarios aimed at shifting short-term load.

A.3. Core NE-MARKAL Database Input Assumptions

This section describes the database inputs required to run a baseline NE-MARKAL reference case scenario. The core NE-MARKAL database was constructed from several data sources. Foremost of these was the U.S. Department of Energy's Energy Information Administration (EIA) Annual Energy Outlook (AEO) and the Environmental Protection Agency's (EPA's) US 9 Region MARKAL database (US9R). Technology characterizations were extracted from the US9R database, along with data on base year technology stocks, resource supply options, and the sectoral growth rates used in developing demand projections for each model region (state). Other data sources included: the State Energy Data System (SEDS), which provides final energy use for each demand sector by fuel type; Gross State Product data from the Bureau of Economic Analysis; EIA's three sectoral energy consumption surveys; and EPA's eGRID emissions database.

The data presented in the following sections characterize the cost, operation, and configuration of the various components of the region's energy infrastructure, from basic energy resource supply and electricity generation to all end-use demands and demand technologies. The baseline reference case is typically not calibrated to specific policies; rather, energy supply outcomes and technology choices are based solely on the objective of satisfying the projected demand through least-cost optimization.

This policy-neutral reference case was then examined and compared against state and regional energy and environmental policy trends to understand where least-cost projections may have differed from conventional wisdom or known policy direction. In areas where the baseline reference case needed adjustment, the choice of technology deployment and fuel share constraints were tailored to better reflect a reasonable "business as usual" reference for specific state and regional policy analysis exercises. The calibrated Maryland-specific NE-MARKAL reference case used in the weight-of-evidence is described in section A.4.

A.3.1. Energy Supply Input Assumptions

Table A-1 lists the updates and data sources for the NE-MARKAL energy supply and emissions characterization. In the NE-MARKAL database, energy supply refers to all of the data necessary to characterize the core fuel supply infrastructure in the NE-MARKAL region. In the model, CO_2 and all building sector emissions factors are tracked at the fuel consumption level. These factors are presented in this section. Criteria emissions for all other sectors are tracked at the technology-specific level, and are discussed in the sector-specific sections that follow.

Table A-1. Data Sources for Energy Supply Inputs

Model Input	Data Sources
Energy Price Projections	U.S. Department of Energy's (DOE's) Annual Energy Outlook (AEO) 2012 Reference Case Price Forecasts by Region
Carbon Dioxide Emissions Factors	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET), version 1.8.c.0, ANL, 2009 / U.S. DOE's Energy Information Administration (EIA) Carbon Dioxide Emissions Coefficients by Fuel, 2013
Residential and Commercial Criteria Emissions Factors	U.S. Environmental Protection Agency (EPA) US9R MARKAL database, version 1.1, 2012
Biomass Resource Bounds	U.S. DOE Billion Ton Study, 2011 Update

Figures A-1 through **A-4** display the 2012 AEO energy price projections for the Mid-Atlantic region that were used in the NE-MARKAL analysis. AEO 2012 was the latest EIA forecast available when the NE-MARKAL database was set up and calibrated for this analysis.

After the calibration process was complete, AEO 2013 became available and the project team was interested in assessing whether there would be major implications for the outcomes of the project if AEO 2012 fuel price projections were updated to AEO 2013. NESCAUM collaborated with MDE to investigate differences between AEO 2012 and AEO 2013 fuel price projections. The investigation did not reveal any compelling reasons to replace AEO 2012 fuel price projections with AEO 2013 projections.

Figure A-1. Commercial Sector Energy Price Projections, 2005–2053

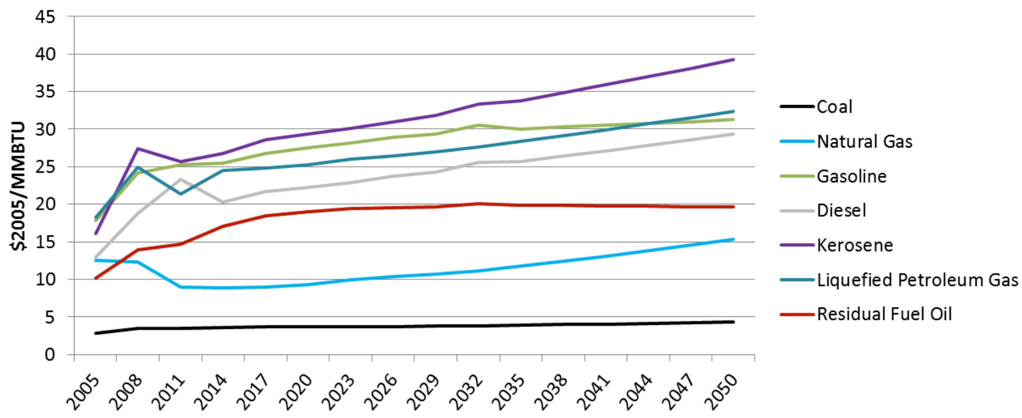


Figure A-2. Residential Sector Energy Price Projections, 2005–2053

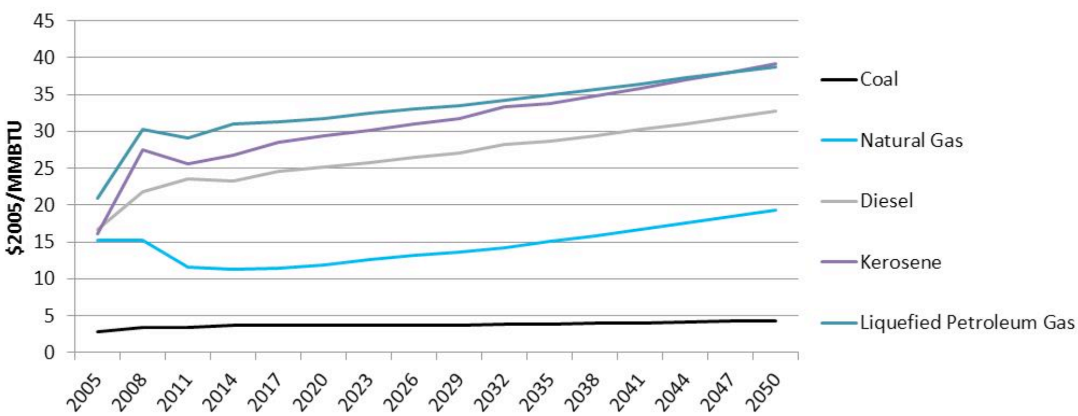


Figure A-3. Power Sector Energy Price Projections, 2005–2053

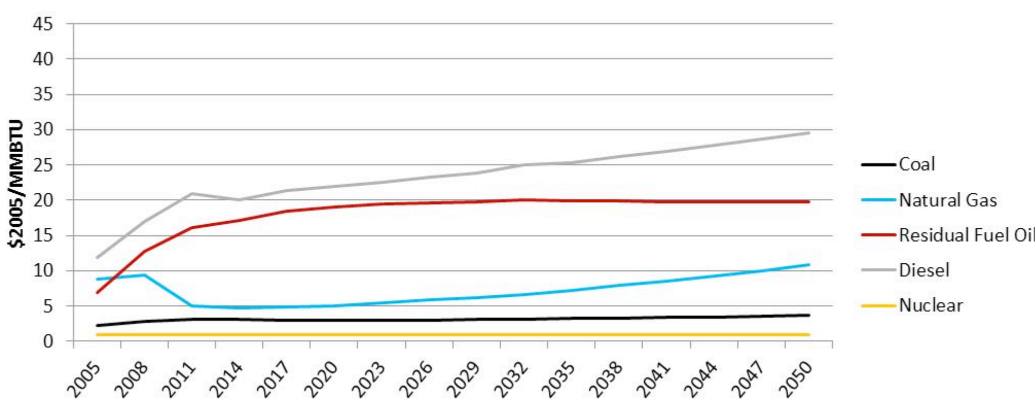


Figure A-4. Transportation Sector Energy Price Projections, 2005–2053

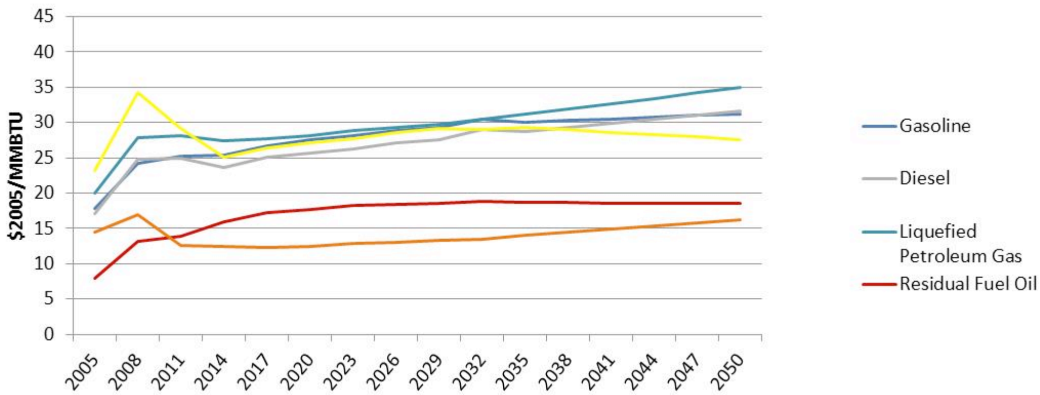


Table A-2 presents CO_2 emissions factors used in the MARKAL model. The data sources for these emissions factors are: (1) the 2009 Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by Argonne National Laboratory for the transportation sector ;[43] and (2) the EIA's *Carbon Dioxide Emissions Coefficients by Fuel 2013*[44] data set for all other sectors.

Table A-2. CO_2 Emission Factors (in kT/tBTU)

Fuel		Commerical Sector	Power Sector	Residential Sector	Transportation Sector
Coal	Bituminous	95.35	93.31	95.35	NA
	Sub-Bituminous		97.21		
Diesel		73.17	NA	73.17	70.91
Gasoline		70.91	NA	NA	71.09
Kerosene		72.30	NA	72.30	NA
LPG		64.01	NA	64.01	62.68
Natural Gas		53.07	53.14	53.07	NA
Residual Fuel Oil		78.79	78.83	NA	NA
Distillate Fuel Oil		NA	70.91	NA	NA
Landfill Gas		NA	13.97	NA	NA
MSW		NA	31.36	NA	NA
Fossil Fuel Waste		NA	72.62	NA	NA
E85		NA	NA	NA	67.04
CNG		NA	NA	NA	53.14
B20X		NA	NA	NA	74.06
LNG		NA	NA	NA	52.08
RFH		NA	NA	NA	78.83
JTF		NA	NA	NA	70.90

Table A-3 presents criteria emissions factors for the residential and commercial sectors. These emissions factors came from the EPA US9R MARKAL database. Only the commercial and residential sectors track criteria emissions at the fuel level; the other sectors track criteria emissions at the technology-specific level.

Table A-3. Commercial and Residential Criteria Emission Factors (in kT/tBTU)

[43] https://greet.es.anl.gov/.
[44] http://www.eia.gov/environment/emissions/co2_vol_mass.cfm.

	Fuel	SO2	NOX	VOC	PM25	CO
Commercial	Coal	0.000	0.000	0.000	0.000	0.000
	Diesel	0.140	0.050	0.001	0.007	0.016
	Gasoline	0.000	0.000	0.000	0.000	0.000
	Kerosene	0.143	0.065	0.001	0.007	0.016
	LPG	0.000	0.066	0.003	0.000	0.019
	Natural Gas	0.000	0.044	0.002	0.003	0.037
	Residual Fuel	1.070	0.162	0.003	0.268	0.015
Residential	Biomass-wood	0.000	0.044	0.002	0.003	0.037
	Coal	0.000	0.000	0.000	0.000	0.000
	Diesel	0.139	0.059	0.002	0.007	0.016
	Kerosene	0.143	0.060	0.002	0.007	0.017
	LPG	0.000	0.066	0.003	0.000	0.019
	Natural Gas	0.000	0.041	0.002	0.000	0.018

Table A-4 presents Maryland-specific biomass resource bounds between 2012 and 2030. For this analysis, "biomass" refers to dedicated biomass-fueled electric generating plants, and does not include disaggregated wood burning for residential heating or in outdoor wood-fired boilers. The values represent the maximum amount of biomass available for use in applications ranging from direct combustion in the power sector to thermal heating applications in the buildings sector. Within NE-MARKAL, each resource is also broken out into a number of cost categories (typically 10). The cost categories deployed first are the cheapest and easiest-to-recover types of each resource, and later include the more expensive and difficult-to-collect biomass resources. The data for the biomass resource bounds come from the U.S. DOE's Billion Ton Study, 2011 Update.[45]

Table A-4. Biomass Resource Bounds (in million tons)

	2012	2015	2020	2025	2030
Agricultural Residues	2.1	2.1	2.4	2.8	3.0
Annual Energy Crops	0.000	0.022	0.022	0.022	0.022
Grassy Energy Crops	0.0	1.8	4.1	2.4	4.2
Woody Energy Crops	0.0	0.5	1.5	3.1	4.0
Soybeans	137.6	129.1	135.3	136.6	139.0
Forest Residues	1.4	1.4	1.4	1.4	1.4
Mill Residues	0.6	0.6	0.6	0.6	0.6
C&D Waste	3.1	3.1	3.2	3.3	3.4
MSW	1.6	1.7	1.7	1.8	1.8

A.3.2. Power Sector Input Assumptions

The power sector updates were divided into two categories: existing and new power plants. The key differences in characterizing new versus existing power plants are that existing plants are represented by the residual capacity of each generating unit in the NE-MARKAL region, and thus do not require investment cost parameters. New power plants are represented from a suite of technologies in the database available for future investment. The database contains groupings of new power plant types that are broader than those of existing power plants.

45 https://bioenergykdf.net/content/billiontonupdate.

A.3.2.1. Existing Power Plants

Table A-5 presents the inputs and data sources used to model the existing power plants in NE-MARKAL. The set of power plants represented in the NE-MARKAL model was mined from EPA's National Electric Energy Data System (NEEDS) Base Case, version 4.10. The database was developed by EPA's Clean Air Markets Division, and contains operational characteristics and emissions information for all power plants in the United States. It is also used as a key data source for EPA to analyze electric sector-related impacts from air quality programs, such as the National Ambient Air Quality Standards (NAAQS), the Clean Air Interstate Rule (CAIR), the Cross State Air Pollution Rule (CSAPR), and various regional haze regulations. The NEEDS database was the primary source of operational and emissions data for the NE-MARKAL database. Supplemental data sources for emissions and operational characteristics included the EPA US9R MARKAL database and EIA Forms 860 and 923. Operating cost data were mined from the EIA report *Updated Estimates of Power Plant Capital and Operating Costs*.

Table A-5. Data Sources for Existing Power Plant Inputs

Model Input	Data Sources
Existing Plants in the NE-MARKAL States • Capacity • Heat Rate • Start Year • Nitrogen Oxides, Mercury, and Sulfur Dioxide Emissions Factors	EPA National Electric Energy Data System (NEEDS) Version 4.10 Database
Carbon Monoxide, Volatile Organic Compounds, and Fine Particulate Emissions Factors	EPA US9R MARKAL database, version 1.1, 2012
Capacity Factors	EIA Forms 860 & 923, 2005-2011
Fixed and Variable Operation and Maintenance Costs	EIA Updated Estimates of Power Plant Capital and Operating Costs, 2012

Tables A-6 through **A-9** list all of the existing power plants in Maryland that were represented in the multi-pollutant planning exercise. The tables are sorted by primary plant fuel type, and present the operational and emissions characteristics used in the NE-MARKAL optimization framework to determine the electricity generation mix and emissions profile over the modeled timeframe.

