Evaluating Reduced-Form Tools for Estimating Air Quality Benefits

Presentation to the SAB reduced form modeling peer review panel

May 28, 2020

Outline of EPA overview presentation

- Background
- Overview of EPA air quality models and health impact estimation tools
  - Review usual EPA full-form air quality modeling and health impact approach
  - Describe core concepts underlying reduced form approaches
  - Review EPA's benefit-per-ton reduced-form approach
  - Identify other reduced-form approaches considered in the evaluation report
  - Discuss the differences between the reduced-form approaches considered in the evaluation report
- Overview of report: "Evaluating Reduced-Form Tools for Estimating Air Quality Benefits"
  - Report objectives
  - Analytical approach
  - Results
  - Discussion / Limitations of the analysis
  - Recommendations for the future
- Charge questions

Background

- Consistent with OMB guidance, EPA routinely estimates the anticipated impacts of regulatory actions. This includes:
  - Changes in emissions
  - Changes in air quality (change in pollutant concentrations across impacted domain)
  - Costs and benefits of changes, including the number and value of air pollution-attributable health impacts

- Whenever possible, EPA strives to estimate these impacts using a state-of-the-science "full-form" approach:
  - Emissions: source-specific estimates from EPA's National Emissions Inventory (NEI)
  - Air quality: photochemical air quality model (e.g., Community Multiscale Air Quality)
  - Health impacts: benefits tool (e.g., Environmental Benefits Mapping and Analysis Program)

Background

- However, in certain instances, EPA has used “reduced-form” tools, which employ simpler approaches to approximate the more complex analyses.

- Reduced-form tools are used when time and resources are constrained, such as when rule development timelines are compressed.

- Analytical results from reduced-form tools can diverge from full-form results to varying degrees, depending on critical factors such as the vintage of modeling that underlies the reduced-form approach and the geographic pattern of emissions changes.

Background

- In October 2017, as part of the proposed rule to repeal the Clean Power Plan, EPA committed to systematically evaluating the uncertainty associated with reduced-form techniques, with the goal of better understanding the suitability of such approaches to estimating the health impacts of pollutant emissions changes.
  - EPA's "benefit per ton" approach was specifically highlighted for evaluation
  - EPA committed to make the evaluation available for peer review

- In October 2019, EPA released the contractor report: "Evaluating Reduced-Form Tools for Estimating Air Quality Benefits".
  - https://www.epa.gov/benmap/reduced-form-evaluation-project-report
  - EPA has made public the modeling inputs and processing scripts to assist model developers and users in conducting similar evaluations. https://github.com/epa-kpc/RFMEVAL
  - EPA also authored a "Data in Brief" publication to document the github dataset: https://doi.org/10.1016/j.dib.2019.104886

EPA contacts on reduced-form modeling

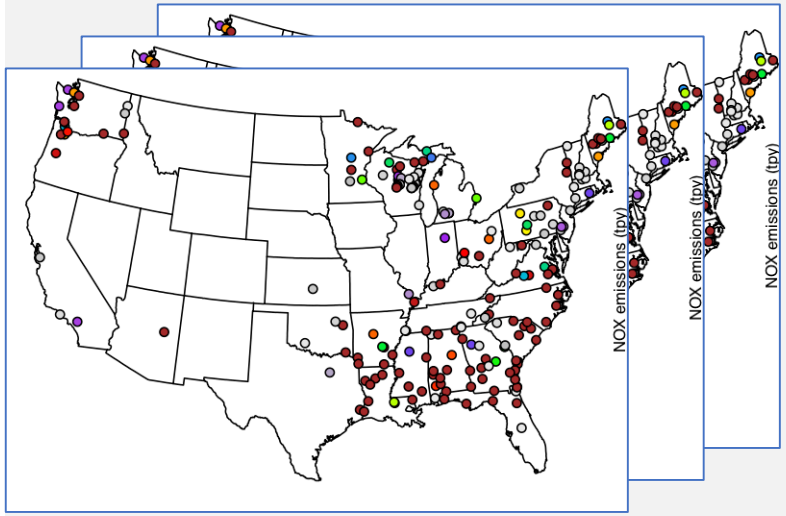
- The reduced-form report was jointly managed by two divisions of EPA's Office of Air Quality Planning and Standards (OAQPS) within the Office of Air and Radiation (OAR).

