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Future U.S. air quality and health using GCAM-USA

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Foreword

- Purpose of this presentation
  - Discuss development and applications of GLIMPSE, a GCAM-USA-based decision support tool for air quality management
- Intended audience
  - The GCAM modeling community
- Caveats
  - Acronyms that are very familiar to the GCAM modeling community are not defined
  - All results shown are intended to be illustrative. Caveats and assumptions are not fully discussed here. Please do not cite results.
- Disclaimer
  - The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. EPA

Outline

- Background and objectives
- Example applications
  - Example 1 – Projecting future air pollutant emissions
  - Example 2 – Estimating air quality health costs and understanding the drivers of state-level trends
  - Example 3 – Examining the emission implications of alternative population growth scenarios
- Additional considerations and future steps
- Questions?

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Background and objectives

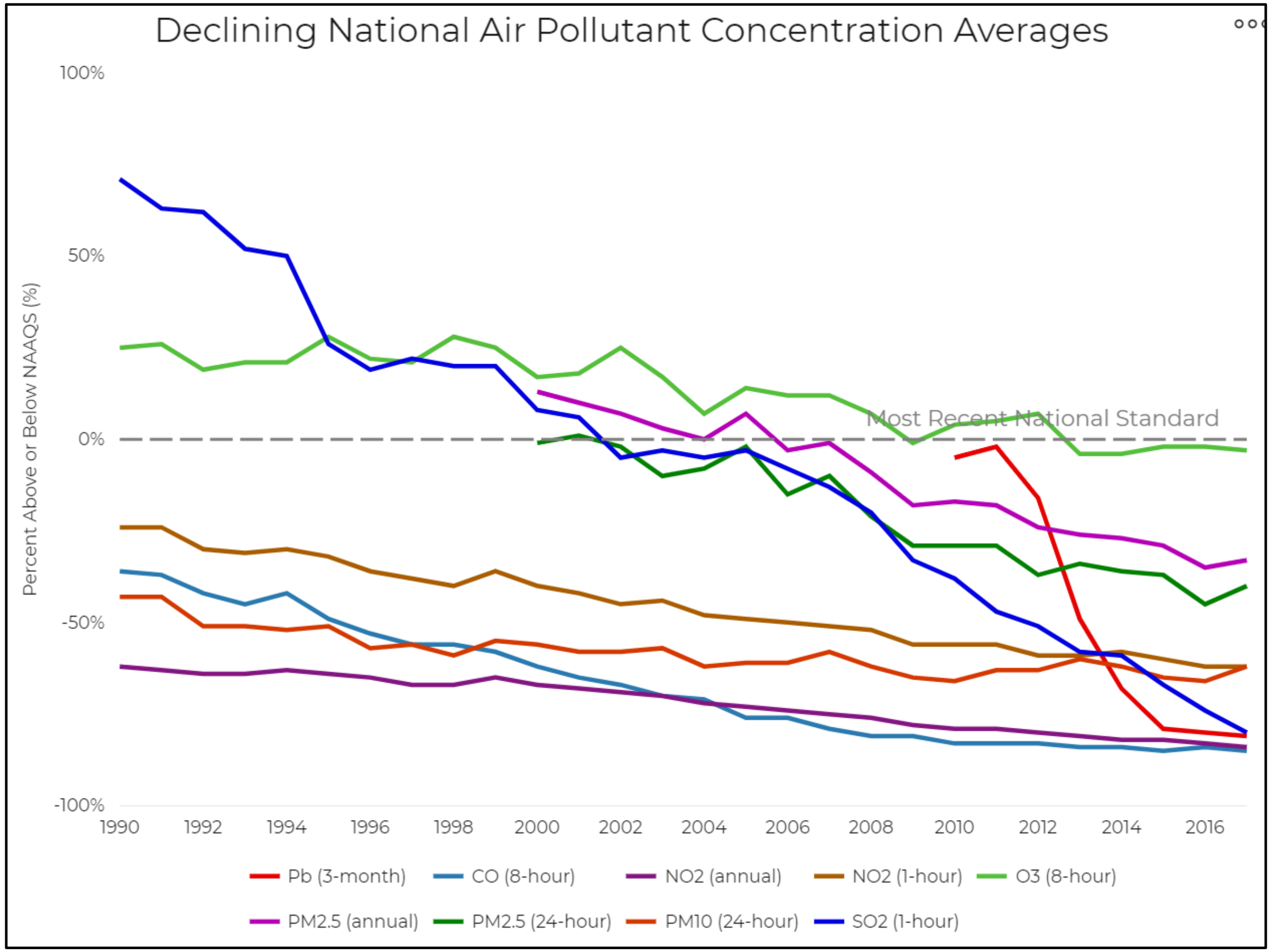
Air quality management

The Clean Air Act (1963) and its 1970, 1977 and 1990 Amendments provide EPA the authority to regulate air emissions