Table A-6. Existing Maryland Coal Power Plants

Unit Name	Fuel	Start Year	Life	Retirement	Efficiency	Capacity (MW)	Emission Factors (kt/TBtu)				
							SO2	NOX	VOC	PM25	CO
MD - R Paul Smith Power Station - 9	Coal	1947	60	2007	28.9%	28	1.800	0.311	0.000	0.004	0.001
MD - R Paul Smith Power Station - 11	Coal	1958	60	2018	23.1%	87	1.800	0.422	0.000	0.004	0.136
MD - Dickerson - 1	Coal	1959	60	2019	31.5%	182	2.800	0.200	0.000	0.004	0.136
MD - Herbert A Wagner - 2	Coal	1959	60	2019	26.2%	135	1.450	0.320	0.000	0.004	0.129
MD - Dickerson - 2	Coal	1960	60	2020	31.6%	182	2.800	0.200	0.000	0.004	0.136
MD - C P Crane - 1	Coal	1961	60	2021	30.0%	200	3.500	0.250	0.000	0.004	0.129
MD - Dickerson - 3	Coal	1962	60	2022	31.3%	182	2.800	0.200	0.000	0.004	0.136
MD - C P Crane - 2	Coal	1963	60	2023	30.6%	200	3.500	0.250	0.000	0.004	0.129
MD - Chalk Point LLC - 1	Coal	1964	60	2024	30.2%	341	3.500	0.060	0.000	0.004	0.136
MD - Chalk Point LLC - 2	Coal	1965	60	2025	30.2%	342	3.500	0.060	0.000	0.004	0.136
MD - Herbert A Wagner - 3	Coal	1966	60	2026	31.5%	324	1.450	0.071	0.000	0.004	0.129
MD - Morgantown Generating Plant - 1	Coal	1970	60	2030	33.2%	624	3.500	0.059	0.000	0.004	0.136
MD - Morgantown Generating Plant - 2	Coal	1971	60	2031	33.8%	620	3.500	0.060	0.000	0.004	0.136
MD - Brandon Shores - 1	Coal	1984	60	2044	34.8%	643	1.200	0.078	0.000	0.004	0.001
MD - Brandon Shores - 2	Coal	1991	60	2051	33.3%	643	1.200	0.082	0.000	0.004	0.001
MD - AES Warrior Run Cogeneration Facility - BLR1	Coal	2000	60	2060	28.1%	180	0.420	0.053	0.000	0.004	0.001

Table A-7. Existing Maryland Distillate Power Plants

Unit Name	Fuel	Start Year	Life	Retirement	Efficiency	Capacity (MW)	Emission Factors (kt/TBtu)				
							SO2	NOX	VOC	PM25	CO
MD - Easton - 8	Distillate	1957	60	2017	29.8%	2	0.300	2.505	0.001	0.006	0.136
MD - Easton - 9	Distillate	1961	60	2021	29.8%	3	0.300	2.505	0.001	0.006	0.136
MD - Berlin - 1A	Distillate	1961	60	2021	23.1%	1	0.300	2.505	0.001	0.006	0.136
MD - Chalk Point LLC - GT1	Distillate	1967	60	2027	19.9%	18	0.300	0.807	0.001	0.006	0.136
MD - Dickerson - GT1	Distillate	1967	60	2027	18.3%	13	0.300	0.807	0.001	0.006	0.136
MD - C P Crane - GT1	Distillate	1967	60	2027	16.5%	14	1.053	0.807	0.001	0.006	0.136
MD - Herbert A Wagner - GT1	Distillate	1967	60	2027	18.2%	14	1.053	0.807	0.001	0.006	0.136
MD - Easton - 11	Distillate	1968	60	2028	29.8%	4	0.300	2.505	0.001	0.006	0.136
MD - Crisfield - CRS4	Distillate	1968	60	2028	28.7%	3	0.300	2.505	0.001	0.006	0.136
MD - Crisfield - CRS3	Distillate	1968	60	2028	28.7%	3	0.300	2.505	0.001	0.006	0.136
MD - Crisfield - CRS2	Distillate	1968	60	2028	28.7%	3	0.300	2.505	0.001	0.006	0.136
MD - Crisfield - CRIS	Distillate	1968	60	2028	28.7%	3	0.300	2.505	0.001	0.006	0.136
MD - Vienna Operations - 10	Distillate	1968	60	2028	19.4%	16	2.106	0.807	0.001	0.006	0.080
MD - Smith Island - 2	Distillate	1969	60	2029	18.7%	0	0.300	2.505	0.001	0.006	0.136
MD - Morgantown Generating Plant - GT1	Distillate	1970	60	2030	21.8%	16	0.300	0.807	0.001	0.006	0.136
MD - Philadelphia - GT4	Distillate	1970	60	2030	20.3%	16	1.053	0.807	0.001	0.006	0.136
MD - Philadelphia - GT2	Distillate	1970	60	2030	20.3%	16	1.053	0.807	0.001	0.006	0.136
MD - Philadelphia - GT3	Distillate	1970	60	2030	20.3%	16	1.053	0.807	0.001	0.006	0.136
MD - Philadelphia - GT1	Distillate	1970	60	2030	20.3%	16	1.053	0.807	0.001	0.006	0.080
MD - Riverside - GT7	Distillate	1970	60	2030	18.6%	17	1.053	0.807	0.001	0.006	0.080
MD - Riverside - GT8	Distillate	1970	60	2030	18.6%	17	1.053	0.807	0.001	0.006	0.080
MD - Morgantown Generating Plant - GT2	Distillate	1971	60	2031	21.8%	16	0.300	0.807	0.001	0.006	0.136
MD - Perryman - GT2	Distillate	1972	60	2032	18.5%	52	1.053	0.372	0.001	0.006	0.136
MD - Perryman - GT3	Distillate	1972	60	2032	19.5%	52	1.053	0.490	0.001	0.006	0.136
MD - Perryman - GT1	Distillate	1972	60	2032	20.1%	52	1.053	0.493	0.001	0.006	0.136
MD - Perryman - GT4	Distillate	1972	60	2032	15.7%	52	1.053	0.700	0.001	0.006	0.136
MD - Morgantown Generating Plant - 6	Distillate	1973	60	2033	22.0%	54	0.300	0.560	0.001	0.006	0.136
MD - Morgantown Generating Plant - 5	Distillate	1973	60	2033	21.7%	54	0.300	0.665	0.001	0.006	0.136
MD - Morgantown Generating Plant - 4	Distillate	1973	60	2033	21.0%	54	0.300	0.792	0.001	0.006	0.136
MD - Morgantown Generating Plant - 3	Distillate	1973	60	2033	21.9%	54	0.300	1.263	0.001	0.006	0.136
MD - Chalk Point LLC - GT2	Distillate	1974	60	2034	18.3%	30	0.300	2.288	0.001	0.006	0.136
MD - Easton 2 - 22	Distillate	1978	60	2038	29.6%	6	2.106	3.037	0.001	0.006	0.080
MD - Easton 2 - 21	Distillate	1978	60	2038	29.6%	6	2.106	3.037	0.001	0.006	0.080
MD - Berlin - 5A	Distillate	1989	60	2049	28.8%	3	0.300	2.505	0.001	0.006	0.136
MD - Easton 2 - 24	Distillate	1989	60	2049	24.6%	6	2.106	3.037	0.001	0.006	0.080
MD - Easton 2 - 23	Distillate	1989	60	2049	24.6%	6	2.106	3.037	0.001	0.006	0.080
MD - Smith Island - 3	Distillate	1994	60	2054	18.7%	1	0.300	2.505	0.001	0.006	0.136
MD - Easton - 102	Distillate	1995	60	2055	24.8%	2	0.300	2.505	0.001	0.006	0.136
MD - Easton - 101	Distillate	1995	60	2055	24.8%	2	0.300	2.505	0.001	0.006	0.136
MD - Easton 2 - 201	Distillate	1995	60	2055	29.6%	2	0.300	2.505	0.001	0.006	0.136
MD - Easton 2 - 202	Distillate	1995	60	2055	24.7%	2	0.300	2.505	0.001	0.006	0.136
MD - Berlin - 2A	Distillate	1999	60	2059	28.8%	2	0.300	2.505	0.001	0.006	0.136
MD - Berlin - 3A	Distillate	1999	60	2059	28.8%	2	0.300	2.505	0.001	0.006	0.136
MD - Berlin - 4A	Distillate	2000	60	2060	28.8%	2	0.300	2.505	0.001	0.006	0.136

Table A-8. Existing Maryland Gas/Oil Power Plants

Unit Name	Fuel	Start Year	Life	Retirement	Efficiency	Capacity (MW)	Emission Factors (kt/TBtu)				
							SO2	NOX	VOC	PM25	CO
MD - Easton - 7	Gas / Oil	1954	60	2014	29.8%	2	0.300	2.505	0.001	0.005	0.000
MD - Herbert A Wagner - 1	Gas / Oil	1956	60	2016	25.9%	131	1.100	0.250	0.002	0.004	0.129
MD - Easton - 10	Gas / Oil	1966	60	2026	29.8%	4	0.300	2.505	0.001	0.005	0.000
MD - Riverside - GT6	Gas / Oil	1970	60	2030	18.6%	127	0.001	0.216	0.001	0.005	0.080
MD - Easton - 12	Gas / Oil	1970	60	2030	29.8%	4	0.300	2.505	0.001	0.005	0.000
MD - Easton - 13	Gas / Oil	1973	60	2033	29.8%	6	0.300	2.505	0.001	0.005	0.000
MD - Easton - 14	Gas / Oil	1973	60	2033	29.8%	6	0.300	2.505	0.001	0.005	0.000
MD - Chalk Point LLC - 3	Gas / Oil	1975	60	2035	23.8%	612	0.920	0.127	0.002	0.004	0.129
MD - Chalk Point LLC - 4	Gas / Oil	1981	60	2041	23.4%	612	0.800	0.134	0.002	0.004	0.129
MD - Chalk Point LLC - SGT1	Gas / Oil	1990	60	2050	23.1%	84	0.200	0.194	0.001	0.005	0.080
MD - Chalk Point LLC - GT5	Gas / Oil	1991	60	2051	20.8%	109	0.200	0.045	0.001	0.005	0.080
MD - Chalk Point LLC - GT6	Gas / Oil	1991	60	2051	20.3%	109	0.200	0.071	0.001	0.005	0.080
MD - Chalk Point LLC - GT4	Gas / Oil	1991	60	2051	23.0%	86	0.200	0.076	0.001	0.005	0.080
MD - Chalk Point LLC - GT3	Gas / Oil	1991	60	2051	23.4%	86	0.200	0.082	0.001	0.005	0.080
MD - Dickerson - GT2	Gas / Oil	1992	60	2052	28.9%	147	0.300	0.135	0.001	0.005	0.080
MD - Dickerson - GT3	Gas / Oil	1992	60	2052	27.6%	147	0.300	0.172	0.001	0.005	0.000
MD - Perryman - GT5	Gas / Oil	1995	60	2055	24.5%	152	0.001	0.243	0.001	0.005	0.080
MD - Panda Brandywine LP - 3	Gas / Oil	1996	60	2056	37.7%	73	0.424	0.041	0.001	0.005	0.080
MD - Panda Brandywine LP - 2	Gas / Oil	1996	60	2056	37.7%	79	0.424	0.041	0.001	0.005	0.080
MD - Panda Brandywine LP - 1	Gas / Oil	1996	60	2056	37.7%	79	0.424	0.041	0.001	0.005	0.080
MD - Millennium Hawkins Point - 2A	Gas / Oil	2000	60	2060	39.6%	1	0.424	0.031	0.001	0.005	0.080
MD - Millennium Hawkins Point - 2B	Gas / Oil	2000	60	2060	39.6%	1	0.424	0.031	0.001	0.005	0.080
MD - Millennium Hawkins Point - 1B	Gas / Oil	2000	60	2060	39.6%	1	0.424	0.031	0.001	0.005	0.080
MD - Millennium Hawkins Point - 1A	Gas / Oil	2000	60	2060	39.6%	1	0.424	0.031	0.001	0.005	0.080
MD - Millennium Hawkins Point - 3A	Gas / Oil	2000	60	2060	39.6%	1	0.424	0.031	0.001	0.005	0.080
MD - Millennium Hawkins Point - ST1	Gas / Oil	2000	60	2060	39.6%	1	0.424	0.031	0.001	0.005	0.080
MD - Millennium Hawkins Point - 3B	Gas / Oil	2002	60	2062	39.6%	1	0.424	0.031	0.001	0.005	0.080
MD - UMCP CHP Plant - 3	Gas / Oil	2003	60	2063	39.6%	2	0.424	0.031	0.001	0.005	0.080
MD - UMCP CHP Plant - 2	Gas / Oil	2003	60	2063	39.6%	9	0.424	0.031	0.001	0.005	0.080
MD - UMCP CHP Plant - 1	Gas / Oil	2003	60	2063	39.6%	9	0.424	0.031	0.001	0.005	0.080
MD - Easton 2 - 203	Gas / Oil	2004	60	2064	22.6%	5	0.300	0.256	0.001	0.005	0.000
MD - Easton 2 - 204	Gas / Oil	2004	60	2064	22.6%	5	0.300	0.256	0.001	0.005	0.000

Table A-9. Existing Maryland Hydro Power Plants

Unit Name	Fuel	Start Year	Life	Retirement	Efficiency	Capacity (MW)	Emission Factors (kt/TBtu)				
							SO2	NOX	VOC	PM25	CO
MD - Deep Creek - 1	Hydro	1925	60	N/A	100.0%	9	0.000	0.000	0.000	0.000	0.000
MD - Deep Creek - 2	Hydro	1925	60	N/A	100.0%	9	0.000	0.000	0.000	0.000	0.000
MD - Conowingo - 4	Hydro	1928	60	N/A	100.0%	48	0.000	0.000	0.000	0.000	0.000
MD - Conowingo - 7	Hydro	1928	60	N/A	100.0%	36	0.000	0.000	0.000	0.000	0.000
MD - Conowingo - 5	Hydro	1928	60	N/A	100.0%	36	0.000	0.000	0.000	0.000	0.000
MD - Conowingo - 3	Hydro	1928	60	N/A	100.0%	48	0.000	0.000	0.000	0.000	0.095
MD - Conowingo - 2	Hydro	1928	60	N/A	100.0%	36	0.000	0.000	0.000	0.000	0.095
MD - Conowingo - 1	Hydro	1928	60	N/A	100.0%	48	0.000	0.000	0.000	0.000	0.095
MD - Conowingo - 6	Hydro	1928	60	N/A	100.0%	36	0.000	0.000	0.000	0.000	0.095
MD - Conowingo - 9	Hydro	1964	60	N/A	100.0%	65	0.000	0.000	0.000	0.000	0.095
MD - Conowingo - 8	Hydro	1964	60	N/A	100.0%	65	0.000	0.000	0.000	0.000	0.095
MD - Conowingo - 11	Hydro	1964	60	N/A	100.0%	65	0.000	0.000	0.000	0.000	0.095
MD - Conowingo - 10	Hydro	1964	60	N/A	100.0%	65	0.000	0.000	0.000	0.000	0.095

Table A-10. Existing Maryland Landfill Gas Power Plants

Unit Name	Fuel	Start Year	Life	Retirement	Efficiency	Capacity (MW)	Emission Factors (kt/TBtu)				
							SO2	NOX	VOC	PM25	CO
MD - Prince Georges County Brown Station Road - 3972	LFG	1987	60	2047	23.0%	1	0.171	0.043	0.002	0.004	0.129
MD - Prince Georges County Brown Station Road - 9314	LFG	1987	60	2047	23.0%	1	0.171	0.043	0.002	0.004	0.129
MD - Prince Georges County Brown Station Road - 9340	LFG	1987	60	2047	23.0%	1	0.171	0.043	0.002	0.004	0.129
MD - PG Cnty Brown Station Road II - 4	LFG	2003	60	2063	23.0%	1	0.171	0.043	0.002	0.004	0.095
MD - PG Cnty Brown Station Road II - 1	LFG	2003	60	2063	23.0%	1	0.171	0.043	0.002	0.004	0.095
MD - PG Cnty Brown Station Road II - 3	LFG	2003	60	2063	23.0%	1	0.171	0.043	0.002	0.004	0.095
MD - PG Cnty Brown Station Road II - 2	LFG	2003	60	2063	23.0%	1	0.171	0.043	0.002	0.004	0.095
MD - Eastern Landfill Gas LLC - 3	LFG	2006	60	2066	23.0%	1	0.171	0.043	0.002	0.004	0.095
MD - Eastern Landfill Gas LLC - 1	LFG	2006	60	2066	23.0%	1	0.171	0.043	0.002	0.004	0.129
MD - Eastern Landfill Gas LLC - 2	LFG	2006	60	2066	23.0%	1	0.171	0.043	0.002	0.004	0.129
MD - Newland Park SLF - 1	LFG	2007	60	2067	29.9%	3	0.171	0.090	0.002	0.004	0.129
MD - MACS_MD_Landfill Gas - 1	LFG	2011	60	2071	23.0%	5	0.171	0.090	0.002	0.004	0.024
MD - MACE_MD_Landfill Gas - 1	LFG	2011	60	2071	23.0%	2	0.171	0.090	0.002	0.004	0.024

Table A-11. Existing Maryland Municipal Solid Waste Power Plants

Unit Name	Fuel	Start Year	Life	Retirement	Efficiency	Capacity (MW)	Emission Factors (kt/TBtu)				
							SO2	NOX	VOC	PM25	CO
MD - Wheelabrator Baltimore Refuse - BLR2	MSW	1984	60	2044	16.2%	20	0.344	0.310	0.005	0.006	0.024
MD - Wheelabrator Baltimore Refuse - BLR1	MSW	1984	60	2044	16.2%	20	0.344	0.310	0.005	0.006	0.024
MD - Wheelabrator Baltimore Refuse - BLR3	MSW	1984	60	2044	16.2%	20	0.344	0.310	0.005	0.006	0.024
MD - Montgomery County Resource Recovery - 1	MSW	1995	60	2055	16.2%	18	0.344	0.330	0.005	0.006	0.024
MD - Montgomery County Resource Recovery - 3	MSW	1995	60	2055	16.2%	18	0.344	0.340	0.005	0.006	0.024
MD - Montgomery County Resource Recovery - 2	MSW	1995	60	2055	16.2%	18	0.344	0.340	0.005	0.006	0.024

Table A-12. Existing Maryland Natural Gas Power Plants

Unit Name	Fuel	Start Year	Life	Retirement	Efficiency	Capacity (MW)	Emission Factors (kt/TBtu)				
							SO2	NOX	VOC	PM25	CO
MD - Riverside - 4	Natural Gas	1951	60	2011	22.6%	78	0.001	0.443	0.001	0.003	0.024
MD - Notch Cliff - GT1	Natural Gas	1969	60	2029	18.0%	16	0.001	0.476	0.001	0.003	0.024
MD - Westport - GT5	Natural Gas	1969	60	2029	16.8%	121	0.001	0.635	0.001	0.003	0.024
MD - Notch Cliff - GT6	Natural Gas	1969	60	2029	18.0%	16	0.300	0.476	0.001	0.003	0.024
MD - Notch Cliff - GT3	Natural Gas	1969	60	2029	18.0%	16	0.300	0.476	0.001	0.003	0.000
MD - Notch Cliff - GT4	Natural Gas	1969	60	2029	18.0%	16	0.300	0.476	0.001	0.003	0.000
MD - Notch Cliff - GT5	Natural Gas	1969	60	2029	18.0%	16	0.300	0.476	0.001	0.003	0.000
MD - Notch Cliff - GT8	Natural Gas	1969	60	2029	18.0%	16	0.300	0.476	0.001	0.003	0.000
MD - Notch Cliff - GT2	Natural Gas	1969	60	2029	18.0%	16	0.300	0.476	0.001	0.003	0.012
MD - Notch Cliff - GT7	Natural Gas	1969	60	2029	18.0%	16	0.300	0.476	0.001	0.003	0.012
MD - Rock Springs Generation Facility - 2	Natural Gas	2003	60	2063	28.5%	190	0.300	0.032	0.001	0.003	0.024
MD - Rock Springs Generation Facility - 1	Natural Gas	2003	60	2063	27.5%	190	0.300	0.037	0.001	0.003	0.024
MD - Rock Springs Generation Facility - 3	Natural Gas	2003	60	2063	28.7%	190	0.300	0.038	0.001	0.003	0.024
MD - Rock Springs Generation Facility - 4	Natural Gas	2003	60	2063	26.9%	190	0.300	0.040	0.001	0.003	0.024
MD - Gould Street - 3	Natural Gas	2008	60	2068	28.6%	100	0.354	0.150	0.001	0.003	0.000
MD - MACS_MD_Combustion Turbine - 1	Natural Gas	2011	60	2071	29.5%	30	0.354	0.080	0.001	0.003	0.012

Table A-13. Existing Maryland Other Power Plants

Unit Name	Fuel	Start Year	Life	Retirement	Efficiency	Capacity (MW)	Emission Factors (kt/TBtu)				
							SO2	NOX	VOC	PM25	CO
MD - Calvert Cliffs Nuclear Power Plant - 1	Nuclear	1975	30	N/A	30.1%	885	0.000	0.000	0.000	0.000	0.000
MD - Calvert Cliffs Nuclear Power Plant - 2	Nuclear	1977	32	N/A	30.1%	874	0.000	0.000	0.000	0.000	0.000
MD - Vienna Operations - 8	Residual Oil	1971	60	2031	27.2%	153	3.500	0.300	0.002	0.005	0.001
MD - Herbert A Wagner - 4	Residual Oil	1972	60	2032	23.7%	397	0.600	0.250	0.002	0.005	0.001
MD - MACS_MD_Solar PV - 1	Solar	2011	60	2071	100.0%	0	0.000	0.000	0.000	0.000	0.000

A.3.2.2. New Power Plants

Table A-14 presents key inputs and data sources for the new power plants that were modeled in the multi-pollutant planning exercise. These plants were characterized similarly to existing plants except for residual capacity, as new power plants do not have residual capacity in their base year.