- OAR/OAQPS/Air Quality Assessment Division (AQAD)
  - Division Director: Chet Wayland
  - Group Leader, Air Quality Modeling Group: Tyler Fox
  - Participating staff: Kirk Baker, Heather Simon

- OAR/OAQPS/Health and Environmental Impacts Division (HEID)
  - Division Director: Erika Sasser
  - Group leader, Risk and Benefit Group: Bob Wayland
  - Participating staff: Elizabeth Chan, Pat Dolwick, Neal Fann, Lisa Thompson

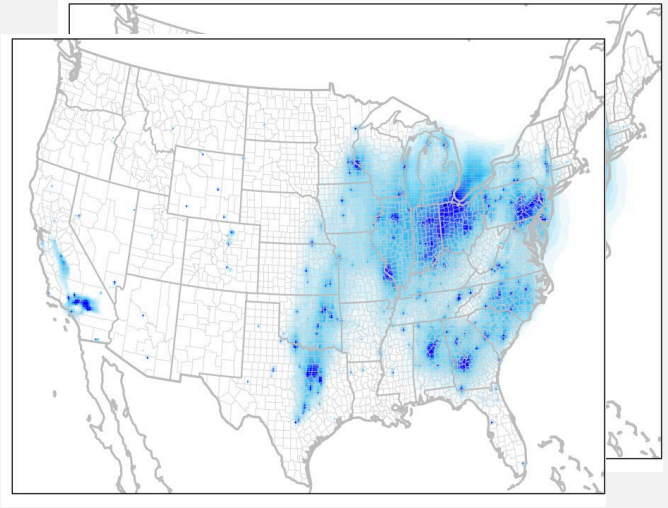
EPA routinely estimates AQ changes & health benefits for regulatory actions (Schematic of typical full form approach)

Base year & projected future year emissions scenarios are developed (pre- & post-control) based on the National Emissions Inventory and complex emissions models (e.g., IPM and MOVES)



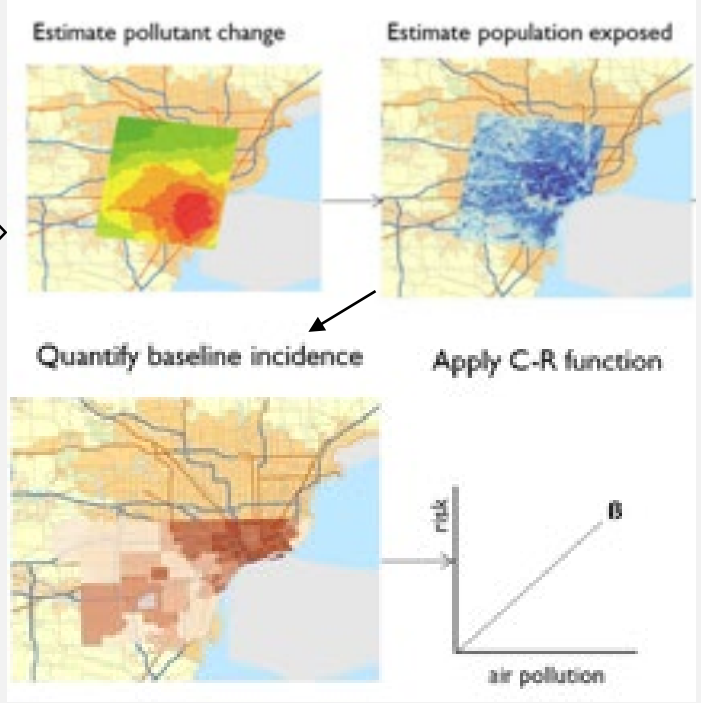
Changes in emissions

Air quality model surfaces for each emissions scenario are generated with a photochemical grid model (e.g., CMAQ or CAMx)