- Key issues targeted:
  - Acid rain, urban smog, regional haze, stratospheric ozone, air toxics
  - Interstate transport of pollutants
- Require EPA to set and periodically revisit National Ambient Air Quality Standards (NAAQS) for six criteria pollutants
  - Carbon monoxide (CO), ground-level ozone (O_3), nitrogen dioxide (NO_2), particulate matter (PM), sulfur dioxide (SO_2), and lead (Pb)
- Federal regulatory mechanisms that reduce emissions include:
  - New Source Performance Standards (NSPS)
  - Maximum Achievable Control Technology (MACT) requirements
  - Cap and trade programs
    - Acid Rain Program
    - Cross-State Air Pollution Rule
- States that are not in attainment with the NAAQS must develop and implement State Implementation Plans (SIPS) that specific how attainment will be achieved over specified timelines

U.S. air quality trends

The U.S. has made great strides in reducing air pollution since the passage of the Clean Air Act Amendments

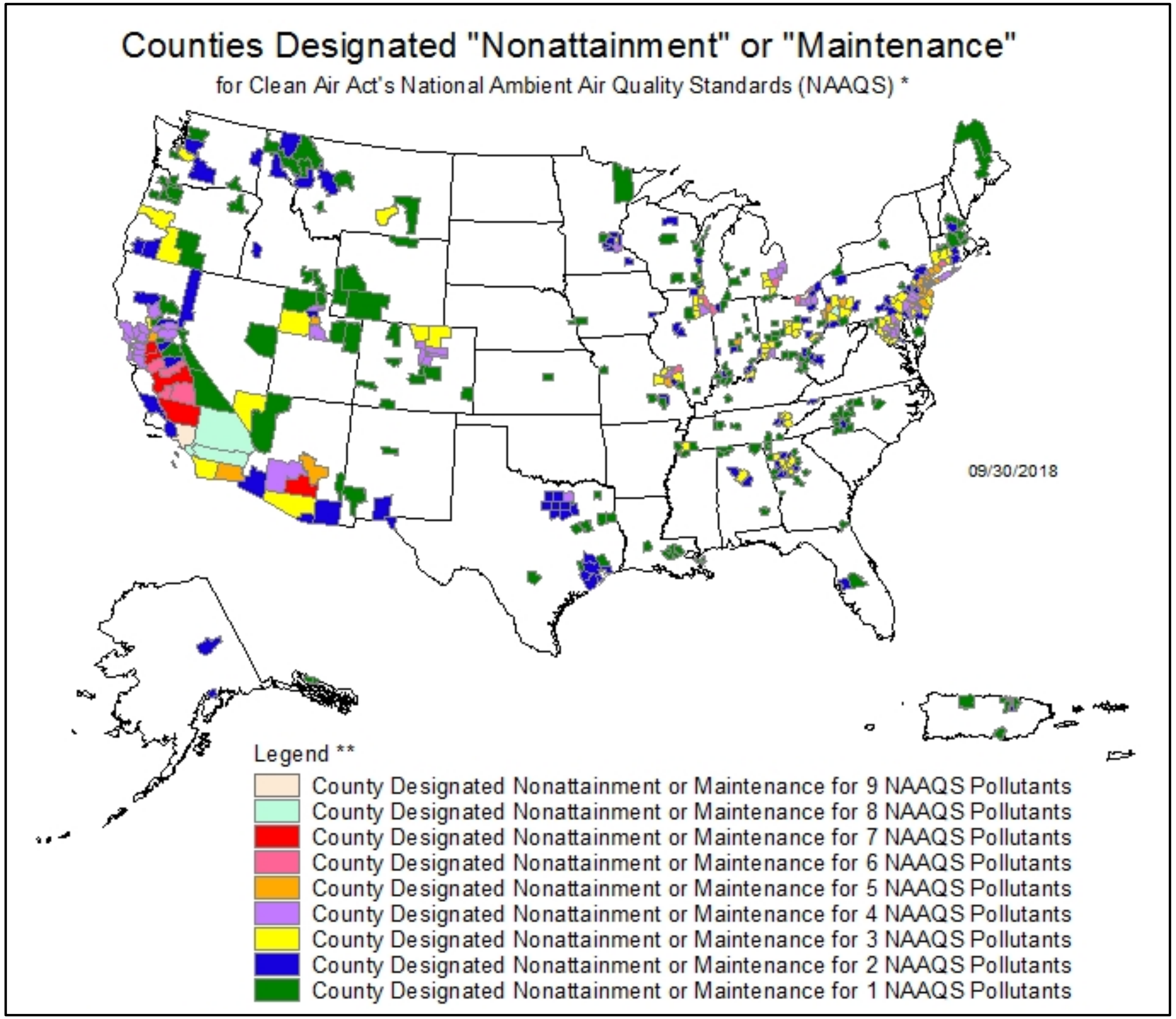


Source: https://gispub.epa.gov/air/trendsreport/2018/#highlights

Nat'l average concentration changes since 1990

- Carbon Monoxide (CO) 8-Hour, ↓ 77%
- Lead (Pb) 3-Month Average, ↓ 80%
- Nitrogen Dioxide (NO_2) Annual, ↓ 56%
- Nitrogen Dioxide (NO_2) 1-Hour, ↓ 50%
- Ozone (O_3) 8-Hour, ↓ 22%
- Particulate Matter 10 microns (PM_{10}) 24-Hour, ↓ 34%
- Particulate Matter 2.5 microns ($PM_{2.5}$) Annual, ↓ 41%
- Particulate Matter 2.5 microns ($PM_{2.5}$) 24-Hour, ↓ 40%
- Sulfur Dioxide (SO_2) 1-Hour, ↓ 88%

Remaining air quality issues



- Despite this progress, an estimated 132 million people (40% of the U.S. population) live in areas that exceed a NAAQS or that have been re-designated to attainment subject to maintenance

Source: https://www.epa.gov/green-book/green-book-map-download

Potential considerations for air quality managers

- What is the relative cost-effectiveness of potential measures?
  - Controls devices, process changes, energy efficiency, conservation, fuel-switching, electrification
- How is the long-term efficacy of candidate management strategies affected by factors such as the following (and uncertainty in those factors)?
  - Population growth and migration
  - Economic growth and transformation
  - Energy supplies and their depletion
  - Technology stock and turnover
  - Technology development
  - New and emerging demands for energy
  - Transformations in mobility and land use patterns