Table A-14. Data Sources for New Power Plant Inputs

Model Input	Data Sources
New Plant Types • Operating Cost • Investment Cost • Capacity Factor • Heat Rate	EIA Updated Estimates of Power Plant Capital and Operating Costs, 2012
Criteria Pollutant Emission Factors	EPA US9R MARKAL database, version 1.1, 2012

Table A-15 presents the operational characteristics of new power plants available to the model for investment in future years. The field entitled "Average Annual Percentage Change" represents the annual yearly decrease in the cost of investing in new power plants. Investment cost decline factors were based on the EIA's *Updated Estimates of Power Plant Capital and Operating Costs, 2012*.[46]

Table A-15. New Power Plant Operating Characteristics

Technology	2014 Investment Cost (2005$)	Average Annual % Change	Variable O&M Cost (2005$/MWh)	Fixed O&M Cost (2005$/kW)	Capacity Factor	Heatrate nth (BTU/kwh)
Scrubbed Coal New	$2,377	-0.7%	1.13	27.03	0.85	8,740
Integrated Coal- Gasification Comb Cycle (IGCC)	$3,065	-0.8%	1.83	44.54	0.85	7,450
Pulverized Coal with Carbon Sequestration	$4,113	-0.9%	1.13	57.61	0.85	9,316
Conventional Gas/Oil Combined Cycle	$757	-0.7%	0.91	11.42	0.82	6,800
Advanced Gas/Oil Combined Cycle	$821	-0.8%	0.83	13.32	0.82	6,333
Advanced Combined Cycle with Carbon Sequestration	$1,617	-0.9%	1.72	27.55	0.85	7,493
Conventional Combustion Turbine	$803	-0.7%	3.92	6.36	0.92	10,450
Advanced Combustion Turbine	$558	-0.9%	2.63	6.10	0.92	8,550
Municipal Solid Waste - Landfill Gas	$6,932	0.0%	2.20	336.75	0.85	13,648
Fuel Cells	$5,333	0.0%	0.00	315.34	0.92	6,960
Advanced Nuclear	$4,146	-0.9%	0.54	80.85	0.90	10,452
Biomass	$3,251	-0.9%	1.34	91.56	0.85	13,500
Geothermal	$2,156	0.0%	0.00	97.87	0.50	9,756
Conventional Hydropower	$1,922	0.0%	0.67	12.85	0.90	9,756
Wind	$1,793	-1.2%	0.00	34.28	0.00	9,756
Wind Offshore	$3,927	-0.6%	0.00	64.14	0.00	9,756

Table A-16 presents the emissions factors for new fossil fuel power plants available in future years. These factors came from the EPA US9R MARKAL database.

[46] http://www.eia.gov/forecasts/capitalcost/.

Table A-16. New Power Plant Criteria Emissions Factors (kT/tBTU)

Technology	SO2	NOX	VOC	PM25	CO
Scrubbed Coal New	1.197	0.056	0.000	0.004	0.001
Integrated Coal- Gasification Comb Cycle (IGCC)	1.197	0.056	0.000	0.004	0.001
Pulverized Coal with Carbon Sequestration	1.197	0.056	0.000	0.004	0.001
Conventional Gas/Oil Combined Cycle	0.739	0.051	0.001	0.003	0.027
Advanced Gas/Oil Combined Cycle	0.739	0.051	0.001	0.003	0.027
Advanced Combined Cycle with Carbon Sequestration	0.177	0.002	0.001	0.003	0.024
Conventional Combustion Turbine	0.177	0.002	0.001	0.003	0.024
Advanced Combustion Turbine	0.177	0.002	0.001	0.003	0.024
Municipal Solid Waste - Landfill Gas	0.172	0.077	0.005	0.006	0.129

A.3.3. Commercial and Residential Sector Input Assumptions

The commercial and residential sectors collectively make up the end-use demands for the buildings sector, which is one of the two main end-use sectors modeled in this analysis. The other end-use sector, transportation, is covered in section A.3.4.
Table A-17 presents key inputs and data sources for the NE-MARKAL buildings sector. Updates for this sector came primarily from the EPA US9R database.

Table A-17. Data Sources for Commercial and Residential Building Inputs

Model Input	Data Sources
Energy Demand	EPA US9R MARKAL database, version 1.1, 2012 EIA State Energy Data System (SEDS) Database, 2012
Technology Definitions • Investment Costs • Residual Capacity • Operating Costs • Lifetime • Efficiency	EPA US9R MARKAL database, version 1.1, 2012 EIA SEDS Database, 2012 *(for residual capacity)*

Table A-18 summarizes Maryland-specific residential demand shares and growth rates over the modeled timeframe. These data are key inputs into the NE-MARKAL model and have a large impact on modeled energy consumption trends. The "Units" field indicates how particular demands are measured. Most demands are measured in energy units of trillion British Thermal Units (tBTU), with the exception of cooling and heating, which are measured in millions of units installed, and lighting, which is measured in billion lumens per year (bn-lum-yr).

Table A-18. Summary of Residential Demand Shares and Growth

Demand	Units	% of Total Demand in 2005	% of Total Demand in 2011	% of Total Demand in 2053	Average Annual Growth Rate from 2005-2011	Average Annual Growth Rate from 2011-2053
Space Cooling	tBTU	38.0%	45.8%	49.3%	6.9%	1.7%
Space Heating	tBTU	29.1%	23.9%	18.2%	0.0%	0.5%
Other Appliances - Electricity	tBTU	18.2%	15.9%	21.0%	4.9%	2.6%
Other Appliances - Gas	tBTU	2.7%	2.2%	2.0%	0.2%	1.0%
Other Appliances - LPG	tBTU	1.4%	1.3%	1.5%	11.5%	2.1%
Water Heating	tBTU	10.6%	10.9%	8.1%	19.4%	0.5%
Refrigeration	million units	25.3%	26.8%	24.7%	2.7%	2.1%
Freezing	million units	74.7%	73.2%	75.3%	9.0%	2.6%
Residential	bn-lum-yr	100.0%	100.0%	100.0%	1.0%	2.1%

Table A-19 summarizes Maryland-specific commercial demand shares and growth rates over the modeled timeframe. As with the residential sector, these are important data inputs for the multi-pollutant modeling exercise. Most of these demands are measures in energy units (tBTU), except for commercial ventilation, which is tracked in trillion cubic feet per meter per hour (tcfm-hr).

Table A-19. Summary of Commercial Demand Shares and Growth

Demand	Units	% of Total Demand in 2005	% of Total Demand in 2011	% of Total Demand in 2053	Average Annual Growth Rate from 2005-2011	Average Annual Growth Rate 2011-2053
Space Cooling	tBTU	32%	31.5%	27.6%	0.6%	1.2%
Office Equipment	tBTU	6%	5.2%	6.6%	-1.8%	2.8%
Space Heating	tBTU	10%	11.5%	8.1%	2.7%	0.5%
Cooking	tBTU	2%	2.5%	2.6%	2.5%	1.9%
Other - Diesel	tBTU	5%	4.9%	2.0%	0.5%	-0.6%
Other - Electricity	tBTU	13%	12.2%	20.5%	0.4%	4.5%
Other - Gas	tBTU	16%	16.0%	16.4%	0.9%	1.8%
Other - LPG	tBTU	1%	1.3%	1.1%	9.1%	1.0%
Other - RFO	tBTU	0%	0.2%	0.1%	-4.0%	0.4%
Refrigeration	tBTU	9%	9.1%	9.1%	1.2%	1.8%
Water Heating	tBTU	5%	5.6%	5.8%	1.6%	1.9%
Lighting	bn-lum-yr	100%	100%	100%	2.1%	1.8%
Ventilation	tcfm-hr	100%	100%	100%	1.3%	1.9%

Tables A-20 and **A-21** present economic and operating characteristics of the residential and commercial technologies within the model. The sectors in each table correspond to the demand sectors in **Tables A-18** and **A-19**. Typically, within each technology group, a number of distinct technologies are represented. The distinct technologies are differentiated by the year they become available. Technology groups with larger numbers of distinct technologies generally represent groups with larger enhancements in efficiency.

Table A-20. Summary of Residential Technology Characteristics

Sector	Technology Group	# of Technologies	Investment Cost ($/MMBtu)		Efficiency	
			Min	Max	Min	Max
Cooling	Central Air Conditioner	4	9.1	14.7	4.1	6.7
	Electric Heat Pump	4	6.6	11.0	4.0	6.9
	Geothermal Heat Pump	2	11.5	15.0	4.1	7.8
	Natural Gas Heat Pump	1	12.2	12.2	0.7	0.7
	Room Air Conditioner	3	2.8	4.6	3.0	3.6
Freezing	Freezer	4	494.2	729.5	0.4	1.0
Heating	Distillate Furnace	3	6.6	9.0	0.8	1.0
	Distillate Radiant	3	9.2	11.5	0.9	1.0
	Electric Heat Pump	4	6.6	11.1	2.3	3.2
	Electric Radiant	1	3.7	3.7	1.0	1.0
	Geothermal Heat Pump	2	11.5	15.0	3.3	5.0
	Kerosene Furnace	3	6.6	9.1	0.8	1.0
	Liquid Gas Furnace	5	4.9	7.2	0.8	1.0
	Natural Gas Furnace	5	4.9	7.2	0.8	1.0
	Natural Gas Heat Pump	1	12.2	12.2	1.4	1.4
	Natural Gas Radiant	3	6.6	8.3	0.8	1.0
Lighting	Compact Fluorescent Lighting	1	3.0	3.0	2.1	2.1
	Halogen Lighting	1	0.5	0.5	0.6	0.6
	Incandescent Lighting	1	2.0	2.0	0.5	0.5
	Linear Fluorescent	1	1.3	1.3	2.6	2.6
	Reflector Lamps	3	2.0	6.8	0.3	1.5
	Solid State	1	96.0	96.0	4.0	4.0
Refrigeration	Refrigeration	8	482.4	1776.8	0.4	0.8
Water Heating	Wood	1	7.9	7.9	1.0	1.0
	Distillate	3	15.0	17.7	0.5	0.7
	Electric Base	5	4.7	15.0	0.9	2.4
	Liquid Gas	4	7.2	16.1	0.6	0.9
	Natural Gas	4	7.2	16.3	0.6	0.9

Table A-21. Summary of Commercial Technology Characteristics

Sector	Technology Group	# of Technologies	Investment Cost ($/MMBtu)		Efficiency	
			Min	Max	Min	Max
Cooking	Electric Range	2	4.1	4.7	0.7	0.8
	Natural Gas Range	2	2.9	4.0	0.5	0.6
Cooling	Electric Air Source Heat Pump	2	7.8	9.8	3.2	3.5
	Electric Central Air Conditioner	3	4.6	19.8	3.0	7.0
	Electric Centrifugal Chiller	2	1.8	4.5	7.2	9.4
	Electric Ground Source Heat Pump	2	14.3	17.3	4.1	8.1
	Electric Reciprocating Chiller	3	4.6	5.4	3.1	4.4
	Electric Rooftop Air Conditioner	2	9.4	26.0	3.3	4.1
	Electric Wall/Window room Air Conditioner	2	2.7	3.9	3.1	3.4
	Natural Gas Heat Pump	6	7.0	22.2	0.6	1.8
Heating	Diesel Boiler	2	1.8	2.6	0.8	0.9
	Diesel Furnace	1	1.4	1.4	0.8	0.8
	Electric Air Source Heat Pump	2	7.8	9.8	3.3	3.4
	Electric Boiler	2	1.6	1.6	0.9	0.9
	Electric Groud Source Heat Pump	2	14.3	17.3	3.5	4.9
	Natural Gas Boiler	2	3.1	3.9	0.8	1.0
	Natural Gas Furnace	2	1.0	1.1	0.8	0.9
	Natural Gas Heat pump	1	22.2	22.2	1.4	1.4
Lighting	Fluorescent	8	11.6	30.6	1.6	3.0
	Halogen	2	60.4	63.7	0.4	0.5
	High Pressure Sodium	2	24.1	73.4	1.4	2.2
	Incandescent	3	35.3	84.1	0.3	1.3
	Light Emitting Diode	1	179.0	179.0	4.0	4.0
	Mercury Vapor	2	21.5	62.2	0.8	0.9
	Metal Halide	2	22.5	41.8	1.5	1.7
Refrigeration	Refrigeration	16	17.5	267.0	0.5	7.5
Ventilation	Electric CAV	2	854.8	899.7	0.6	1.1
	Electric VAV	2	856.3	895.4	0.7	1.6
Water Heating	Diesel	3	2.1	2.2	0.8	0.8
	Electric Heat Pump	2	25.7	29.8	2.0	2.4
	Solar	2	23.2	28.7	2.5	3.0
	Electric	2	3.4	3.4	1.0	1.0
	Natural Gas Instantaneous	3	0.5	1.0	0.8	0.9
	Natural Gas	2	2.6	3.0	0.8	0.9

A.3.4. Transportation Sector Input Assumptions

The transportation sector is broken out into light- and heavy-duty vehicles. Within each major class, a number of sub-categories of vehicle are represented in the NE-MARKAL model. **Table A-22** presents key inputs and data sources for the NE-MARKAL transportation sector.

Table A-22. Data Sources for Transportation Inputs

Model Update	Data Sources
Energy Demand	EPA US9R MARKAL database, version 1.1, 2012 MOVES EIA SEDS Database, 2012
Technology Definitions • Investment Costs • Residual Capacity • Operating Costs • Lifetime • Efficiency • Criteria Emissions Factors	EPA US9R MARKAL database, version 1.1, 2012 EIA SEDS Database, 2012 *(for residual capacity)*

Table A-23 summarizes Maryland-specific transportation demand shares and growth rates over the modeled timeframe. The demands are measured in billion vehicle miles traveled (bVMT).

Table A-23. Summary of Transportation Demand Shares and Growth

Demand	Units	% of Total Demand in 2005	% of Total Demand in 2011	% of Total Demand in 2053	Average Annual Growth Rate from 2005-2011	Average Annual Growth Rate 2011-2053
Light-Duty	bVMT	91.8%	91.7%	91.7%	0.3%	1.4%
Bus	bVMT	0.2%	0.2%	0.2%	0.2%	0.9%
Medium-Duty	bVMT	1.5%	1.9%	1.9%	3.9%	1.1%
Heavy-Duty	bVMT	4.3%	4.2%	4.2%	0.1%	1.2%
Commercial Trucks	bVMT	2.1%	2.0%	2.0%	-0.8%	1.2%

Tables A-24 and **A-25** present economic and operating characteristics of light- and heavy-duty transportation technologies, respectively. The technology names represent distinct technology types within each major transportation class. The cost data in **Table A-24** are in 2005 dollars.