Changes in air quality

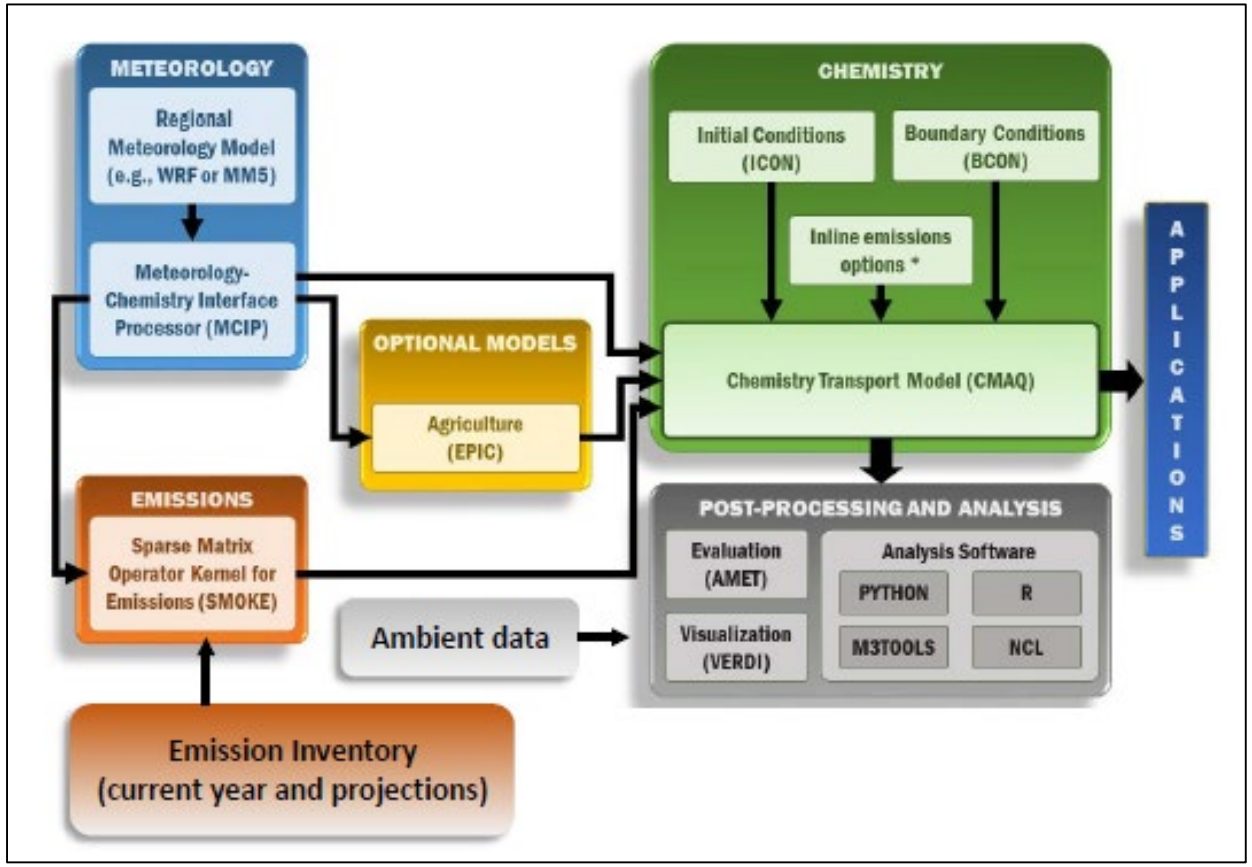
Differences in air quality along with location-specific health incidence rates and population are used to estimate health impacts via BenMAP



Benefits

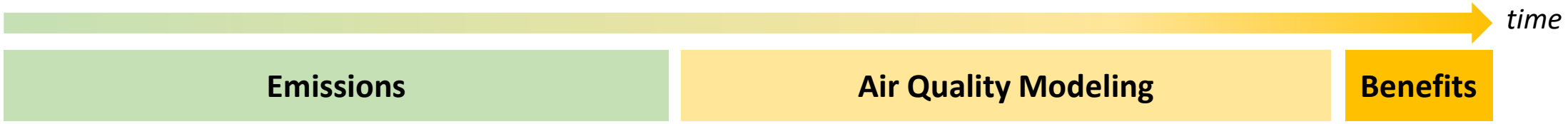
Full-form modeling involves detailed representations of atmospheric processes

- Air quality modeling platforms are a structured system of connected tools and data that provide an evaluated basis for assessing the response of pollutant concentrations to emissions changes
- Providing inputs, scenario development, and the actual model simulations can be time-consuming.
  - For nationwide domains, it may take months to develop a platform and then weeks to months to simulate specific future emissions reduction scenarios using the platform
- For most regulatory actions, EPA analyzes a limited number of scenarios which may diverge from final regulatory decisions
  - Reduced form tools provide one way to add flexibility to regulatory analysis, enabling EPA to analyze more policy options more efficiently



Numerous reduced-form approaches have been developed to expedite process (Different tools use different assumptions to simplify)

Full-form tools assess emission changes (future base/control), model air quality, and estimate benefits