  - Supply limits and competition among sectors for water
  - Climate change
  - Human behavior and choices
  - Other energy, environmental, and climate policies
- Is the air quality management strategy consistent with the state's economic, energy, environmental, and climate goals?
- Even for areas currently in attainment, how will the factors listed above threaten attainment in the future?
  - Can we anticipate problems and be prepared to act when or before they are realized?

The GLIMPSE project

- GLIMPSE: GCAM Long-term Interactive Multi-Pollutant Scenario Evaluator
- Objective: Provide a state-level tool for supporting air quality planning
  - Understand future threats to attainment
  - Evaluate potential management strategies under uncertainty
  - Assist in identifying management strategies that simultaneously, cost-effectively, and robustly meet state energy, environmental, and climate goals
  - Provide insights about cross-sector interactions, counterintuitive responses, and unintended consequences
- Status
  - GCAM-USA has being modified to more fully reflect U.S. air quality regulations
  - "Levers" reflecting management options are being integrated into the model
  - A GLIMPSE graphical-user-interface prototype has been developed
  - Internal beta testers are using GLIMPSE to evaluate its installation and use
  - GCAM-USA is being applied to a range of applications, several of which are summarized here

Three example applications

1. Projecting future air pollutant emissions
2. Estimating air quality health costs and understanding what drives state-level trends
3. Evaluating population scenarios to understand how growth may challenge air quality management

Other ongoing efforts:

- Emissions and air quality implications of state-level greenhouse gas strategies
- Net energy and emissions impacts of electric vehicle and other forms of increased end-use electrification (e.g., space and water heating)
- Life-cycle emissions associated with electricity production scenarios

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Example 1

Projecting future air pollutant emissions

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Projection of air pollutant emissions

Evaluation

Shi, W., Ou, Y., Smith, S.J., Ledna, C., Nolte, C.G., and D.H. Loughlin. Projecting state-level air pollutant emissions using an integrated assessment model: GCAM-USA. *Applied Energy*, 208(2017), pp 511-521. DOI: https://doi.org/10.1016/j.apenergy.2017.09.122