Table A-24. Light-duty Vehicle Technology Characteristics

Technology Class	Technology Name	1st Year Investment Cost ($/bVMT)	O&M Cost ($/bVMT)	Efficiency (MPG)
Compact/mini	Gasoline	$2,606	$38.5	25.1
	Electric 100 mile range	$4,783	$28.8	
	Electric 200 mile range	$4,428	$28.8	
	Advanced Gasoline	$2,679	$38.5	32.6
	Diesel	$2,008	$38.5	32.8
	CNG	$2,357	$34.6	27.6
	Diesel Hybrid EV	$2,410	$40.4	0.0
	E85 Flex Fuel	$1,817	$38.5	26.8
	Hydrogen Fuel Cell	$5,859	$40.4	48.5
	Gasoline Hybrid EV	$2,367	$40.4	46.0
	LPG	$2,252	$34.6	26.5
	Gasoline Plug-in Hybrid EV	$2,220	$40.4	67.6
	Advanced E85 Flex Fuel	$2,682	$38.5	32.4
Fullsize	Gasoline	$2,154	$43.3	25.4
	Electric 100 mile range	$4,548	$32.5	
	Electric 200 mile range	$4,157	$32.5	
	Advanced Gasoline	$2,227	$43.3	33.1
	CNG	$2,911	$38.9	25.4
	Diesel Hybrid EV	$2,671	$45.5	
	Diesel	$2,322	$43.3	31.4
	E85 Flex Fuel	$2,162	$43.3	25.7
	Hydrogen Fuel Cell	$5,921	$45.4	44.0
	Gasoline Hybrid EV	$2,733	$45.4	44.2
	LPG	$2,597	$38.9	25.4
	Gasoline Plug-in Hybrid EV	$2,590	$45.5	65.0
	Advanced E85 Flex Fuel	$2,227	$43.3	32.9
Minivan	Gasoline	$2,052	$43.3	22.3
	Electric 100 mile range	$5,590	$32.5	
	Electric 200 mile range	$4,890	$32.5	
	Advanced Gasoline	$2,166	$43.3	30.6
	CNG	$2,696	$38.9	23.1
	Diesel Hybrid EV	$2,855	$45.4	39.5
	Diesel	$2,479	$43.3	27.5
	E85 Flex Fuel	$2,060	$43.3	22.5
	Hydrogen Fuel Cell	$6,891	$47.6	34.7
	Gasoline Hybrid EV	$2,564	$45.5	37.0
	LPG	$2,748	$38.9	23.1
	Gasoline Plug-in Hybrid EV	$2,646	$45.5	55.3
	Advanced E85 Flex Fuel	$2,166	$43.3	29.2
Pickup	Gasoline	$1,777	$48.1	18.9
	Electric 100 mile range	$5,511	$36.1	
	Electric 200 mile range	$4,781	$36.1	
	Advanced Gasoline	$1,891	$48.1	25.9
	CNG	$2,552	$48.1	19.3
	Diesel	$2,211	$48.1	23.5
	E85 Flex Fuel	$1,785	$48.1	19.1
	Gasoline Hybrid EV	$2,507	$48.1	34.4
	LPG	$2,598	$48.1	19.3
	Gasoline Plug-in Hybrid EV	$2,396	$48.1	51.4
	Advanced E85 Flex Fuel	$1,891	$48.1	24.7
Small SUV	Gasoline	$1,925	$43.3	22.8
	Electric 100 mile range	$5,120	$32.5	
	Electric 200 mile range	$4,516	$32.5	
	Advanced Gasoline	$2,039	$43.3	31.3
	Diesel Hybrid EV	$2,693	$45.5	45.6
	Diesel	$2,289	$43.3	28.1
	E85 Flex Fuel	$1,933	$43.3	23.0
	Hydrogen Fuel Cell	$6,358	$45.5	
	Gasoline Hybrid EV	$2,522	$45.5	40.3
	Gasoline Plug-in Hybrid EV	$2,519	$45.5	60.3
	Advanced E85 Flex Fuel	$2,063	$43.3	33.2
Large SUV	Gasoline	$2,907	$43.3	18.3
	Electric 100 mile range	$6,593	$32.5	
	Electric 200 mile range	$5,866	$32.5	
	Advanced Gasoline	$3,021	$43.3	25.1
	Diesel Hybrid EV	$3,737	$45.5	39.1
	Diesel	$3,290	$43.3	22.7
	E85 Flex Fuel	$2,915	$43.3	18.5
	Hydrogen Fuel Cell	$6,633	$45.5	30.8
	Gasoline Hybrid EV	$3,549	$45.5	33.0
	Gasoline Plug-in Hybrid EV	$3,501	$45.5	49.4
	Advanced E85 Flex Fuel	$3,021	$43.3	24.0

Table A-25. Heavy-duty Vehicle Characteristics

Technology Class	Technology Name	1st Year Investment Cost ($2005/bVMT)	O&M Cost ($2005/bVMT)	Lifetime
Busses	Bus, Conventional/improved	$10,519	$555.1	12
	Bus, Advanced	$14,348	$559.8	12
	Bus, Conventional/improved Biodiesel	$10,808	$524.2	12
	Bus, Advanced	$14,348	$544.3	12
	Bus, Conventional/improved CNG	$12,211	$639.7	12
	Bus, Advanced CNG	$15,316	$644.4	12
	Bus, Hydrogen Fuel Cell	$63,772	$1,317.1	12
Commercial Trucks	Commercial Truck, Advanced Hybrid B20	$1,905	$55.3	15.5
	Commercial Truck, Conventional/improved B20	$1,420	$56.0	15.5
	Commercial Truck, Advanced CNG	$1,656	$56.3	15.5
	Commercial Truck, Conventional/improved CNG	$1,468	$39.4	15.5
	Commercial Truck, Advanced Hybrid Diesel	$1,905	$31.0	15.5
	Commercial Truck, Conventional/improved Diesel	$1,420	$31.0	15.5
	Commercial Truck, Advanced/hybrid E85	$1,333	$43.7	15.5
	Commercial Truck, Conventional/improved E85	$1,161	$56.3	15.5
	Commercial Truck, Advanced Tech Gasoline	$1,346	$56.3	15.5
	Commercial Truck, Conventional/improved Gasoline	$1,137	$56.3	15.5
	Commercial Truck, Hydrogen Fuel Cell	$2,696	$56.3	15.5
	Commercial Truck, Advanced/hybrid LPG	$1,612	$56.3	15.5
	Commercial Truck, Improved/conventional LPG	$1,436	$56.3	15.5
	Commercial Truck, LPG 2010	$1,398	$15.5	15.5
Medium Duty Trucks	Medium Duty Truck, Advanced Tech B20	$7,553	$192.8	19
	Medium Duty Truck, Conventional/improved B20	$6,393	$248.8	19
	Medium Duty Truck, B20, 2010	$6,277	$248.8	19
	Medium Duty Truck, Advanced Hybrid CNG	$7,844	$248.8	19
	Medium Duty Truck, Conventional/improved CNG	$6,834	$207.8	19
	Medium Duty Truck, Advanced Diesel	$7,551	$136.8	19
	Medium Duty Truck, Conventional/improved Diesel	$6,445	$133.2	19
	Medium Duty Truck, Advanced Hybrid Gasoline	$6,616	$136.8	19
	Medium Duty Truck, Conventional/improved Gasoline	$6,040	$207.8	19
	Medium Duty Truck, Advanced Hybrid LPG	$6,998	$237.9	19
	Medium Duty Truck, Conventional/improved LPG	$6,437	$248.8	19
Heavy Trucks	Heavy Truck, Short Haul, Advanced/hybrid B20	$5,323	$233.6	19
	Heavy Truck, Short Haul, Conventional/improved B20	$4,679	$221.1	19
	Heavy Truck, Short Haul, Advanced/hybrid CNG	$5,695	$165.8	19
	Heavy Truck, Short Haul, CNG existing	$5,076	$166.0	19
	Heavy Truck, Short Haul, Improved/conventional CNG	$5,026	$165.9	19
	Heavy Truck, Short Haul, Advanced/hybrid Diesel	$5,323	$193.6	19
	Heavy Truck, Short Haul, Conv./improved Diesel	$4,679	$248.8	19
	Heavy Truck, Short Haul, Gasoline, 2010	$4,265	$249.0	19
	Heavy Truck, Long Haul, Diesel Conventional/improved 2010	$1,721	$148.9	12
	Heavy Truck, Long Haul, Advanced/hybrid/smart way Diesel	$2,250	$170.8	12
	Heavy Truck, Long Haul, B20 Conventional/improved	$1,718	$148.9	12
	Heavy Truck, Long Haul, Advanced/hybrid/smart way B20	$2,077	$170.8	12
	Heavy Truck, Long Haul, LNG 2010	$2,389	$289.8	12
	Heavy Truck, Long Haul, Conventional LNG	$2,399	$289.8	12
	Heavy Truck, Long Haul, Advanced/hybrid/smart way LNG	$2,673	$289.8	12

A.4. Calibrated Maryland Reference Case

This section describes how the baseline NE-MARKAL reference case was modified or supplemented to reflect a Maryland-specific reference case for the weight-of-evidence exercise. It also presents the results for the energy and criteria emissions calibration. The calibration process was necessary for replacing the model's base default data (described in the sections above) to create the Maryland-specific reference case that was used for the analysis. **Figure A-5** qualitatively presents the NE-MARKAL calibration process.

For this analysis, the reference case NE-MARKAL energy calibration was accomplished in three phases:

(1) Aligning energy consumption in NE-MARKAL with observed historical trends between 2005 and 2011. This phase was executed by fixing NE-MARKAL energy consumption trends by sector and fuel type to Maryland-specific data reported in the EIA State Energy Data System (SEDS).

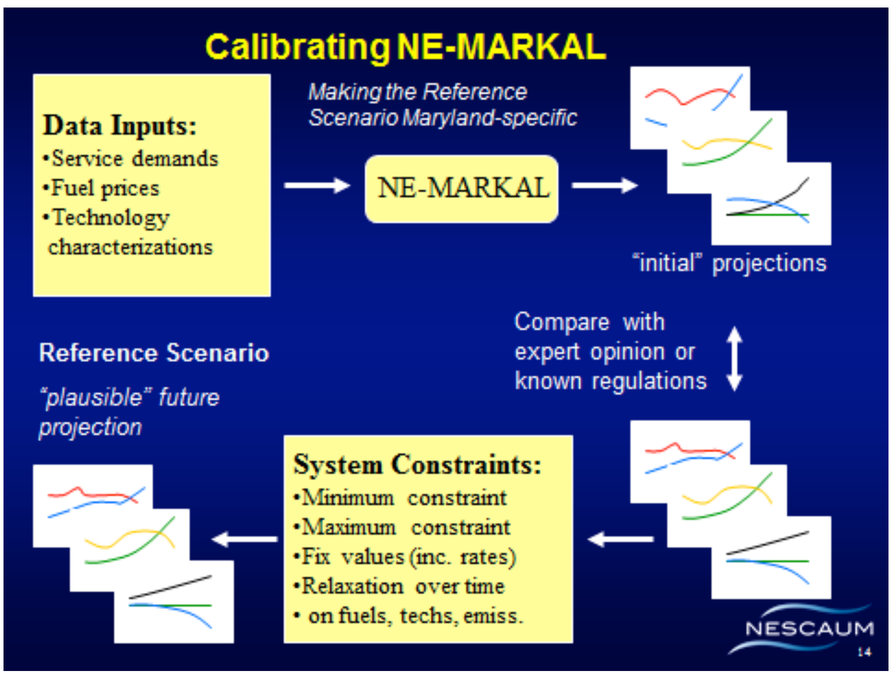
(2) Developing future NE-MARKAL reference case energy consumption trends by sector and fuel type.

a. Construct a set of benchmark future energy consumption trends that NE-MARKAL could be calibrated to by applying AEO 2012 energy consumption growth rates by sector and fuel for the 2011-2023 period to the SEDS data used in the first phase of the energy calibration.

b. Set up a series of soft constraints in NE-MARKAL by sector and fuel to ensure that the model's reference case energy consumption trends match the main features of the AEO 2012 reference case.

(3) Review full reference case energy calibration with MDE and other project stakeholders to identify potential issues.

Figure A-5. Process for Calibrating NE-MARKAL



NESCAUM conducted a series of weekly calls and in-person meetings to review and discuss the NE-MARKAL reference case calibration process. The review process, conducted over a 2 to 3 month period, was aimed at identifying potential issues with the energy calibration and to provide critical project partners an opportunity to provide feedback on the NE-MARKAL reference case. All modeled results were reviewed and approved by MDE, MEA, and MDOT before finalizing the multi-pollutant reference case and policy analysis scenarios. The NE-MARKAL model begins in 2005 and models state and regional energy decision-making out to 2053 in three year time increments.

For the core GGRA analysis, the modeling timeframe ranged between the years 2008 and 2023. For the climate sensitivity analysis, however, the timeframe was extended to 2050. The energy calibration was conducted over the full modeling timeframe of 2005-2053, which are presented in **Figures A-6** through **A-9**. In each of the calibration figures, the solid black line indicates the break between historical data calibration and future trend calibration. Values to the left of the black lines were fixed to historical trends while values to the right represent the AEO / SEDS benchmark future trends (dotted lines) and the calibrated NE-MARKAL future trends (solid lines). The goal of the NE-MARKAL future trend calibration was to qualitatively align with the AEO / SEDS benchmark trends while at the same time ensuring NE-MARKAL had flexibility to meet future climate and air quality modeling targets. The project partners approved the calibration as representing acceptable future trajectories for the reference case.

Figure A-6. Commercial Sector Energy Calibration

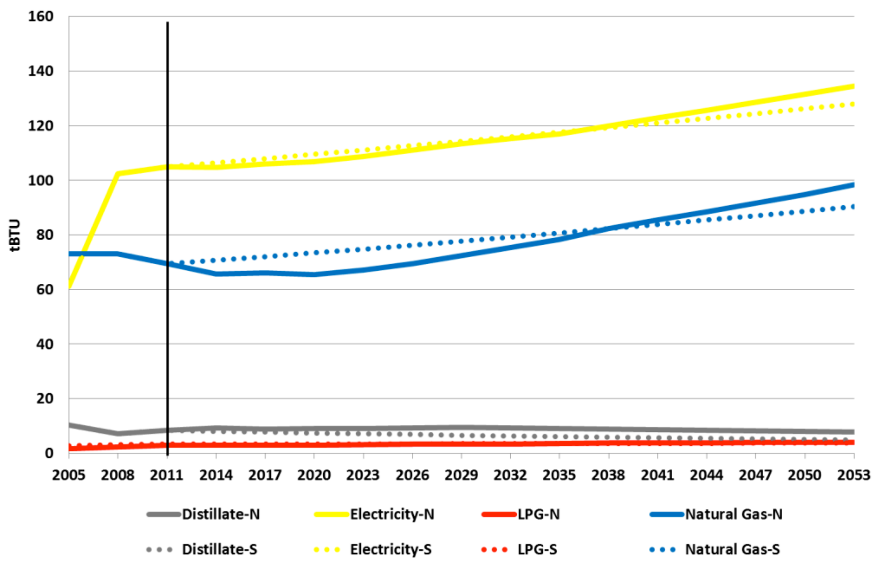


Figure A-7. Residential Sector Energy Calibration

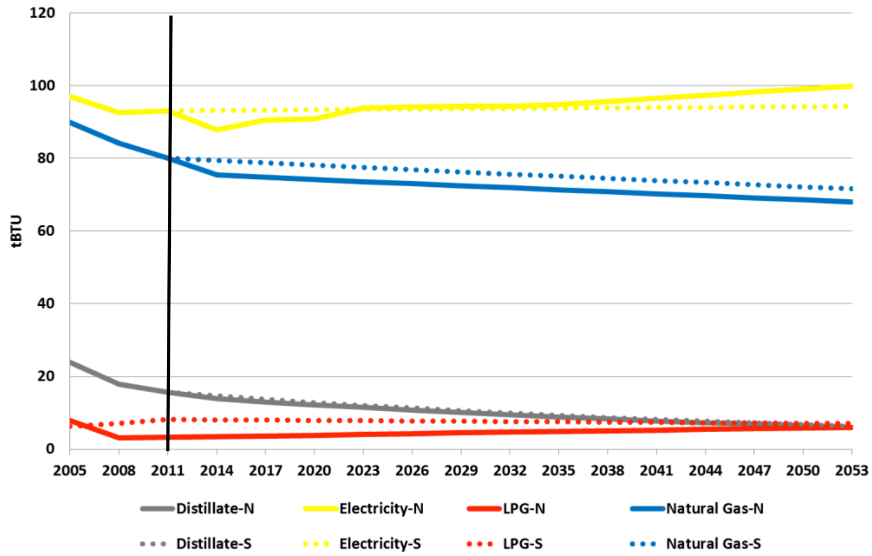


Figure A-8. Power Sector Energy Calibration

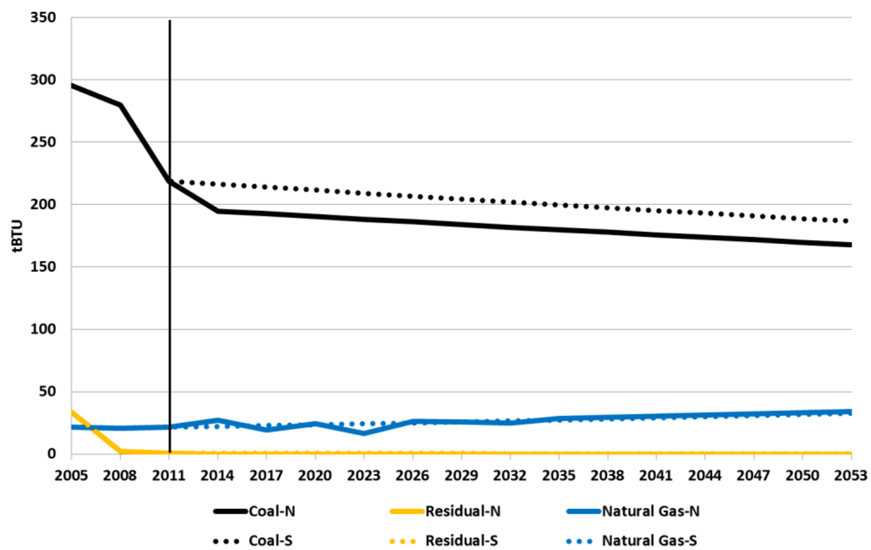


Figure A-9. Transportation Sector Energy Calibration

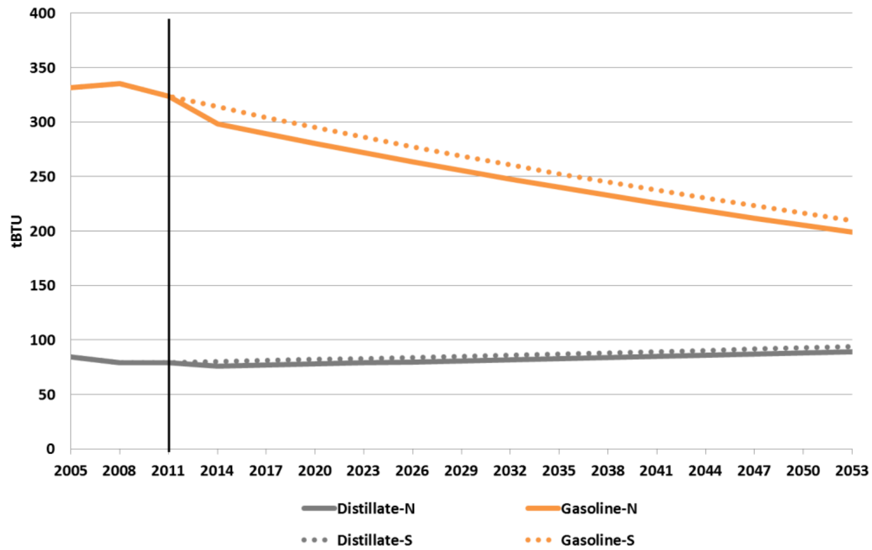


Table A-26 presents the NE-MARKAL emissions calibration results. NESCAUM used 2008 emissions inventory data provided by MDE to benchmark the NE-MARKAL air emissions. The goal of the emissions calibration was to ensure that base year criteria emissions aligned well with the 2008 emissions inventory. We did not attempt to benchmark future NE-MARKAL air emissions to a particular set of modeled results. We felt that the energy calibration accomplished appropriate future trajectories for criteria air emissions. The results in **Table A-26** were reviewed and approved by MDE. We feel this calibration provides an acceptable starting point for the GGRA policy modeling efforts.