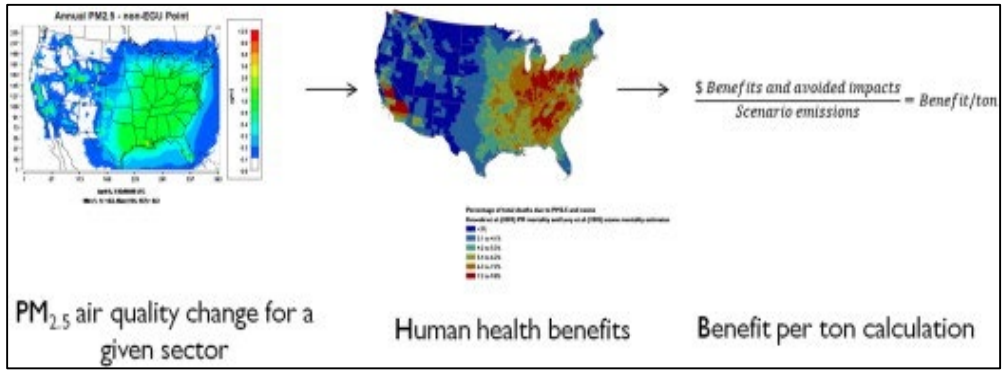


Some **reduced-form** tools simplify the AQ modeling step using pre-derived emissions -> AQ relationships

Other **reduced-form** tools simplify the AQ & benefit steps using pre-derived emissions -> benefit relationships

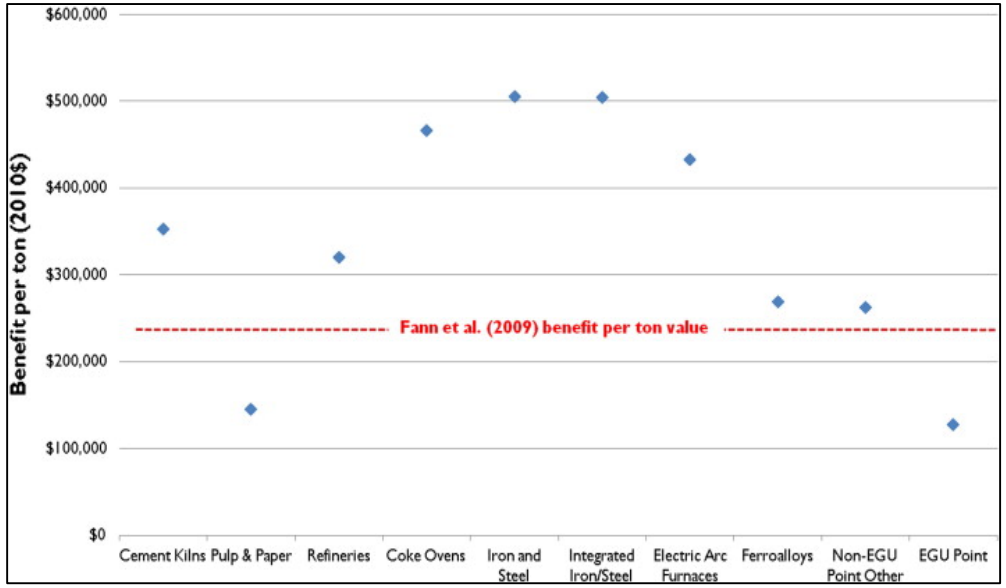
EPA developed a source-specific reduced-form approach to estimate benefits (Source apportionment-based benefit-per-ton or SA-BPT)

- In 2012, EPA conducted national photochemical modeling using source apportionment and emissions based on the 2005 NEI to determine the relationship between emissions from specific source sectors and $PM_{2.5}$ concentrations (Fann et al., 2012)



- The $PM_{2.5}$ contributions for each sectors were converted to benefits in BenMAP

- Finally, these national sector benefits were divided by total sector emissions to derive a benefit-per-ton value for each of the 17 sectors



- EPA is in the process of updating these SA-BPT estimates to reflect more current emissions from specific sectors

This report evaluated 4 reduced-form models against the full-form approach

- EPA's Source Apportionment-Based Benefit-Per-Ton (SA-BPT) approach
- Estimating Air Pollution Social Impact Using Regression (EASIUR) model
- Intervention Model for Air Pollution (InMAP)
- Air Pollution Policy Experiments and Policy Analysis model, versions 2 and 3 (AP2, AP3)