Summary

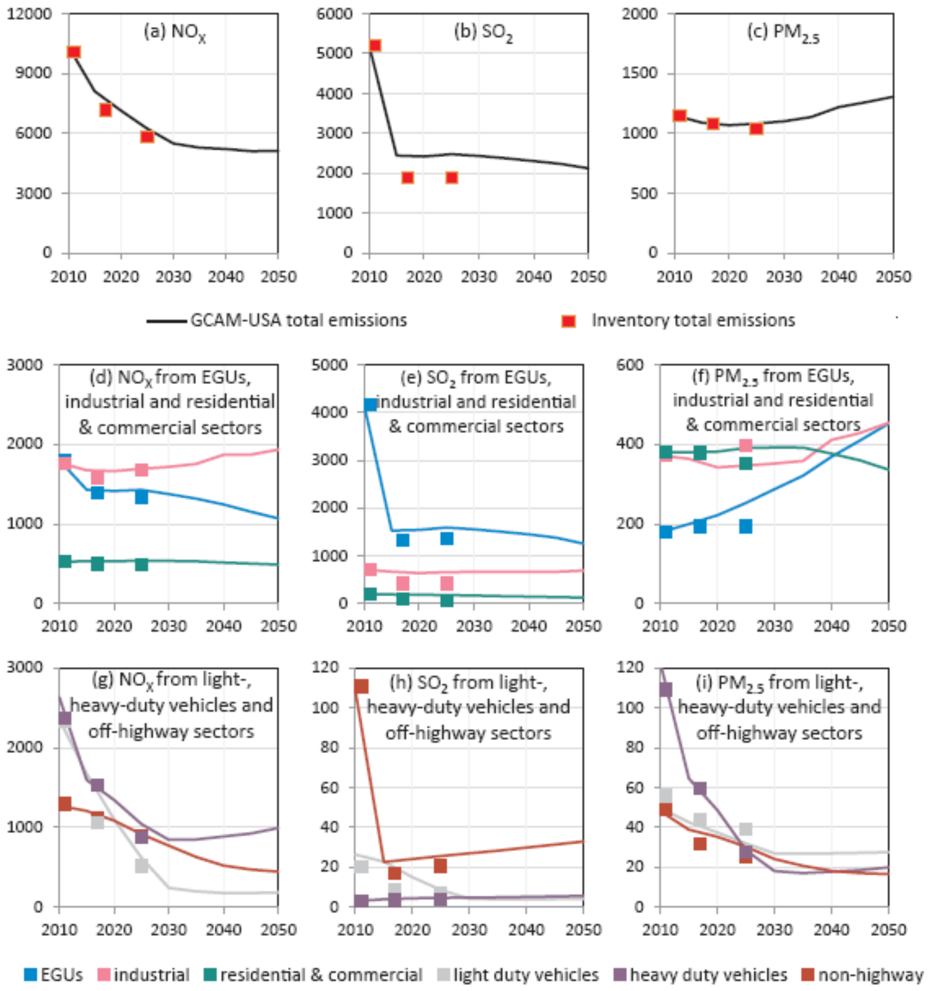
Objectives:

- Describe U.S. EPA modifications to GCAM-USA to support air pollutant emission projections
- Apply the updated GCAM-USA to project emission of NOx, SO_2, and $PM_{2.5}$
- Compare the projections by comparing to EPA regulatory analyses
- Introduce and apply “Quality Metric (QM)” to evaluate national- and state-level results

Findings:

- GCAM-USA is a fast and flexible mechanism for projecting state and national air pollutant emissions
- After the modifications, GCAM-USA projections much more closely matched EPA estimates, capturing major trends at the national and sectoral levels
- The QM provides information that may be useful in examining state- and sectoral-level performance, helping determine the types of questions that can be answered

Comparison of GCAM-USA outputs with EPA projections



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Projection of air pollutant emissions

Application to alternative scenarios

Ou, Y., Shi, W., Smith, S.J., Ledna, C.M., West, J.J., Nolte, C.G., and D.H. Loughlin. Estimating environmental co-benefits of U.S. GHG reduction pathways using an integrated assessment model with state-level resolution. *Applied Energy*, 216(2018) pp. 482-493. DOI: https://doi.org/10.1016/j.apenergy.2018.02.122

Summary

Objectives:

- Apply the modified GCAM-USA that was described by Shi et al.
- Describe the addition of PM mortality and water use factors
- Evaluate the low-carbon scenarios from the Energy Modeling Forum 24 exercise to compare their relative air quality-related health co-benefits