Table A-26. Criteria Emissions Calibration

Commercial Sector (2008, Thousand Tons)

	NE-MARKAL Output	Maryland Inventory Data	% Difference
CO	6.6	6.5	1.3%
$PM_{2.5}$	0.1	0.1	29.8%
NO_x	3.8	3.4	11.2%
SO_2	1.8	1.7	9.2%
VOC	0.3	0.3	-17.2%

Residential Sector (2008, Thousand Tons)

	NE-MARKAL Output	Maryland Inventory Data	% Difference
CO	2.4	2.4	2.0%
$PM_{2.5}$	0.2	0.2	-5.1%
NO_x	5.5	5.3	3.4%
SO_2	2.5	2.9	-14.1%
VOC	0.3	0.3	3.2%

Power Sector (2008, Thousand Tons)

	NE-MARKAL Output	Maryland Inventory Data	% Difference
CO	22.0	23.0	-4.1%
$PM_{2.5}$	10.6	11.7	-9.6%
NO_x	53.6	54.5	-1.5%
SO_2	273.7	274.8	-0.4%
VOC	0.4	0.4	-5.8%

Transportation Sector On-Road (Thousand Tons)

	NE-MARKAL Output	MARAMA MOVES	% Difference
CO	468.4	471.6	-0.7%
$PM_{2.5}$	3.7	3.8	-3.5%
NO_x	118.8	124.9	-4.9%
SO_2	0.8	1.0	-16.6%
VOC	35.0	35.1	-0.1%

A.5. Developing Policy Scenarios for Modeling

After calibrating the reference case, MDE and NESCAUM defined policy scenarios to analyze. The goal was to identify two meta-scenarios comprised of individual GHG reduction policies that were part of Maryland's GGRA Plan. NESCAUM reviewed the GGRA Plan and identified 12 policies that were best suited for analysis within the NE-MARKAL modeling framework. NESCAUM then worked with MDE to define an initial and an enhanced meta-scenario. This required examining each policy and assessing initial and enhanced goals. For the initial meta-scenario, GGRA Plan policy goals were used. For the enhanced meta-scenario, NESCAUM used enhanced goals that were defined either in the GGRA Plan or by MDE. In some cases, especially with some of the transportation sector policies, only an initial version of the policy was defined for analysis in both meta-scenarios.

Once the initial and enhanced meta-scenarios were defined, the two meta-scenarios were translated into NE-MARKAL modeling runs. NESCAUM held a series of phone calls and in-person meetings with MDE, MEA, and MDOT to review how each meta-scenario was defined and to review the initial modeling results. After MDE approved the meta-scenario definitions and initial results, NESCAUM began to prepare a final spread sheet-based template to present the final versions of each meta-scenario.

Table A-27 summarizes the initial and enhanced policies, and **Table A-28** summarizes which policies are contained in the two meta-scenarios, with "I" denoting initial policies and "E" denoting enhanced level policies. The scenarios highlighted in blue font, collectively referred to as the transportation bundle, remained at initial levels in both the initial and enhanced meta-scenarios.

Table A-27. Initial and Enhanced Policy Definitions

Policy	Definition
RGGI	• Initial GGRA: model the RGGI cap before the updated model rule. • Enhanced GGRA: model the 91 MT updated model rule cap (using scenario: 91cap alt bank MR).
EmPOWER Maryland	• Initial GGRA: reduce MD per capita total electricity consumption 15% by 2015 relative to 2007; represented as an energy efficiency program. • Enhanced GGRA: expand energy efficiency to include natural gas
MD RPS	• Initial GGRA: require 20% qualified renewable generation regionally by 2022--only solar required in-state; the rest can come from the region. • Enhanced GGRA: require 25% qualified renewable generation regionally by 2020. • For both scenarios: (1) Tier 2 hydro to remain constant at 2.5% until 2018, and then sunset; (2) 2% solar by 2020.
Main Street Initiatives	• Initial GGRA: defined using the analysis of the low potential for energy efficiency provided by MDE. • Enhanced GGRA: defined using the analysis of the high potential for energy efficiency provided by MDE
Energy Efficiency for Affordable Housing	• Initial GGRA: Use methodology on pp. 115-116 of the GGRA Plan at $6,500 per retrofit. • Enhanced GGRA: Use methodology on pp. 115-116 of the GGRA Plan at $5,268 per retrofit.
CAFE Model Year 2008-2011	• NHTSA's pre-existing 2008-2011 fuel efficiency standards of 20.5 mpg. • No enhanced scenario.

Table A-27. Continued

Policy	Definition
MD Clean Cars Program	• For model years 2012-2025: assume passenger fleet achieves most recent CAFE standards (~54.5 mpg by 2025). • No enhanced scenario.
National Fuel Efficiency and Emissions Standards for Medium- and Heavy-Duty Trucks	• EPA/NHTSA standards for model years 2012-2016 for medium- and heavy-duty trucks. • Standard does not sunset after 2016. • No enhanced scenario.
Public Transportation and Intercity Transportation Initiatives	• Initial GGRA: Assume 2.3% of Maryland's passenger vehicle fleet will be composed of BEVs and PHEVs by 2020. • No enhanced scenario
Building and Trade Codes	• Commercial and residential buildings to increase energy efficiency by 15%, starting in 2012. • No enhanced scenario.
Gas Tax	• Initial GGRA: Based on the documentation sent by MDOT, apply a gas tax of $0.24 per gallon. • Enhanced GGRA: Based on the documentation sent by MDOT, apply a gas tax of $1.20 per gallon.
Tier 3	• Initial: Adopt new SO2, NOx, and PM standards for motor gasoline beginning in 2017. • No enhanced scenario.

Table A-28 summarizes which policies are contained in the two meta-scenarios, with "I" denoting initial policies and "E" denoting enhanced level policies. The scenarios highlighted in blue font, collectively referred to as the transportation bundle, remained at initial levels in both the initial and enhanced meta-scenarios.

Table A-28. Modeled Policies and Meta-scenario Definitions

	Scenario Definitions	
Policy	**Initial Meta-scenario**	**Enhanced Meta-scenario**
Regional Greenhouse Gas Initiative	I	E
Maryland Renewable Portfolio Standard	I	E
EmPOWER Maryland	I	E
Main Street	I	E
Energy Efficiency for Affordable Housing	I	E
Maryland Clean Cars	I	I
CAFE 2008-2011	I	I
Fuel Efficiency for Medium and Heavy Duty Trucks	I	I
Public Transportation and Intercity Transportation Initiatives	I	I
Tier 3 Vehicle and Emission Standards	I	I
Gas Tax	I	E
Building and Trade Codes	I	I

A.5.1. Individual Policy Descriptions

This section describes each policy that was included in the analysis. The initial and enhanced policy definitions were provided by either the GGRA Plan or MDE. Note that enhanced policies not based on the GGRA Plan are for analytical exercise purposes only, and may not reflect current Maryland policy.

A.5.1.1. The Regional Greenhouse Gas Initiative

The initial version of the Regional Greenhouse Gas Initiative (RGGI) assumed that each RGGI state's CO_2 budget remained at levels determined in the 2008 model rule. The enhanced version was based on the 2012 program review carried out by RGGI, Inc.[47] For the enhanced version, the RGGI regional CO_2 cap in 2014 was set at 91 million metric tons; after 2014, the cap declines 2.5 percent each year, out to 2020.

A.5.1.2. Maryland Renewable Portfolio Standard

The initial version of the Maryland Renewable Portfolio Standard (RPS) required 20 percent of electricity generation to come from qualified renewable sources by 2022. The enhanced RPS required 25 percent of electricity generation to come from qualified renewable sources by 2020. In both versions of the RPS, there are in-state solar and hydro carve-outs. The solar carve-out was modeled to reach 2 percent of total generation by 2020, and the hydro carve-out was modeled to reach 2.5 percent of total generation by 2018.

A.5.1.3. EmPOWER Maryland

EmPOWER Maryland's initial target was to reduce per-capita electricity consumption 15 percent by 2015, relative to 2007. The electricity reduction was simulated as an energy efficiency scenario in the NE-MARKAL framework. The enhanced version of EmPOWER Maryland layered a natural gas efficiency component on top of the electric efficiency modeled in the initial version. The enhanced target for natural gas efficiency reduced forecast natural gas sales by 1.2 percent by 2020.

A.5.1.4. Main Street Initiative

The initial policy for the Main Street Initiative set a savings target for residential and commercial energy efficiency in heating, cooling and lighting applications of 57,725 MMBtu between 2011 and 2020. The enhanced policy set an efficiency savings target of 94,540 MMBtu between 2011 and 2020.

A.5.1.5. Transportation Scenario Bundle

The transportation bundle included five individual transportation sector policies. They were represented in both the initial and enhanced meta-scenario in their initial form, as follows:

- Maryland Clean Cars: For model years 2012-2025 all passenger vehicles were to achieve the most recent CAFE standards of 54.5 miles per gallon (mpg) by 2025.
- Corporate Average Fuel Economy (CAFE) 2008-2011: For model years 2008-2011 all passenger vehicles were to achieve 20.5 mpg.
- Fuel Efficiency for Medium- and Heavy-Duty Vehicles: Medium- and heavy-duty vehicles were to achieve the 2011 EPA/NHTSA CAFE standards.

[47] http://www.rggi.org/rggi.

- Public Transportation and Intercity Transportation Initiatives: This policy assumed that 2.3 percent of Maryland's passenger vehicle fleet would be battery electric vehicles and plug-in hybrid electric vehicles by 2020.
- Tier 3 Motor Vehicle Emission and Fuel Standards: This policy assumed adoption of the new NO_X and PM standards for all vehicles beginning in 2017, along with a low sulfur gasoline requirement.

A.5.1.6. Gas Tax

The initial version of the gas tax policy assumed a $0.27 per gallon tax by 2020. The enhanced version of the gas tax assumed $1.20 per gallon tax by 2020, and a 3.3 percent reduction in VMT by 2020.

A.5.1.7. Energy Efficiency for Affordable Housing

The initial policy for Energy Efficiency for Affordable Housing set a savings target for residential natural gas energy efficiency applications of 200,260 MMBtu between 2011 and 2020. The enhanced policy set a savings target for residential natural gas energy efficiency applications of 247,000 MMBtu between 2011 and 2020.

A.5.1.8. Building and Trade Codes

Only an initial version of the building and trade codes policy was defined and used in both meta-scenarios. The policy assumed a 15 percent increase in the overall efficiency of commercial and residential buildings by 2020, with efficiency increases assumed to start in 2012.

A.5.2. Policies Modeled Outside of NE-MARKAL

Two GGRA policies were important to analyze within the full Multi-pollutant Policy Analysis Framework but were not well-suited for modeling in NE-MARKAL. For these policies, emissions impacts were estimated through other methods by MDE and then incorporated into the data set that were used as inputs for CMAQ air quality modeling. The policies were:

- Zero Waste: Emission changes were treated as changes to area source emissions.
- Boiler MACT: Emission changes were applied directly to the affected boilers at the appropriate SCC level.

A.6. References

Annual Energy Outlook 2012; DOE/EIA-0383 (2012); *EIA* (Energy Information Administration): Annual Energy Outlook 2012. U.S. EIA Rept. DOE/EIA-0383(2012), U.S. Energy Information Administration: Washington, DC, June 2012. Available: http://www.eia.gov/forecasts/archive/aeo12/

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Appendix B: NE-MARKAL Spreadsheet Results

Appendix B is available as a separate spreadsheet file from the Maryland Department of the Environment.

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Appendix C: Emissions Changes for CMAQ Air Quality Modeling Analysis

Table C-1. Domain-wide Reductions Based on a 2018 Modeling Scenario

SOURCE TYPE	*REGION*	*NO_X*	*SO_2*	*VOC*	*PM*	*CO*
AREA	**SESARM**	**-14.8%**	**-77.9%**	**-7.0%**	**-1.5%**	
	CENRAP	**-8.9%**	**-70.1%**	**-7.0%**	**-0.1%**	
	LADCO	**-10.8%**	**-61.5%**	**-7.0%**	**-0.7%**	
	CANADA	**-8.0%**		**-7.0%**		
	2011 OIL&GAS					
MAR	**DOMAIN**	**-31.0%**		**-13.0%**		
NONROAD	**DOMAIN**	**-43.0%**		**-44.0%**		
MOBILE	**DOMAIN**	**-51.4%**	**-13.4%**	**-46.9%**	**-34.6%**	**-30.1%**
NON-EGU POINT	**SESARM**	**-9.5%**	**-9.7%**	**-1.0%**	**-2.7%**	
	CENRAP	**-17.8%**	**-23.5%**	**-1.0%**	**-0.9%**	
	LADCO	**-13.9%**	**-28.3%**	**-1.0%**	**-3.6%**	
	CANADA	**-8.0%**		**-1.0%**		
EGU	**2018 ERTAC**					

Table C-2. Reference Case Percent Change in Emissions Sector by Pollutant by State

Area	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-14.81%	-10.49%	-3.11%	-32.61%	-29.14%
DC	-0.57%	5.71%	15.00%	-44.74%	-22.31%
DE	2.80%	8.15%	14.39%	-46.97%	-31.35%
MA	-7.53%	-5.24%	-0.17%	-14.46%	-11.95%
MD	7.27%	10.80%	15.76%	-19.49%	-9.13%
ME	-3.56%	-1.25%	2.47%	-11.00%	-8.30%
NH	-3.74%	-1.34%	2.57%	-11.20%	-8.50%
NJ	-19.53%	-13.91%	-5.94%	-52.94%	-46.76%
NY	-15.92%	-11.58%	-4.78%	-38.30%	-30.58%
PA	-12.06%	-9.45%	-4.24%	-29.11%	-24.69%
RI	-22.40%	-16.50%	-7.43%	-45.85%	-41.54%
VT	-4.02%	-1.78%	1.87%	-12.37%	-9.91%

Non-EGU Point	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-7.60%	-2.13%	-13.79%	-59.20%	-56.55%
DC	0.48%	-0.07%	6.13%	-37.70%	-45.72%
DE	-79.07%	-26.28%	-5.95%	-85.25%	-72.72%
MA	-35.25%	-11.75%	-39.83%	-87.28%	-47.94%
MD	-64.62%	13.85%	-16.51%	-88.77%	-75.95%
ME	15.22%	-6.06%	46.40%	-27.27%	-5.18%
NH	-53.40%	61.29%	60.57%	-94.13%	-29.11%

NJ	-59.81%	-4.61%	-31.30%	-93.50%	-62.27%
NY	-66.18%	-9.57%	-16.94%	-72.41%	-60.82%
PA	-75.77%	-0.14%	-17.39%	-94.78%	-60.43%
RI	-40.31%	-0.76%	-43.34%	-5.23%	-9.04%
VT	-0.44%	-23.52%	-39.70%	-24.32%	-14.74%

Onroad	NO_X	VOC	CO	SO_2	$PM_{2.5}$
All states	-67.17%	-64.32%	-47.00%	-20.71%	-46.31%

EGU	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-53.05%	-22.90%	10.85%	-7.98%	-19.13%
DC	-95.30%	-88.90%	-98.12%	-63.32%	-93.33%
DE	-15.36%	-17.48%	-15.86%	-5.89%	-9.79%
MA	-22.13%	-0.68%	36.52%	-10.28%	-0.19%
MD	-42.79%	-11.67%	-16.91%	-27.40%	-25.82%
ME	-55.65%	-38.60%	-19.93%	-59.52%	-41.06%
NH	-46.73%	-15.31%	-9.45%	-57.11%	-28.08%
NJ	-39.00%	-22.70%	-22.09%	-25.18%	-20.65%
NY	-29.45%	-10.29%	-4.32%	-16.65%	-9.34%
PA	-21.95%	-8.89%	-13.04%	-13.40%	-12.98%
RI	5.94%	-15.70%	-9.74%	2.15%	-14.58%
VT	-65.34%	-52.07%	-52.67%	-54.90%	-52.73%

Nonroad	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-34.28%	-4.71%	-2.80%	-90.95%	-52.45%
DC	19.86%	-0.11%	-2.49%	-92.65%	-34.77%
DE	-27.35%	-4.42%	-2.49%	-92.62%	-50.41%
MA	-34.63%	-4.73%	-2.80%	-90.95%	-52.52%
MD	-30.16%	-4.57%	-2.49%	-92.62%	-51.00%
ME	-36.69%	-4.81%	-2.80%	-90.94%	-52.92%
NH	-37.01%	-4.83%	-2.80%	-90.95%	-52.99%
NJ	-22.39%	-4.77%	-1.77%	-94.04%	-48.47%
NY	-18.80%	-4.47%	-1.77%	-94.04%	-47.64%
PA	-20.95%	-4.66%	-1.77%	-94.04%	-48.14%
RI	-31.87%	-4.60%	-2.80%	-90.95%	-51.98%
VT	-37.09%	-4.84%	-2.80%	-90.94%	-53.04%

Table C-3. Initial meta-scenario percent change in emissions sector by pollutant by state.