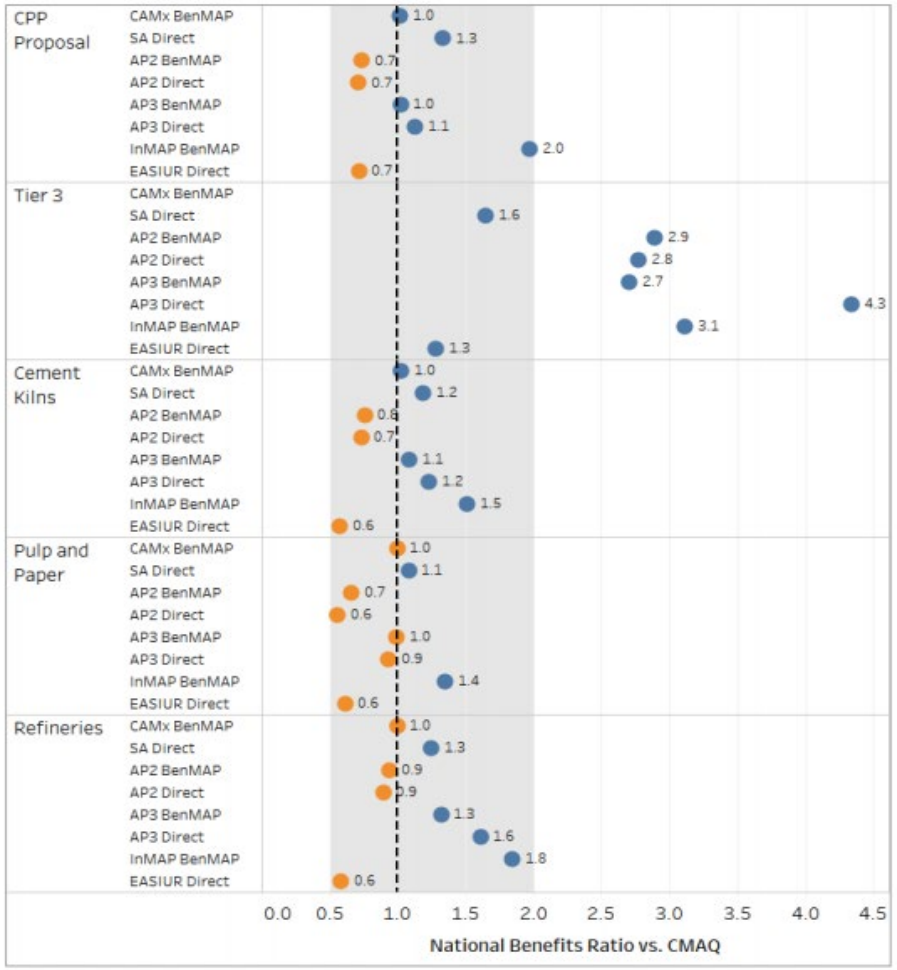
	Tool	Gridded/county level changes in annual $PM_{2.5}$ concentrations	County level health impacts	County level economic values	National aggregate health impacts	National aggregate economic values
Full form	CMAQ/CAMx-BenMAP	Y	Y	Y	Y	Y
Reduced Form	SA-BPT	N	N	N	N	Y
	EASIUR	N	N	N	N	Y
	InMAP	Y	Y	Y	Y	Y
	AP2 / AP3	Y	Y	Y	Y	Y

Comparing Results among Reduced-Form Tools

- Some reduced-form tools only estimate economic benefits, while others also calculate the $PM_{2.5}$ air quality changes that lead to those benefits
  - Reduced-form tools that only estimate economic benefits: SA-BPT, EASIUR
  - Reduced-form tools that estimate $PM_{2.5}$ changes and economic benefits: AP2, AP3, InMAP
- Accurately comparing these tools required matching inputs and outputs to the extent possible:
  - For all tools, we compared the benefits estimates generated directly by the tool ("Direct")
  - If the model generated $PM_{2.5}$ air quality changes as an interim output prior to calculating benefits (AP2, AP3, and InMAP), we also input the model-estimated $PM_{2.5}$ changes into BenMAP to generate benefits estimates using EPA's "full form" benefits tool ("BenMAP")
    - This additional comparison allows one to better evaluate whether any differences between the full- and reduced-form approaches result from the reduced-form assumptions about the relationship between emissions and $PM_{2.5}$, or from the assumptions related to the relationship between $PM_{2.5}$ and economic benefits.