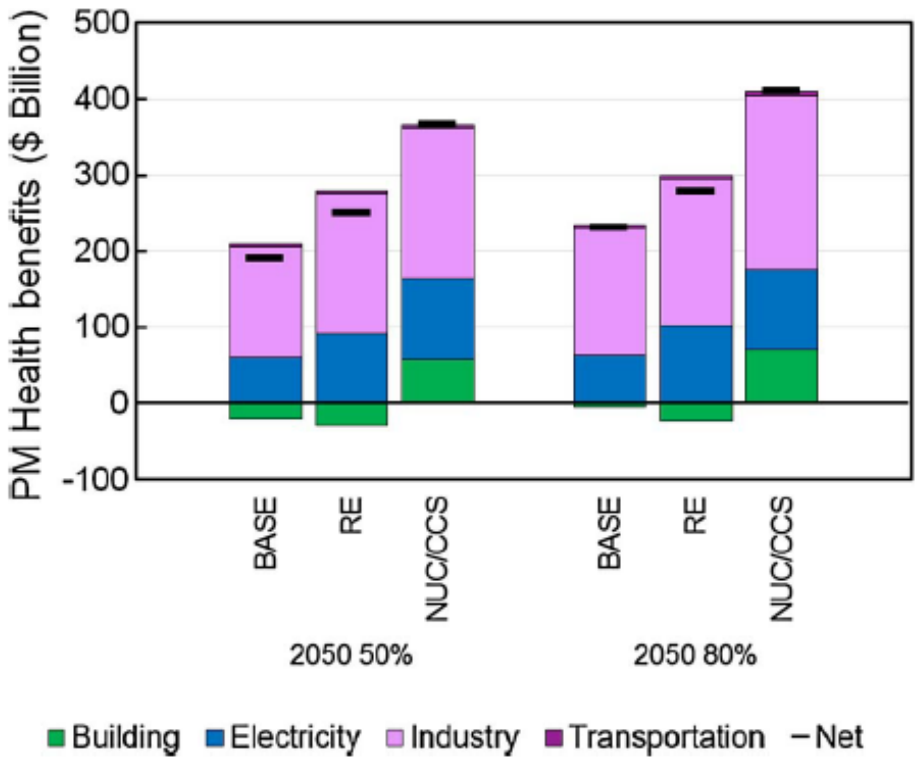
  Pathways:
  - All technologies; Renewables focus; Nuclear and carbon capture focus

  Low-carbon targets:
  - 50% reduction from 2005; 80% reduction from 2005

Findings:

- GCAM-USA can be used to evaluate co-benefits of alternative low-carbon pathways
- Co-benefits are shown to differ by pathway and spatially
- RE (as modeled) achieves greater water use co-benefits
- NUC/CCS (as modeled) achieves greater health co-benefits
- Treatment of residential biomass and assumptions about the adoption of cleaner biomass combustion technologies has a large effect on health results

PM mortality health benefits by sector for low-carbon pathways



BASE – all technologies are available
RE – emphasis on renewable technologies
NUC/CCS – emphasis on nuclear power and CCS

Example 2

Estimating air quality health costs and understanding drivers of state-level trends

Research being conducted by Yang Ou. Please see his poster for more details.

Air quality costs and state-level trends

Approach

- Add state-, pollutant-, and source category-specific $PM_{2.5}$ mortality cost factors to GCAM-USA

  derived from EASIUR (Heo et al, 2016)

- Evaluate the resulting state-level $PM_{2.5}$ mortality costs through 2050 for a Reference Scenario

- Use the Logarithmic Mean Divisia Index (LDMI) to investigate the major factors driving state-level mortality costs in 2050