Area	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-14.81%	-10.49%	-3.11%	-32.61%	-29.14%
DC	-0.57%	5.71%	15.00%	-44.74%	-22.31%
DE	2.80%	8.15%	14.39%	-46.97%	-31.35%
MA	-7.53%	-5.24%	-0.17%	-14.46%	-11.95%
MD	-14.12%	10.72%	15.30%	-25.51%	-9.31%
ME	-3.56%	-1.25%	2.47%	-11.00%	-8.30%
NH	-3.74%	-1.34%	2.57%	-11.20%	-8.50%
NJ	-19.53%	-13.91%	-5.94%	-52.94%	-46.76%
NY	-15.92%	-11.58%	-4.78%	-38.30%	-30.58%
PA	-12.06%	-9.45%	-4.24%	-29.11%	-24.69%
RI	-22.40%	-16.50%	-7.43%	-45.85%	-41.54%
VT	-4.02%	-1.78%	1.87%	-12.37%	-9.91%

Non-EGU Point	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-7.60%	-2.13%	-13.79%	-59.20%	-56.55%
DC	0.48%	-0.07%	6.13%	-37.70%	-45.72%
DE	-79.07%	-26.28%	-5.95%	-85.25%	-72.72%
MA	-35.25%	-11.75%	-39.83%	-87.28%	-47.94%
MD	-64.75%	13.85%	-16.51%	-88.89%	-75.97%
ME	15.22%	-6.06%	46.40%	-27.27%	-5.18%
NH	-53.40%	61.29%	60.57%	-94.13%	-29.11%
NJ	-59.81%	-4.61%	-31.30%	-93.50%	-62.27%
NY	-66.18%	-9.57%	-16.94%	-72.41%	-60.82%
PA	-75.77%	-0.14%	-17.39%	-94.78%	-60.43%
RI	-40.31%	-0.76%	-43.34%	-5.23%	-9.04%
VT	-0.44%	-23.52%	-39.70%	-24.32%	-14.74%

Onroad	NO_X	VOC	CO	SO_2	$PM_{2.5}$
All states	-69.58%	-71.10%	-55.68%	-95.66%	-48.48%

EGU	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-53.05%	-22.90%	10.85%	-7.98%	-19.13%
DC	-95.30%	-88.90%	-98.12%	-63.32%	-93.33%
DE	-15.36%	-17.48%	-15.86%	-5.89%	-9.79%
MA	-22.13%	-0.68%	36.52%	-10.28%	-0.19%
MD	-49.73%	-20.01%	-17.82%	-37.68%	-38.88%
ME	-55.65%	-38.60%	-19.93%	-59.52%	-41.06%

NH	-46.73%	-15.31%	-9.45%	-57.11%	-28.08%
NJ	-39.00%	-22.70%	-22.09%	-25.18%	-20.65%
NY	-29.45%	-10.29%	-4.32%	-16.65%	-9.34%
PA	-21.95%	-8.89%	-13.04%	-13.40%	-12.98%
RI	5.94%	-15.70%	-9.74%	2.15%	-14.58%
VT	-65.34%	-52.07%	-52.67%	-54.90%	-52.73%

Nonroad	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-34.28%	-4.71%	-2.80%	-90.95%	-52.45%
DC	19.86%	-0.11%	-2.49%	-92.65%	-34.77%
DE	-27.35%	-4.42%	-2.49%	-92.62%	-50.41%
MA	-34.63%	-4.73%	-2.80%	-90.95%	-52.52%
MD	-30.16%	-4.57%	-2.49%	-92.62%	-51.00%
ME	-36.69%	-4.81%	-2.80%	-90.94%	-52.92%
NH	-37.01%	-4.83%	-2.80%	-90.95%	-52.99%
NJ	-22.39%	-4.77%	-1.77%	-94.04%	-48.47%
NY	-18.80%	-4.47%	-1.77%	-94.04%	-47.64%
PA	-20.95%	-4.66%	-1.77%	-94.04%	-48.14%
RI	-31.87%	-4.60%	-2.80%	-90.95%	-51.98%
VT	-37.09%	-4.84%	-2.80%	-90.94%	-53.04%

Table C-4. Enhanced meta-scenario percent change in emissions sector by pollutant by state.

Area	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-14.81%	-10.49%	-3.11%	-32.61%	-29.14%
DC	-0.57%	5.71%	15.00%	-44.74%	-22.31%
DE	2.80%	8.15%	14.39%	-46.97%	-31.35%
MA	-7.53%	-5.24%	-0.17%	-14.46%	-11.95%
MD	-14.16%	10.66%	15.21%	-34.68%	-9.90%
ME	-3.56%	-1.25%	2.47%	-11.00%	-8.30%
NH	-3.74%	-1.34%	2.57%	-11.20%	-8.50%
NJ	-19.53%	-13.91%	-5.94%	-52.94%	-46.76%
NY	-15.92%	-11.58%	-4.78%	-38.30%	-30.58%
PA	-12.06%	-9.45%	-4.24%	-29.11%	-24.69%
RI	-22.40%	-16.50%	-7.43%	-45.85%	-41.54%
VT	-4.02%	-1.78%	1.87%	-12.37%	-9.91%

Non-EGU Point	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-7.60%	-2.13%	-13.79%	-59.20%	-56.55%
DC	0.48%	-0.07%	6.13%	-37.70%	-45.72%
DE	-79.07%	-26.28%	-5.95%	-85.25%	-72.72%
MA	-35.25%	-11.75%	-39.83%	-87.28%	-47.94%
MD	-65.48%	13.85%	-16.51%	-89.59%	-76.10%
ME	15.22%	-6.06%	46.40%	-27.27%	-5.18%
NH	-53.40%	61.29%	60.57%	-94.13%	-29.11%
NJ	-59.81%	-4.61%	-31.30%	-93.50%	-62.27%
NY	-66.18%	-9.57%	-16.94%	-72.41%	-60.82%
PA	-75.77%	-0.14%	-17.39%	-94.78%	-60.43%
RI	-40.31%	-0.76%	-43.34%	-5.23%	-9.04%
VT	-0.44%	-23.52%	-39.70%	-24.32%	-14.74%

Onroad	NO_X	VOC	CO	SO_2	$PM_{2.5}$
All states	-69.63%	-71.19%	-55.86%	-95.66%	-48.59%

EGU	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-86.35%	-37.27%	4.04%	-12.99%	-31.14%
DC	-95.30%	-88.90%	-98.12%	-63.32%	-93.33%
DE	-21.81%	-24.82%	-22.53%	-8.37%	-13.90%
MA	-28.49%	-0.88%	26.03%	-13.23%	-0.24%

MD	-56.66%	-24.07%	-18.73%	-51.54%	-51.51%
ME	-62.87%	-43.60%	-22.51%	-67.24%	-46.38%
NH	-47.22%	-15.47%	-9.35%	-57.70%	-28.37%
NJ	-39.00%	-22.70%	-22.09%	-25.18%	-20.65%
NY	-47.97%	-16.75%	-7.04%	-27.13%	-15.22%
PA	-21.95%	-8.89%	-13.04%	-13.40%	-12.98%
RI	4.76%	-18.81%	-11.67%	1.72%	-17.46%
VT	-81.67%	-65.09%	-65.84%	-68.63%	-65.91%

Nonroad	NO_X	VOC	CO	SO_2	$PM_{2.5}$
CT	-34.28%	-4.71%	-2.80%	-90.95%	-52.45%
DC	19.86%	-0.11%	-2.49%	-92.65%	-34.77%
DE	-27.35%	-4.42%	-2.49%	-92.62%	-50.41%
MA	-34.63%	-4.73%	-2.80%	-90.95%	-52.52%
MD	-30.16%	-4.57%	-2.49%	-92.62%	-51.00%
ME	-36.69%	-4.81%	-2.80%	-90.94%	-52.92%
NH	-37.01%	-4.83%	-2.80%	-90.95%	-52.99%
NJ	-22.39%	-4.77%	-1.77%	-94.04%	-48.47%
NY	-18.80%	-4.47%	-1.77%	-94.04%	-47.64%
PA	-20.95%	-4.66%	-1.77%	-94.04%	-48.14%
RI	-31.87%	-4.60%	-2.80%	-90.95%	-51.98%
VT	-37.09%	-4.84%	-2.80%	-90.94%	-53.04%

Appendix D: BenMAP Health Benefits Assessment

Introduction

This appendix describes the BenMAP analysis of health impacts from air quality changes associated with implementing strategies under Maryland's Greenhouse Gas Reduction Act (GGRA) Plan. It includes a detailed overview of the technical approach, summary of the results, and discussion of the conclusions and uncertainties inherent in the approach. We also provide contextual description of the health benefits model and its limitations. The analysis is part of a weight-of-evidence multi-pollutant exercise conducted for the Maryland Department of the Environment. The focus is on health benefits within Maryland, but we also present results for nearby states in the Mid-Atlantic and Northeast regions.

Description of Assessment Tool and Approach

To assess the effects of improvement in air quality resulting from GGRA policies on human health, we used EPA's Environmental Benefits Modeling and Analysis Program, Community Edition (BenMAP-CE; USEPA 2014). BenMAP is a tool that has been extensively tested and used to determine the health impacts from air quality changes associated with many major national air quality policy initiatives. The model determines the magnitude and value of avoided adverse health endpoints associated with changes in air pollution.

Future year air quality associated with and without implementation of the GGRA control strategies were first simulated using the Community Multi-scale Air Quality modeling system (CMAQ), as described in Chapter 3. Two GGRA meta-scenarios were compared to a reference case, under which no GGRA control strategies were included. The two GGRA meta-scenarios are the initial and enhanced meta-scenarios. The initial meta-scenario included emissions reductions (compared to the reference case) for area sources, electric generating unit (EGU) point sources, and non-EGU point sources within Maryland, as well as mobile source emissions reductions in and beyond Maryland. The enhanced meta-scenario included additional in-state emissions reductions for those source sectors, as well as reductions in out-of-state EGU emissions. These policy scenarios are described in greater detail in the main body of the report and Appendix A.

BenMAP-CE is an open source and community-owned tool incorporating geographic information systems. BenMAP was designed by EPA to estimate health impacts and associated economic values resulting from changes in ambient air pollution. The model estimates health impacts by applying health impact functions that relate changes in pollutant concentrations with changes in incidence of health endpoints. It estimates economic values of those health impacts based on valuation studies. Estimates of uncertainty and variability are incorporated into the program design and are standard options for data output.

BenMAP can estimate health effects using air quality values from a monitoring network or from gridded modeling results. Population exposure estimates are based on U.S. Census data built into the model, and projected using growth factors to future years. BenMAP allows users to estimate exposure among sensitive subpopulations as well.

Users of the BenMAP program select health effects and valuation configurations that are already built into the software package to estimate incidence and monetary values of changes in air quality. The program allows also users to select various statistical methods for presenting results. The current version of the program is BenMAP-CE 1.0.8.

Inputs and configuration options

Researchers at the University of Maryland (UMD) performed the air quality modeling and processed the resulting hourly concentration data for ozone and $PM_{2.5}$ into comma separated values (csv) text files for the reference case and the two meta-scenarios.[48] We restricted our analysis to assess the benefits from changes in ground-level concentrations of ozone and fine particulate matter (i.e., particulate matter with aerodynamic diameter of 2.5 µm or less, or $PM_{2.5}$), which generally account for the vast majority of health effects from changes in ambient air quality.

We retrieved the csv files from UMD and further processed the ozone and $PM_{2.5}$ data into timescales for health-relevant impact analysis using Python scripts and data post-processing routines developed by NESCAUM. In the final step, we processed the data for the reference case and each meta-scenario using BenMAP to generate differences in health outcome incidence (and valuation thereof) resulting from modeled implementation of the GGRA policies.

We used the 12 km eastern U.S. CMAQ modeling domain to develop gridded population estimates for 2020 based on the 2010 U.S. Census database included with BenMAP. We accomplished this population gridding through the use of the PopGrid preprocessor. The horizontal modeling domain is 172 by 172 grid cells, for a total of 29,584 discreet 12 km-square grid cells. In the final steps of the analysis, we aggregated incidence and valuation results at the state level.

For the selection of studies to estimate health impacts, we relied on current default configuration settings available from EPA.[49] For ozone, the configuration is based on analysis performed by EPA in support of the federal Transport Rule (USEPA 2010). For $PM_{2.5}$, the configuration is based on EPA's regulatory impact analysis for the 2012 revisions to the National Ambient Air Quality Standards for particulate matter (USEPA 2012). The published EPA documentation contains additional details of the health assessment options. The prevented mortality configuration was based on a broad range of studies for both effects and monetary valuation. Several morbidity configuration options also relied on results from several studies.

Caveats and Uncertainty

The uncertainties in this type of BenMAP analysis are described in greater detail in our 2008 report on a similar health assessment (NESCAUM 2008), which we recommend as further reading for those who are interested in a more technical description. Furthermore, the methods used in this health impact assessment are based on the methods reported by EPA (2010, 2012), which we recommend as source material for additional details on the health studies included in this assessment. As described by Fann et al. (2014), it is common practice when performing a health impact assessment using BenMAP to rely on the default EPA configurations because the methods are extensively documented and are reviewed and refined by independent scientific groups.

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[48] Data for January 1 were not available because this first day was considered a spin-up day and therefore csv files were not available. Data for January 2 were used as surrogate data for January 1.
[49] See the BenMAP-CE website: http://www.epa.gov/airquality/benmap/ce.html

Each health impact function contains a central estimate (or point estimate) as well as a standard error of the estimate, which are used to generate a distribution of estimates. BenMAP generates incidence estimates that mirror the variability in the inputs to the health impact function. At each grid cell in the domain, BenMAP calculates the incidence estimate multiple times, each time adjusting the pollutant coefficient to describe a different level of the distribution. BenMAP bases the adjustment on a calculation using the standard error of the pollution coefficient, as derived from the selected published epidemiological study. The output contains the mean of the estimate as well as an estimate of the incidence at multiple levels of the distribution.

Rather than explicitly using estimates of uncertainty and variability in the results for each study, we present results as the point estimate from each study along with the range (minimum to maximum point estimates) from each study used to assess health endpoints. Accounting for the full range of uncertainty and variability from each study results in a broader range of benefits estimates. We also included the 5^{th} and 95^{th} percentile values for each health endpoint in the detailed results tables (described below) to provide a measure of the uncertainty for the incidence and valuation results. These percentile bounds do not include uncertainties carried through from the air quality modeling analysis.

Results

Tables D-1 through **D-4** present point estimates of the annual health effects and valuation for the initial meta-scenario compared to the reference case in 2020. **Tables D-5** through **D-8** present analogous tables for the enhanced meta-scenario. Results are presented for Maryland; the Ozone Transport Region (OTR), an area along the eastern seaboard from northern Virginia to Maine, excluding Virginia and Maryland; areas outside of the OTR; and total effects in the modeled domain. We present both incidence and monetary valuation results for premature mortality, and various morbidity health endpoints assuming a 3 percent discount rate. Estimates using a discount rate of 7 percent for deferred health impacts decrease the estimated value; these estimates are presented in aggregate in the main report, but not in full detail in this report so as to avoid presenting extraneous data. Monetary results are presented in millions of dollars. Ranges of estimates reflect the results based on different studies included in the health impact assessment methodology.

Due to the valuation inputs and the health correlation between health effects and exposure, premature mortality accounts for the majority of health effects from the implementation of the policies. In addition, because the changes in modeled $PM_{2.5}$ concentrations result in more avoided premature deaths than the modeled ozone changes, the overwhelming majority of monetary values shown in the initial and enhanced meta-scenarios result from reductions in $PM_{2.5}$ concentrations.

For Maryland in 2020, this analysis suggests that the initial meta-scenario would result in 43 to 100 fewer premature deaths per year, while the enhanced meta-scenario would result in 84 to 192 fewer premature deaths per year (differences in the values presented here and those presented in the table are due to differences in rounding). Modeled avoided non-lethal (morbidity) effects in Maryland due to reduced ground level ozone concentrations would include (point estimates only for the initial and enhanced meta-scenarios):

- 5 (initial) to 6 (Enhanced) fewer hospital visits for respiratory symptoms;

- 2 (both initial and enhanced) fewer emergency room visits for respiratory symptoms;
- 4,900 (initial) to 5,800 (enhanced) fewer instances of acute respiratory symptoms; and
- 1,700 (initial) to 2,000 (enhanced) fewer school loss days.

For $PM_{2.5}$, the analysis indicated that fewer cases of non-lethal health endpoints would result for the initial and enhanced meta-scenarios compared to the reference case, as follows:

- Between 4 to 39 (initial) and 8 and 75 (enhanced) fewer non-fatal heart attacks;
- 13 (initial) to 25 (enhanced) fewer respiratory caused hospital admissions;
- 14 (initial) to 28 (enhanced) fewer cardiovascular caused hospital admissions;
- 30 (initial) to 59 (enhanced) fewer emergency room visits for asthma;
- 63 (initial) to 123 (enhanced) fewer cases of acute bronchitis;
- 810 (initial) to 1,600 (enhanced) fewer cases of lower respiratory symptoms (ages 7-14);
- 1,200 (initial) to 2,200 (enhanced) fewer cases of upper respiratory symptoms (ages 9-18);
- 3,200 (initial) to 15,000 (enhanced) fewer asthma exacerbations; and
- 6,000 (initial) to 12,000 (enhanced) fewer work loss days.