Comparing Results among Reduced-Form Tools within the Report

EXHIBIT 3-3. RATIO OF NATIONAL AVOIDED PREMATURE MORTALITY BENEFITS ESTIMATES COMPARED AGAINST CMAQ ESTIMATES, BY POLICY SCENARIO. ORANGE DOTS REPRESENT RATIOS LESS THAN 1 AND BLUE DOTS RATIOS GREATER THAN 1.



- This example figure from the report shows the ratio between avoided premature mortality benefits estimated by the reduced-form tools and the same benefits estimates by CMAQ.
- The figure displays “direct” results for four reduced-form tools and “BenMAP” results for AP2, AP3, and InMAP, grouped by scenario. (The figure also shows the CAMx vs. CMAQ ratio between full-form models.)
- A ratio of one indicates that the reduced-form benefits estimate is equivalent to the full-form estimate for that scenario. Blue (orange) dots indicate that the reduced-form tools exceed (are less than) the full-form estimates.

Additional notes involved with comparing results

- There are known differences in the reduced- and full-form model outputs in terms of what species they include and the degree of accuracy with which they simulate those species.
- Combined with different approaches for estimating air quality and benefits, this can lead to various points of divergence among the reduced-form tools
- Thus, there may be more than one reason that a particular tool comes closer (or further) to a full-form result, and the performance of each tool may vary by scenario examined. For example:
  - A reduced form tool may better duplicate a full-form result for some pollutants than others (depending on how the infrastructure of the tool is built)
  - A reduced-form tool may better duplicate a full-form result for a policy change that affects an evenly distributed sector nationwide as compared to a policy change that affects a few geographically isolated sources

Chapter 1: Report objectives

- One of the objectives of the reduced-form evaluation project was to develop and demonstrate a protocol for systematically comparing monetize $PM_{2.5}$ health benefits estimated using reduced-form tools with those generated using full-form air quality and health benefits models, in the specific context of using such tools to inform the economic impacts of regulatory analyses.

- The other objective of the project was to then apply this evaluation protocol across a series of scenarios and existing models.
  - Evaluation was intended to assess the range of results across a suite of tools and policy relevant scenarios
  - Evaluation was not intended to identify "winners or losers" across the various tools

- EPA expects that reduced-form tools will continue to evolve in the future and has already initiated efforts to further enhance Agency reduced-form methods and tools.

Chapter 2: Analytical Approach

- As noted above, four broadly used reduced-form tools were evaluated in the report:
  - EPA's source apportionment benefit-per-ton tool (SA-BPT)
  - The Estimating Air Pollution Social Impacts Using Regression model (EASIUR)
  - The Air Pollution Emission Experiment and Policy analysis models (AP2, AP3)
  - The Intervention Model for Air Pollution (InMAP)

- The report followed two guiding principles when applying these tools in this evaluation:
  - Key model inputs were standardized across reduced-form tools to the extent allowable to ensure comparable results.
  - The underlying model architecture was not substantially altered so results reflect unique nature of tool.

- These reduced-form tools were compared against two full-form photochemical models (CMAQ and CAMx) for five different emissions reduction scenarios:
  - One option from EPA's Clean Power Plan proposal
  - EPA's Tier-3 motor vehicle emission and fuel standards
  - Three hypothetical control scenarios for specific sectors (cement kilns, oil refineries, pulp and paper plants)

Chapter 3: Results

- National-level results:
  - Ratio of total benefits (RFM / FFM) by model
  - Ratio of total benefits (RFM / FFM) by scenario
  - Ratio of benefits (RFM / FFM) by precursor and model