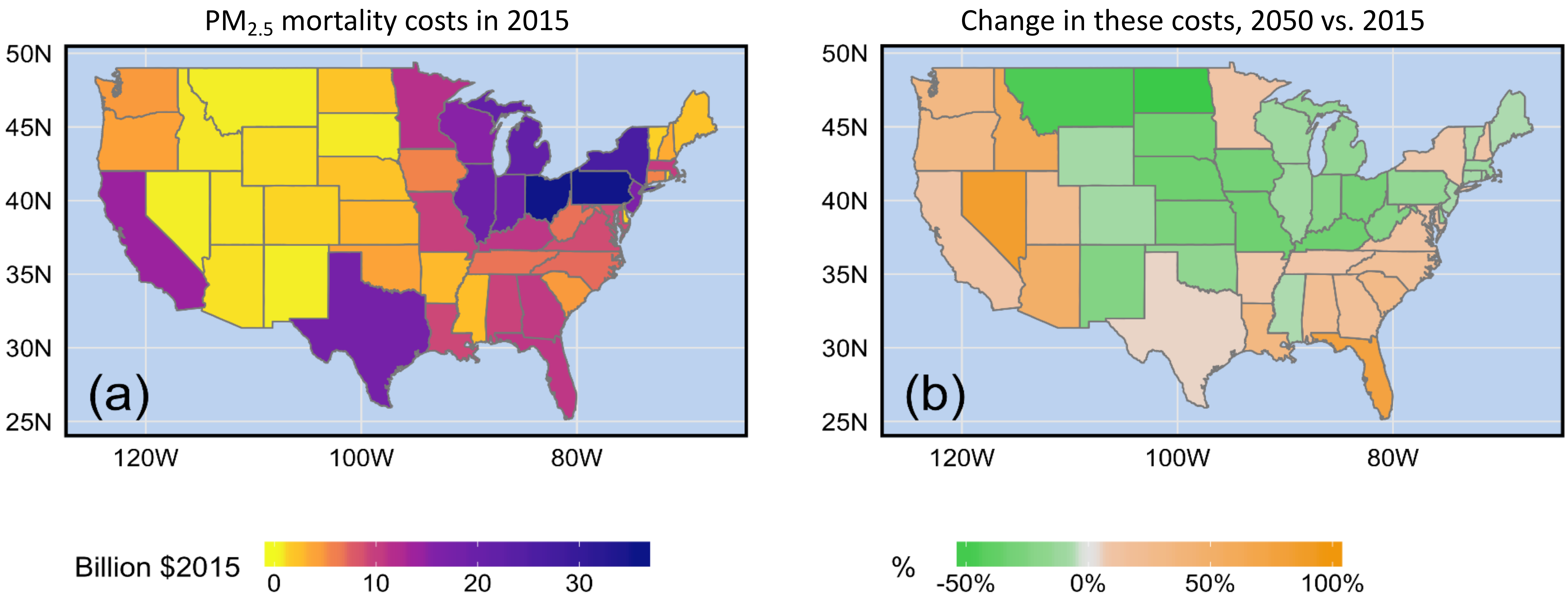
Factors explored using LDMI

National and state-level changes (2015 to 2050) in:

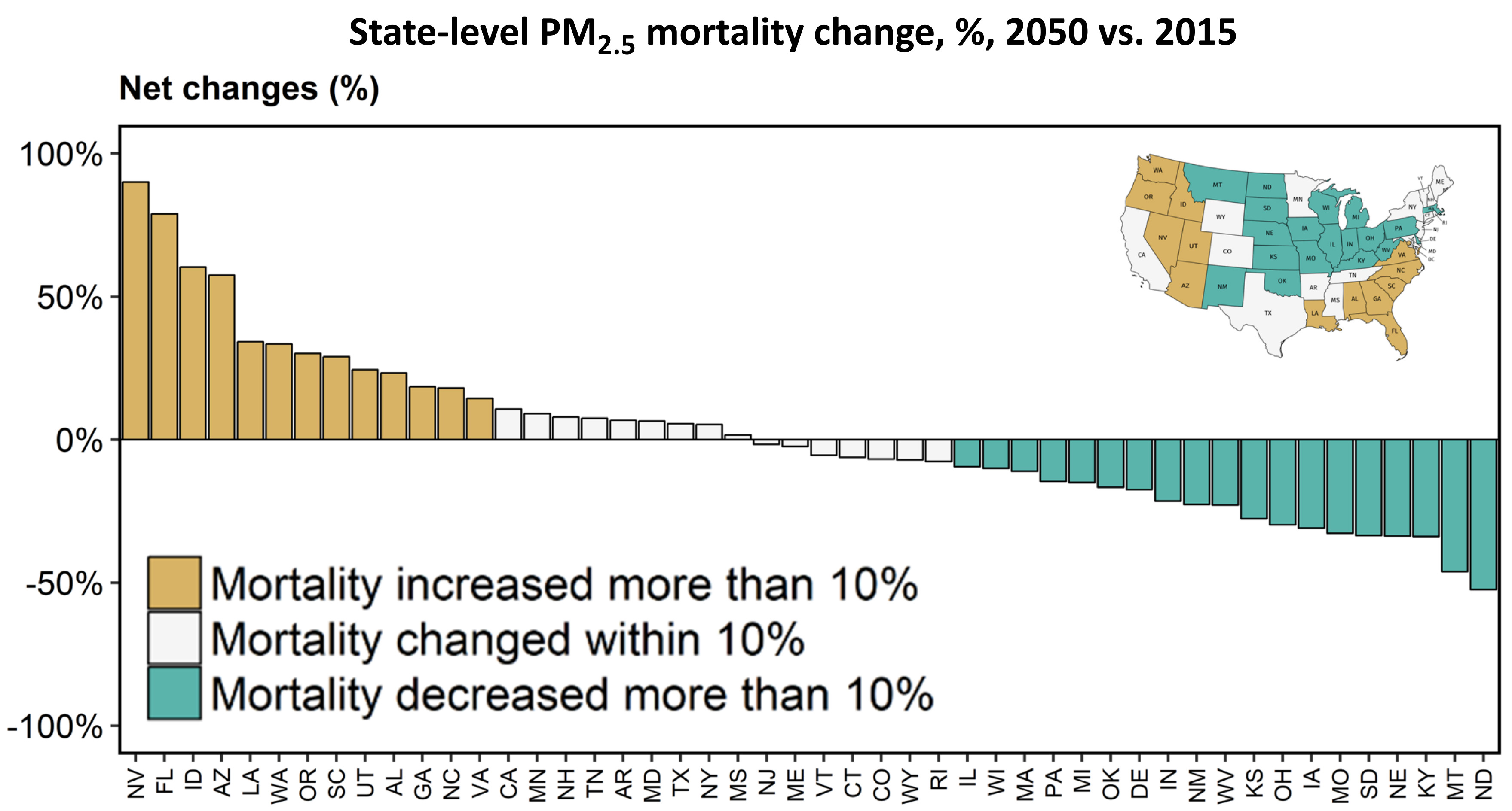
- population
- economic activity per person
- share of energy from:
  - coal
  - natural gas
  - oil
  - biomass
- PM2.5 mortality costs per unit of energy use:
  - coal
  - natural gas
  - oil
  - biomass