The monetary value of reduced incidence of mortality and morbidity health outcomes in Maryland for the initial meta-scenario was estimated to be between $420 million and $860 million (central point estimates, rounded to two significant figures) from the studies with the lowest estimates of outcomes to the studies with the highest estimates of outcomes, assuming a 3 percent discount rate for delayed mortality effects. Assuming a 7 percent discount rate for delayed mortality effects reduces the value of the avoided health impacts to between $330 million and $750 million.

For the enhanced meta-scenario, the monetary value of reduced incidence of mortality and morbidity health outcomes in Maryland was estimated to be between $820 million and $1,600 million (central point estimates, rounded to two significant figures), assuming a 3 percent discount rate for delayed mortality effects. Assuming a 7 percent discount rate for delayed mortality effects reduces the value of the avoided health impacts to between $630 million and $1.4 billion.

In aggregate, other states in the OTR would also benefit from reduced premature mortality in 2020 resulting from the analyzed GGRA policies. The range of point estimates for the prevented premature mortalities in 2020 within the OTR (excluding Maryland and Virginia) for the initial meta-scenario is from 230 to 510 incidences, and between 440 and 1,000 for the enhanced meta-scenario. For the initial meta-scenario, the total monetary benefit to all areas would be between $3.0 billion and $6.3 billion, assuming a 3 percent discount rate; or between $2.4 billion and $5.5 billion, assuming a 7 percent discount rate. Refer to the tables for modeled changes in morbidity incidence in Maryland, in the OTR, beyond the OTR, and in total.

Between 92 and 97 percent of the monetary value of the total air quality improvements can be attributed to prevented premature mortality effects due to reduced $PM_{2.5}$ exposure. It is important to note that effects were not distributed evenly among each state or within any state or county. In a few states, the model analysis indicated very slightly reduced air quality, resulting in slightly elevated risks for adverse health outcomes. More refined analysis would be required to address results in sensitive populations.

The range of values between the 5th and 95th percentile results is large, indicating the range of uncertainties associated with these outcomes. The results for the upper and lower percentile values are directionally uniform—i.e., nearly all results show some kind of benefit—even if the magnitude of the benefits of these upper and lower bounds differed greatly, from nearly an order of magnitude lower to three times higher than the point estimate. We also note that the negative estimates for certain endpoints are the result of the weak statistical power of the study used in BenMAP to calculate these health impacts and do not suggest that increases in air pollution exposure result in decreased health impacts.

While the modeled effects associated with implementing the GGRA policies within Maryland were significant, they were not restricted only to the State. According to this analysis, under both the initial meta-scenario and the enhanced meta-scenario, health benefits expected to accrue from reduced exposure to air pollutants in the OTR are several times the magnitude of the expected benefits within Maryland. Figure D-1 through Figure D-4 show the upper-end modeled distribution of changes mortality incidence for Maryland from the initial and enhanced meta-scenarios for ozone and $PM_{2.5}$. The incidence of other individual health effect estimates (e.g., for other estimates of premature mortality) is expected to scale similarly with population levels for each grid cell.

Table D-1: 2020 Health Impact Incidence, Change from Reference Scenario to Initial Policy Scenario for Ozone (Central Point Estimate and Range of 95 Percent Confidence Intervals)[A]

Health effect		*Maryland*	*OTR (excluding MD and VA)*	*Beyond OTR*	*Total*
Premature mortality					
	Bell et al. (2004) (all ages)	0.67 (0.26—1.1)	4.7 (1.8—7)	3.8 (1.49—6.2)	8.5 (3.3—14)
	Schwartz (2005) (all ages)	1.0 (0.37—1.7)	7 (2.6—11)	6 (2.2—9.6)	13 (4.7—21)
	Huang et al. (2005) (all ages)	0.96 (0.41—1.5)	6.4 (2.7—10)	5.5 (2.3—8.6)	12 (5.1—19)
Meta-analyses	Ito et al. (2005) (all ages)	3.0 (1.9—4.1)	21 (13—29)	17.3 (10.9—24)	38 (24—52)
Meta-analyses	Bell et al. (2005) (all ages)	2.2 (1.1—3.2)	15 (7.8—22)	12.6 (6.5—18.6)	28 (14—41)
Meta-analyses	Levy et al. (2005) (all ages)	3.0 (2.2—3.9)	21 (15—27)	17.7 (12.6—23)	39 (28—50)
Hospital admissions—respiratory causes (ages > 65)		2.9 (0.16—6.0)	21 (-2.4—46)	20 (0.94—38)	41 (-1.4—84)
Hospital admissions—respiratory causes (ages < 2)		1.6 (0.79—2.5)	6.1 (2.9—9)	13.6 (6.5—20.6)	20 (9.4—30)
Emergency room visits for asthma (all ages)		1.8 (-0.12—5.9)	9 (-29—59)	12.3 (-0.8—40)	22 (-30—99)
Minor restricted-activity days (ages 18-65)		4,900 (2,300—7,500)	25,000 (11,000—38,000)	26,000 (12,000—40,000)	51,000 (23,000—78,000)
School absence days		1,700 (670—2,400)	8,400 (2,400—13,000)	8,400 (3,400—12,300)	17,000 (5,800—26,000)

[A] Estimates rounded to two significant figures; values will not sum to total value.

Table D-2: 2020 Health Impact Valuation (Millions 2010$), Change From Reference Scenario to Initial Policy Scenario for Ozone (Central Point Estimate and Range of 95 Percent Confidence Intervals)[A]

	Health effect	*Maryland*	*OTR (excluding MD and VA)*	*Beyond OTR*	*Total*
Premature mortality					
	Bell et al. (2004) (all ages)	$6.4 ($0.5—$19)	$45 (-$7.3—$140)	$37 ($3—$110)	$82 (-$4—$250)
	Schwartz (2005) (all ages)	$9.8 ($0.8—$29)	$68 (-$12—$220)	$57 ($5—$170)	$120 (-$7—$390)
	Huang et al. (2005) (all ages)	$9 ($1—$27)	$62 (-$18—$210)	$53 ($4—$160)	$110 (-$14—$360)
Meta-analyses	Ito et al. (2005) (all ages)	$29 ($3—$80)	$201 (-$27—$600)	$170 ($15—$460)	$370 (-$12—$1,100)
Meta-analyses	Bell et al. (2005) (all ages)	$21 ($2—$60)	$144 (-$22—$450)	$121 ($11—$350)	$260 (-$11—$790)
Meta-analyses	Levy et al. (2005) (all ages)	$29 ($3—$80)	$203 (-$27—$600)	$171 ($16—$460)	$370 (-$11—$1,100)
Hospital admissions—respiratory causes (ages > 65)		$0.093 ($0.01—$0.18)	$0.68 (-$0.01—$1.4)	$0.6 ($0.1—$1.1)	$1.3 ($0.1—$2.5)
Hospital admissions—respiratory causes (ages < 2)		$0.025 ($0.013—$0.037)	$0.093 (-$0.01—$0.2)	$0.21 ($0.11—$0.30)	$0.30 ($0.09—$0.50)
Emergency room visits for asthma (all ages)		$0.001 ($0.000—$0.003)	$0.004 (-$0.012—$0.026)	$0.01 ($0.00—$0.02)	$0.009 (-$0.012—$0.040)
Minor restricted-activity days (ages 18-65)		$0.33 ($0.13—$0.61)	$1.7 ($0.26—$3.5)	$1.8 ($0.7—$3.2)	$3.5 ($1.0—$6.7)
School absence days		$0.16 ($0.07—$0.23)	$0.82 ($0.28—$1.3)	$0.8 ($0.4—$1.2)	$1.6 ($0.6—$2.4)

[A] Estimates rounded to two significant figures; values will not sum to total value.

Table D-3: 2020 Health Impact Incidence, Change from Reference Scenario to Ini Policy Scenario for Fine Particulate Matter ($PM_{2.5}$) (Central Point Estimate and Ran 95 Percent Confidence Intervals)[A]

Health effect	*Maryland*	*OTR (excluding MD and VA)*	*Beyond OTR*	
Avoided mortality				
Krewski et al. (2009) (adult)	43 (30—55)	220 (150—280)	86 (61—110)	(21
Lepeule et al. (2012) (adult)	97 (52—140)	490 (270—720)	200 (110—290)	(37(
Woodruff et al. (1997) (infant)	0.11 (0.05—0.17)	0.41 (0.18—0.64)	0.23 (0.10—0.36)	(0.:
Avoided Morbidity				
Non-fatal heart attacks (age > 18)				
Peters et al. (2001)	39 (12—66)	220 (68—370)	89 (27—150)	(9:
Pooled estimate of 4 studies	4.3 (1.9—10)	24 (11—58)	9.6 (4.4—23)	(1
Hospital admissions—respiratory causes (all ages)	13 (-4.0—25)	69 (-23—132)	27 (-8.4—51)	(-3
Hospital admissions—cardiovascular (age > 18)	14 (7.1—25)	75 (36—130)	31 (15—53)	(5:
Emergency room visits for asthma (age < 18)	30 (-9.8—61)	170 (-55—340)	54 (-17—110)	(-7
Acute bronchitis (age 8-12)	63 (-8.4—130)	300 (-40—650)	130 (-18—280)	(-5
Lower respiratory symptoms (age 7-14)	810 (350—1,300)	3,900 (1,700—6,100)	1,700 (730—2,700)	(2,40
Upper respiratory symptoms (asthmatics age 9-18)	1,200 (290—2,000)	5,500 (1,400—9,700)	2,400 (600—4,200)	(2,00(
Asthma exacerbation (asthmatics 6-18)	3,200 (180—6,700)	16,000 (860—33,000)	6,700 (370—14,000)	2 (1,20(
Lost work days (ages 18-65)	6,000 (5,200—6,900)	29,000 (25,000—33,000)	12,000 (11,000—14,000)	4 (36,00
Minor restricted-activity days (ages 18-65)	36,000 (30,000—42,000)	170,000 (140,000—200,000)	74,000 (61,000—86,000)	2 (21 29

[A] Estimates rounded to two significant figures; values will not sum to total value.

Table D-4: 2020 Health Impact Valuation (Millions 2010$, 3 Percent Discount Rate), Change from Reference Scenario to Initial Policy Scenario for Fine Particulate Matter ($PM_{2.5}$) (Central Point Estimate and Range of 95 Percent Confidence Intervals)[A]

Health effect	*Maryland*	*OTR (excluding MD and VA)*	*Beyond OTR*	*Total*
Avoided mortality				
Krewski et al. (2009) (adult)	$410 ($33—$990)	$2,000 ($170—$5,000)	$830 ($68—$2,000)	$2,900 ($240—$7,000)
Lepeule et al. (2012) (adult)	$820 ($72—$2,300)	$4,200 ($370—$12,000)	$1,700 ($150—$4,700)	$5,800 ($510—$17,000)
Woodruff et al. (1997) (infant)	$1.1 ($0.09—$3.1)	$4.0 ($0.33—$12)	$2.3 ($0.19—$6.6)	$6.2 ($0.52—$18)
Avoided Morbidity				
Non-fatal heart attacks (age > 18)				
Peters et al. (2001)	$4.9 ($0.85—$12)	$27 ($4.6—$67)	$11 ($1.9—$27)	$38 ($6.6—$95)
Pooled estimate of 4 studies	$1.1 ($0.52—$2.3)	$5.8 ($2.9—$13)	$2.4 ($1.2—$5.2)	$8.2 ($4.0—$18)
Hospital admissions—respiratory causes (all ages)	$0.31 (-$0.07—$0.58)	$1.7 (-$0.41—$3.1)	$0.67 (-$0.16—$1.2)	$2.3 (-$0.6—$4.3)
Hospital admissions—cardiovascular (age > 18)	$0.56 ($0.30—$0.94)	$2.9 ($1.5—$5.0)	$1.2 ($0.63—$2.0)	$4.1 ($2.1—$7.0)
Emergency room visits for asthma (age < 18)	$0.013 (-$0.002—$0.028)	$0.073 (-$0.014—$0.16)	$0.023 (-$0.004—$0.050)	$0.096 (-$0.019—$0.21)
Acute bronchitis (age 8-12)	$0.030 (-$0.001—$0.085)	$0.15 (-$0.01—$0.41)	$0.064 (-$0.003—$0.18)	$0.21 (-$0.01—$0.58)
Lower respiratory symptoms (age 7-14)	$0.017 ($0.006—$0.034)	$0.08 ($0.03—$0.16)	$0.036 ($0.012—$0.07)	$0.12 ($0.04—$0.24)
Upper respiratory symptoms (asthmatics age 9-18)	$0.039 ($0.008—$0.094)	$0.18 ($0.04—$0.45)	$0.081 ($0.018—$0.20)	$0.27 ($0.06—$0.65)
Asthma exacerbation (asthmatics 6-18)	$0.19 ($0.02—$0.50)	$0.90 ($0.08—$2.4)	$0.39 ($0.03—$1.0)	$1.3 ($0.1—$3.4)
Lost work days (ages 18-65)	$1.1 ($1.0—$1.3)	$5.0 ($4.4—$5.7)	$2.1 ($1.9—$2.4)	$7.2 ($6.2—$8.1)
Minor restricted-activity days (ages 18-65)	$2.5 ($1.3—$3.7)	$12 ($6.3—$18)	$5.0 ($2.7—$7.6)	$17 ($9.0—$26)

[A] Estimates rounded to two significant figures; values will not sum to total value.

Table D-5: 2020 Health Impact Incidence, Change from Reference Scenario to Enhanced Policy Scenario for Ozone (Central Point Estimate and Range of 95 Percent Confidence Intervals)[A]

	Health effect	*Maryland*	*OTR (excluding MD and VA)*	*Beyond OTR*	*Total*
Premature mortality					
	Bell et al. (2004) (all ages)	0.81 (0.27—1.3)	-1.5 (-0.5—-3)	4.1 (1.39—6.8)	2.6 (0.9—4)
	Schwartz (2005) (all ages)	1.2 (0.38—2.1)	-2 (-0.7—-4)	6 (2—10.5)	4 (1.2—6.3)
	Huang et al. (2005) (all ages)	1.14 (0.43—1.8)	-3.4 (-1.2—-6)	5.5 (2.1—8.7)	2 (0.9—3)
Meta-analyses	Ito et al. (2005) (all ages)	3.6 (2.2—4.9)	-7 (-4—-11)	17.7 (10.9—24)	10 (7—13)
Meta-analyses	Bell et al. (2005) (all ages)	2.6 (1.2—3.9)	-5 (-2.3—-8)	13.3 (6.4—19.7)	8 (4—12)
Meta-analyses	Levy et al. (2005) (all ages)	3.6 (2.5—4.7)	-7 (-5—-10)	18.4 (12.8—24)	11 (8—13)
Hospital admissions—respiratory causes (ages > 65)		4.4 (1.43—11.4)	-9 (-66.8—27)	23 (-35.94—92)	14 (-102.7—120)
Hospital admissions—respiratory causes (ages < 2)		1.5 (0.74—1.9)	-21.6 (-8.2—-38)	9.8 (5.5—10.5)	-12 (-2.7—-28)
Emergency room visits for asthma (all ages)		1.6 (-4.93—6.1)	-22 (-135—94)	8.5 (-66.8—67)	-14 (-202—161)
Minor restricted-activity days (ages 18-65)		5,800 (2,500—8,900)	-20,000 (-8,000—-34,000)	27,000 (12,000—40,000)	7,000 (4,000—6,000)
School absence days		2,000 (720—3,300)	-3,600 (-14,800—4,000)	9,400 (-4,200—21,100)	6,000 (-19,000—25,000)

Notes: [A] Estimates rounded to two significant figures; values will not sum to total value.

Table D-6: 2020 Health Impact Valuation (Millions 2010$), Change From Reference Scenario to Enhanced Policy Scenario for Ozone (Central Point Estimate and Range of 95 Percent Confidence Intervals)[A]

	Health effect	*Maryland*	*OTR (excluding MD and VA)*	*Beyond OTR*	*Total*
Premature mortality					
	Bell et al. (2004) (all ages)	$7.8 ($0.6—$23)	-$15 (-$103.7—$60)	$40 (-$50—$171)	$25 (-$153—$230)
	Schwartz (2005) (all ages)	$11.9 ($0.9—$36)	-$23 (-$162—$90)	$61 (-$77—$260)	$40 (-$239—$350)
	Huang et al. (2005) (all ages)	$11 ($1—$32)	-$33 (-$179—$80)	$53 (-$77—$230)	$20 (-$256—$310)
Meta-analyses	Ito et al. (2005) (all ages)	$34 ($3—$94)	-$72 (-$440—$230)	$170 (-$216—$700)	$100 (-$656—$900)
Meta-analyses	Bell et al. (2005) (all ages)	$25 ($2—$71)	-$49 (-$323—$170)	$128 (-$158—$530)	$80 (-$481—$710)
Meta-analyses	Levy et al. (2005) (all ages)	$35 ($3—$95)	-$72 (-$432—$230)	$177 (-$210—$710)	$100 (-$642—$900)
Hospital admissions—respiratory causes (ages > 65)		$0.139 ($0.05—$0.37)	-$0.29 (-$2.12—$0.9)	$0.7 (-$1.1—$2.9)	$0.4 (-$3.3—$3.8)
Hospital admissions—respiratory causes (ages < 2)		$0.023 ($0.011—$0.030)	-$0.329 (-$0.64—-$0.1)	$0.15 (-$0.10—$0.35)	-$0.18 (-$0.75—$0.29)
Emergency room visits for asthma (all ages)		$0.001 (-$0.002—$0.003)	-$0.009 (-$0.055—$0.038)	$0.00 (-$0.03—$0.03)	-$0.006 (-$0.082—$0.070)
Minor restricted-activity days (ages 18-65)		$0.39 ($0.15—$0.71)	-$1.4 (-$3.76—$0.6)	$1.8 (-$0.6—$4.5)	$0.5 (-$4.3—$5.2)
School absence days		$0.19 ($0.07—$0.32)	-$0.35 (-$1.45—$0.4)	$0.9 (-$0.4—$2.1)	$0.6 (-$1.9—$2.5)

Notes: [A] Estimates rounded to two significant figures; values will not sum to total value.