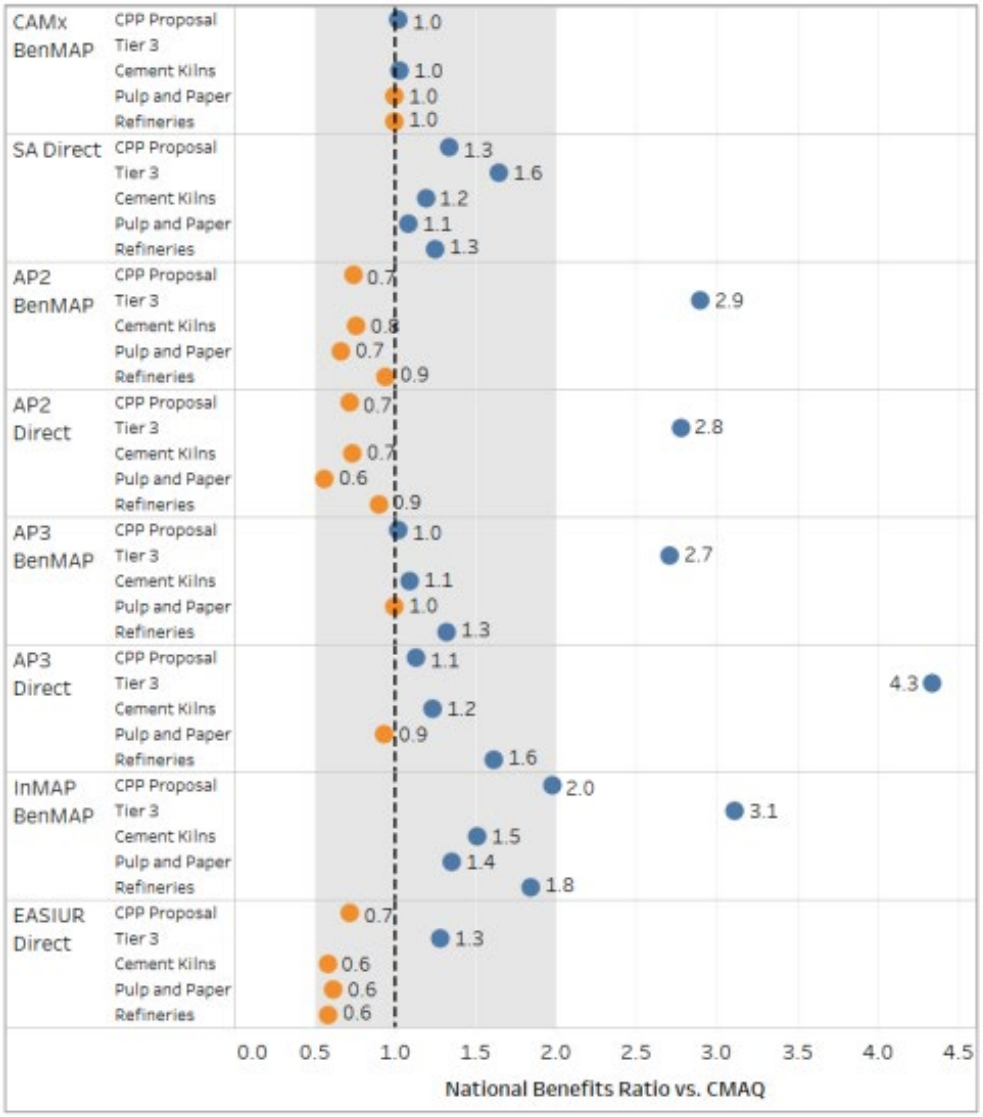
- Regional-level results:
  - Evaluated normalized mean “bias” and “error” of the reduced form tools relative to the full-form model across seven different U.S. regions.

- The report also considered the level of effort required to run each of the models.

Note:

RFM = Reduced-Form Model
FFM = Full-Form Model
SA-Direct = SA Benefit-Per-Ton (SA-BPT)

EXHIBIT 3-2. RATIO OF NATIONAL AVOIDED PREMATURE MORTALITY BENEFITS ESTIMATES COMPARED AGAINST CMAQ ESTIMATES, BY TOOL AND POLICY SCENARIO. ORANGE DOTS REPRESENT RATIOS LESS THAN 1 AND BLUE DOTS RATIOS GREATER THAN 1.



Chapter 4: Discussion

- CMAQ and CAMx produce very similar estimates of both total $PM_{2.5}$ benefits and benefits related to specific $PM_{2.5}$ components.

- Assessment of reduced-form tools:
  - The reduced-form tools replicated the full-form results far better for direct $PM_{2.5}$ and sulfate, than for nitrate $PM_{2.5}$.
  - Of the scenarios tested here, RFM performance was best for point source strategies and poorest for the Tier 3 mobile scenario (possibly due to the higher influence of nitrate reductions in that rule and associated non-linear concentration responses).
  - SA-BPT and EASIUR models required the lowest level of effort across reduced-form tools and produced some of the most similar estimates to full-form results at the national level. Biases ranged from 10-30% across the point source scenarios within the benefit-per-ton tool.
  - The AP2 and AP3 models compared reasonably to full-form approaches when their air pollutant surfaces were processed through BenMAP but not as well in direct mode (where the tool calculates benefits internally).
  - InMAP (BenMAP) results were poorest match with full-form results (overestimation).