Table D-7: 2020 Health Impact Incidence, Change from Reference Scenario to Enha Policy Scenario for Fine Particulate Matter ($PM_{2.5}$) (Central Point Estimate and Rar 95 Percent Confidence Intervals)[A]

Health effect	*Maryland*	*OTR (excluding MD and VA)*	*Beyond OTR*	
Avoided mortality				
Krewski et al. (2009) (adult)	83 (58—110)	440 (310—570)	120 (85—160)	(
Lepeule et al. (2012) (adult)	190 (100—270)	1,000 (540—1,500)	270 (150—400)	(
Woodruff et al. (1997) (infant)	0.21 (0.09—0.33)	0.81 (0.35—1.30)	0.34 (0.15—0.52)	(
Avoided Morbidity				
Non-fatal heart attacks (age > 18)				
Peters et al. (2001)	75 (23—130)	420 (140—680)	98 (35—137)	(
Pooled estimate of 4 studies	8.3 (3.8—20)	49 (22—120)	13 (-5.5—41)	
Hospital admissions—respiratory causes (all ages)	25 (-7.8—48)	140 (-47—260)	37 (-40—99)	
Hospital admissions—cardiovascular (age > 18)	28 (14—48)	150 (73—260)	43 (7—88)	
Emergency room visits for asthma (age < 18)	59 (-19—120)	330 (-110—650)	76 (-91—210)	(
Acute bronchitis (age 8-12)	120 (-16—260)	620 (-81—1,300)	180 (-24—390)	(-
Lower respiratory symptoms (age 7-14)	1,600 (680—2,400)	7,400 (3,300—11,000)	2,000 (960—2,900)	(4,
Upper respiratory symptoms (asthmatics age 9-18)	2,200 (560—3,900)	11,000 (2,800—20,000)	3,300 (830—5,800)	(3,
Asthma exacerbation (asthmatics 6-18)	15,000 (300—95,000)	74,000 (1,400—510,000)	22,000 (-65,000—200,000)	(-63
Lost work days (ages 18-65)	12,000 (10,000—13,000)	58,000 (50,000—66,000)	17,000 (15,000—19,000)	(65
Minor restricted-activity days (ages 18-65)	69,000 (58,000—81,000)	340,000 (290,000—400,000)	98,000 (82,000—110,000)	(370

[A] Estimates rounded to two significant figures; values will not sum to total value.

Table D-8: 2020 Health Impact Valuation (Millions 2010$, 3 Percent Discount Rate), Change from Reference Scenario to Enhanced Policy Scenario for Fine Particulate Matter ($PM_{2.5}$) (Central Point Estimate and Range of 95 Percent Confidence Intervals)[A]

Health effect	*Maryland*	*OTR (excluding MD and VA)*	*Beyond OTR*	*Total*
Avoided mortality				
Krewski et al. (2009) (adult)	$800 ($65—$1,920)	$4,100 ($350—$10,200)	$1,160 (-$949—$3,830)	$5,300 (-$600—$14,100)
Lepeule et al. (2012) (adult)	$1,594 ($140—$4,500)	$8,500 ($740—$24,000)	$2,300 (-$2,260—$9,000)	$10,800 (-$1,520—$33,000)
Woodruff et al. (1997) (infant)	$2.1 ($0.17—$6.1)	$7.7 ($0.65—$23)	$3.2 (-$3.14—$12.9)	$11.0 (-$2.50—$36)
Avoided Morbidity				
Non-fatal heart attacks (age > 18)				
Peters et al. (2001)	$9.3 ($1.64—$23)	$52 ($9.2—$123)	$12 (-$19.3—$48)	$64 (-$10.1—$171)
Pooled estimate of 4 studies	$2.1 ($1.00—$4.4)	$11.9 ($5.8—$26)	$3.2 (-$0.8—$9.2)	$15.1 ($5.0—$35)
Hospital admissions—respiratory causes (all ages)	$0.61 ($0.00—$0.00)	$3.4 ($0.00—$0.0)	$0.90 ($0.00—$0.0)	$4.3 ($0.0—$0.0)
Hospital admissions—cardiovascular (age > 18)	$1.09 ($0.00—$0.00)	$5.9 ($0.0—$0.0)	$1.7 ($0.00—$0.0)	$7.6 ($0.0—$0.0)
Emergency room visits for asthma (age < 18)	$0.025 ($0.000—$0.000)	$0.141 ($0.000—$0.00)	$0.032 ($0.000—$0.000)	$0.173 ($0.000—$0.00)
Acute bronchitis (age 8-12)	$0.059 (-$0.003—$0.164)	$0.30 (-$0.01—$0.82)	$0.088 (-$0.106—$0.35)	$0.38 (-$0.12—$1.17)
Lower respiratory symptoms (age 7-14)	$0.033 ($0.011—$0.066)	$0.16 ($0.05—$0.31)	$0.043 (-$0.031—$0.13)	$0.20 ($0.02—$0.43)
Upper respiratory symptoms (asthmatics age 9-18)	$0.075 ($0.016—$0.182)	$0.37 ($0.08—$0.91)	$0.110 (-$0.079—$0.37)	$0.48 ($0.00—$1.28)
Asthma exacerbation (asthmatics 6-18)	$0.86 ($0.03—$6.04)	$4.27 ($0.16—$32.6)	$1.24 (-$4.06—$12.6)	$5.5 (-$3.9—$45.2)
Lost work days (ages 18-65)	$2.2 ($1.9—$2.5)	$10.1 ($8.8—$11.3)	$3.0 ($2.3—$3.6)	$13.0 ($11.1—$15.0)
Minor restricted-activity days (ages 18-65)	$4.7 ($2.5—$7.2)	$23 ($12.4—$35)	$6.7 ($0.6—$13.0)	$30 ($13.0—$48)

[A] Estimates rounded to two significant figures; values will not sum to total value.

Figure D-1: Distribution of Upper End (Levy et al. 2005) Estimate of Premature Mortality in Maryland from Changes in Ozone Concentrations from Reference Case to Initial Meta-scenario

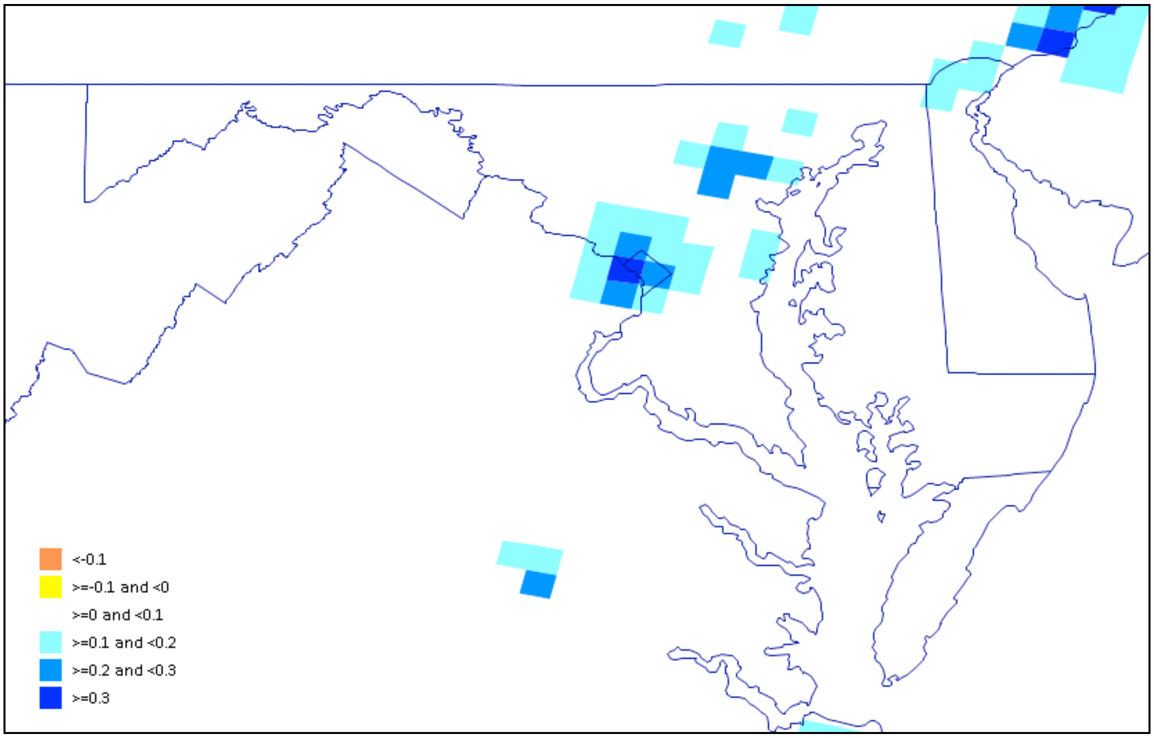


Figure D-2: Distribution of Upper End (Lepeule et al. 2012) Estimate of Premature Mortality in Maryland from Changes in $PM_{2.5}$ Concentrations from Reference Case to Initial Meta-scenario

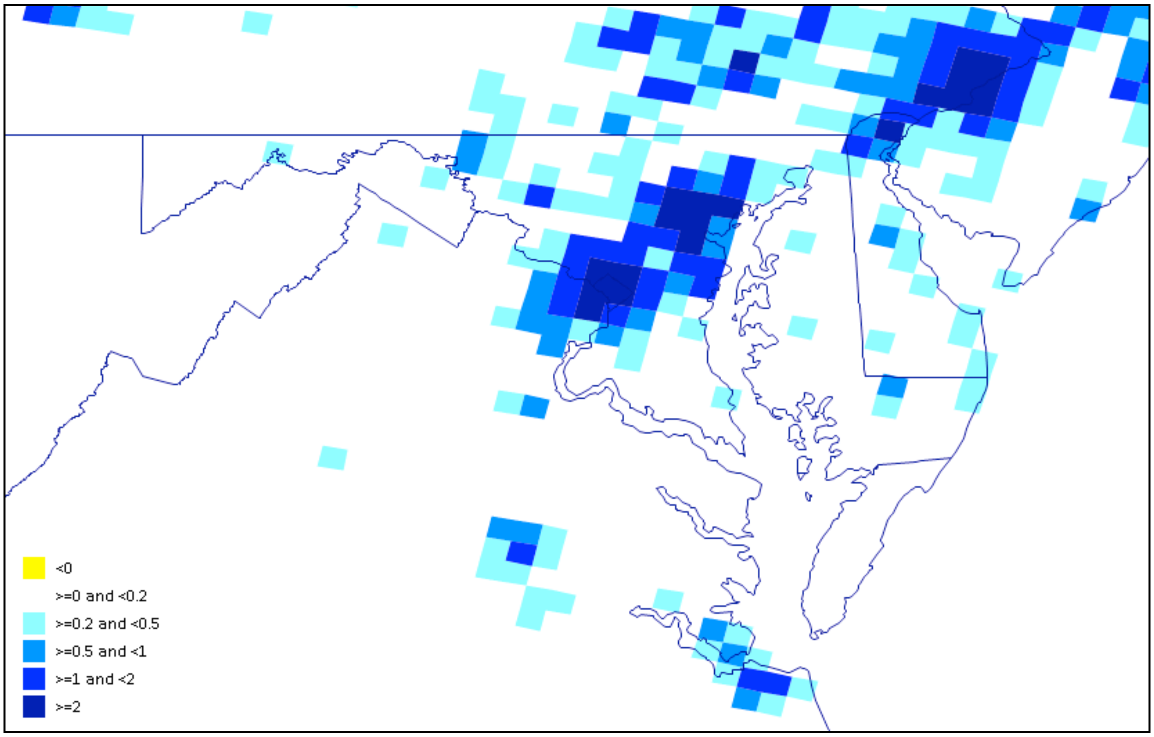


Figure D-3: Distribution of Upper End (Levy et al. 2005) Estimate of Premature Mortality in Maryland from Changes in Ozone Concentrations from Reference Case to Enhanced Meta-scenario

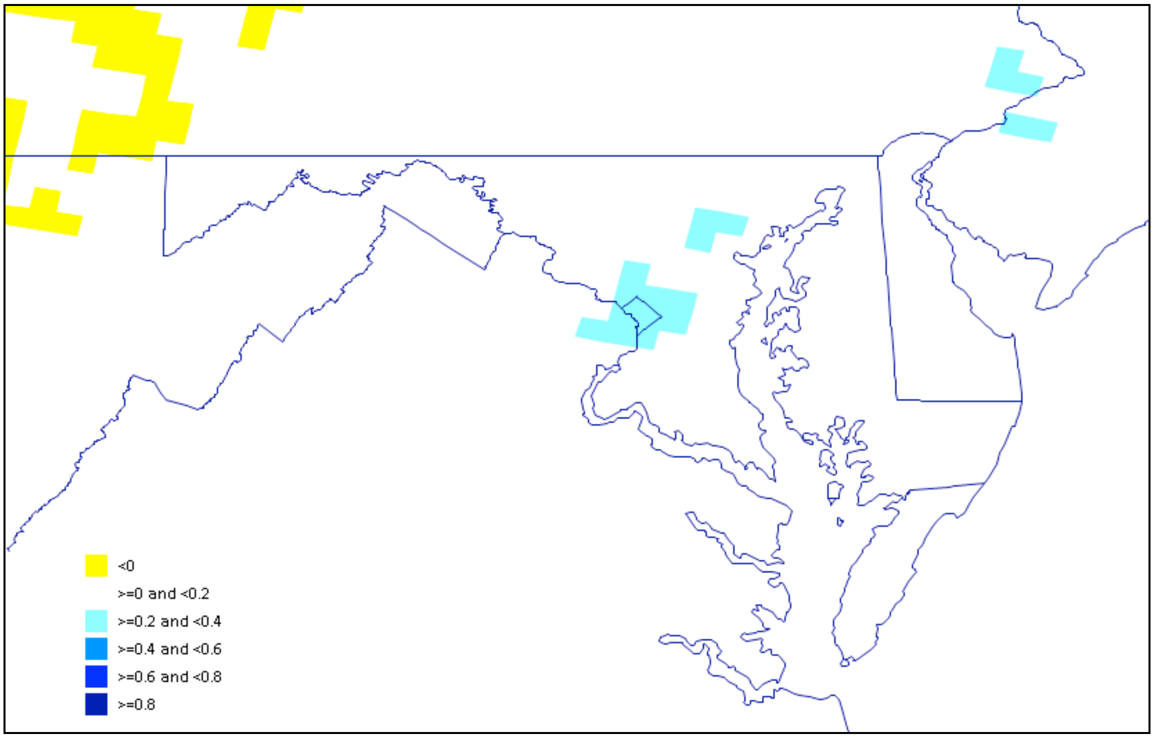
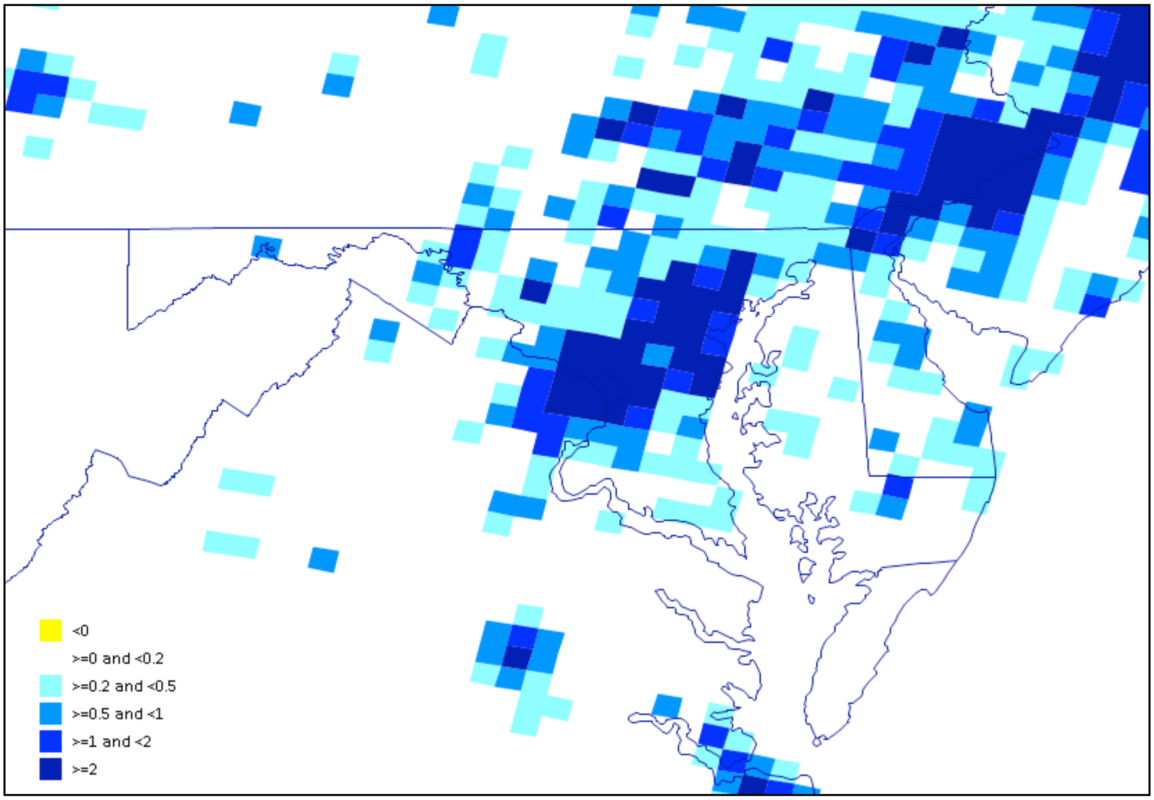


Figure D-4: Distribution of Upper End (Lepeule et al. 2012) Estimate of Premature Mortality in Maryland from Changes in $PM_{2.5}$ Concentrations from Reference Case to Enhanced Meta-scenario



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