Chapter 4: Limitations of this analysis

- This analysis provides a representative snapshot of reduced-form tool performance across a range of potential policy scenarios. However, there are several limitations and important caveats worth noting:
  - The five scenarios tested here do not represent an exhaustive set of potential rule scenarios. This limited sample size makes it difficult to draw conclusive opinions about reduced-form tool performance for any particular type of policy scenario.
  - Other reduced-form approaches that were not part of this specific application of the evaluation framework may perform differently.
  - The reduced-form tools are periodically updated; our observations are only accurate with respect to the versions of the reduced-form tools we tested.

- Further, the present analysis does not attempt to identify and quantify potential sources of uncertainty within each of the broad model approaches (i.e., FFM and RFM). Previous studies have identified other sources of uncertainty, which include uncertainty in the value of statistical life estimates and the shape of the slope of the mortality concentration-response relationship.

Chapter 5: Recommendations for future

- While some of the reduced-form tools included in this evaluation produced results that were reasonably comparable at the national level to full-form model results and offer a quicker approach to generating ballpark estimates of the health-related benefits or costs associated with an air quality policy, EPA believes there is value in continued evaluation of how reduced-form tools compare to full-form model estimates across policy relevant scenarios.

- The accuracy of a reduced form tool depends heavily on the air quality modeling that underlies it. The extent to which the underlying air quality modeling can be updated and improved over time may enable improved benefits estimates that better compare with full form model results.

- EPA is currently working to update our benefit-per-ton estimates and consider possible alternate reduced-form modeling approaches.

Appendix: Charge questions

Charge questions for the panel

- Question 1. Please comment on the evaluation approach developed by EPA to compare reduced-form models to full-form equivalents.
  - Please comment on whether the emissions reduction scenarios used in the proposed evaluation approach provide enough diversity to adequately assess reduced-form performance over a range of possible applications.
  - Please discuss whether the specific assumptions that EPA made to apply each tool as consistently as possible (e.g., emissions, meteorology, use of direct vs. BenMAP estimates, etc.) are appropriate and clearly explained.
  - Please assess whether the report's description of its limitations is complete.

- Question 2. Please comment on the results of the reduced form tool evaluation, considering quantitative and qualitative aspects of the model comparisons.
  - Was the information clearly presented and informative?
  - Were EPA's conclusions reasonable?
  - Are there other results which would be useful to include in the comparison?

Charge questions for the panel

- Question 3. Exhibit ES-4 “Ratio of National Avoided Premature Mortality Benefits Estimates,” shows how different reduced-form tools generated different estimates as compared to full-scale air quality models.
  - Does the report provide a clear and thorough explanation for why some tools under- or over-estimated $PM_{2.5}$ health benefits as compared to the full-scale air quality modeling?
  - How do the results of this study inform our understanding of the suitability of these tools for regulatory economic analyses in their current form?
  - Can any of the reduced-form tools explored in this report easily be modified to allow quantifying the extent to which the total health benefits accrue to specific geographic areas (e.g., by state, or where ambient concentrations are above or below the NAAQS)?

Charge questions for the panel

- Question 4. Since 2008 EPA has used SA-BPT to estimate the health impacts of numerous regulations. Under the scenarios examined in this report, EPA's SA-BPT approach over-estimated $PM_{2.5}$-related health benefits by between 10 and 30 percent, depending on the sector. To ensure BPT estimates correspond to full-form results as closely as possible, the report recommends updating the underlying emissions inventories and air quality modeling used to inform the EPA SA-BPT approach over time.
  - In the interim, how might EPA improve its characterization of results derived from the 2005 SA-BPT approach, specifically the potential degree of over- or underestimation in BPT-based results for a particular regulatory scenario?
  - What criteria (e.g., geographical scale, regulated sector, pollutants/precursors) should EPA examine to determine the potential for divergence between SA-BPT results vs full-form air quality modeling results (resulting in over- or under-estimation)?
  - Based on the results of this study, does the panel have any additional recommendations about BPT-based approaches?

Charge questions for the panel

- Question 5. How do the results of this study inform the future development of reduced-form tools that are capable of providing reliable estimates of impacts associated with different sectors, across a variety of spatial scales, and for different portions of the air quality distribution?
  - Are there other, less resource intensive approaches than full-scale air quality modeling for informing the public about the size and distribution of $PM_{2.5}$ health benefits associated with alternative regulatory scenarios?