Air quality costs and state-level trends

State-level $PM_{2.5}$ mortality cost projection for a Reference Case



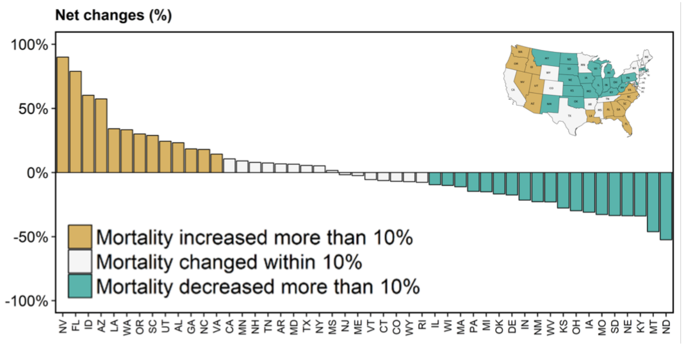
Air quality costs and state-level trends



- For our Reference Case assumptions, states colored tan have the potential for increasing $PM_{2.5}$ mortality costs over time.
- What are the factors driving this result?

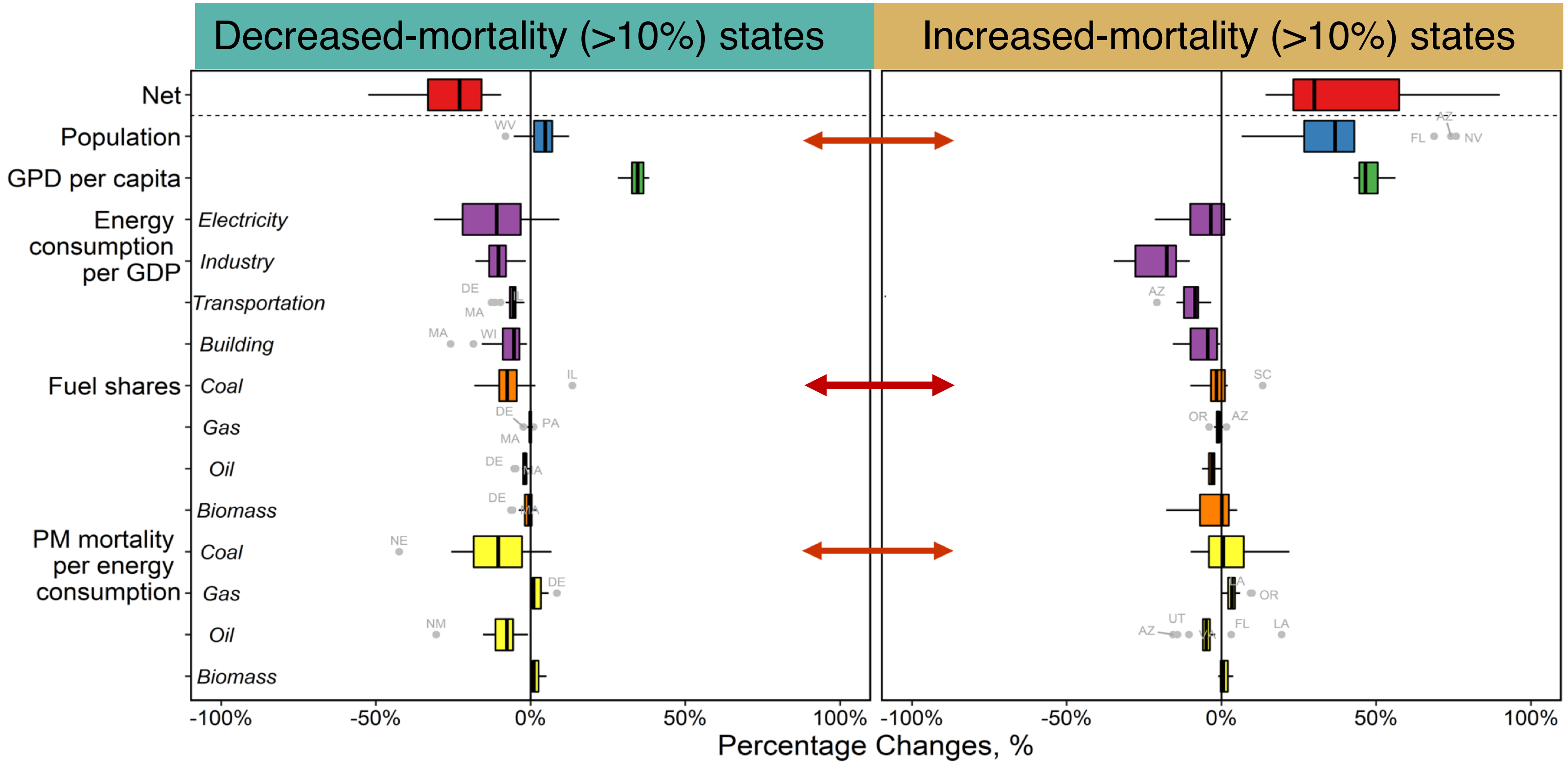
Air quality costs and state-level trends

State-level mortality change, 2050 vs. 2015



LMDI results across green and tan states

(Box plots of the change in $PM_{2.5}$ mortality apportioned to various factors)



States with increasing mortality tend to be those that have:

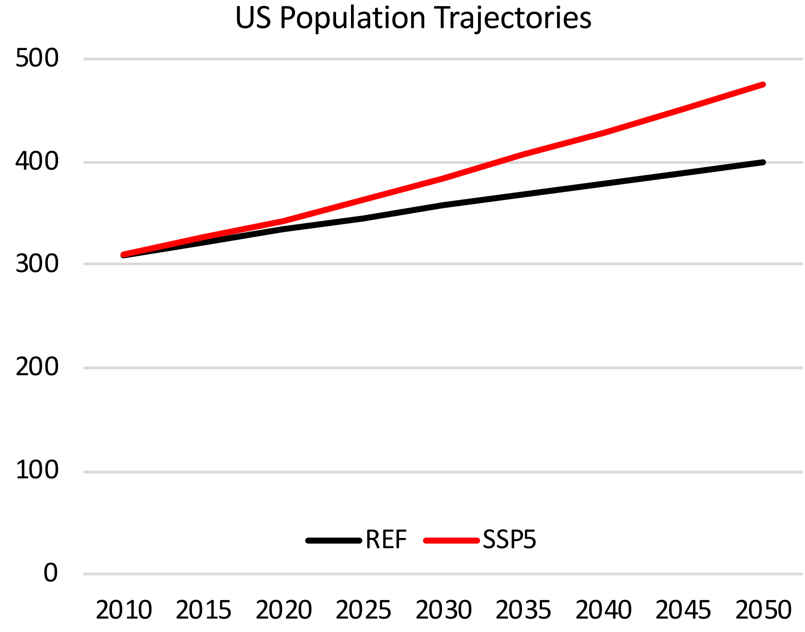
- a larger contribution from population change (e.g., more population growth)
- a smaller contribution from change in coal fuel share (e.g., a slower transition from coal), and,
- a very neutral or even increased mortality associated with PM mortality intensity of coal (warrants additional investigation, but could be from increased utilization of coal in industry, which has higher emission factors, or, for eastern states, interaction with CSAPR emission caps)

Example 3

Examining the emission implications of alternative population growth scenarios

Examining alternative population growth scenarios

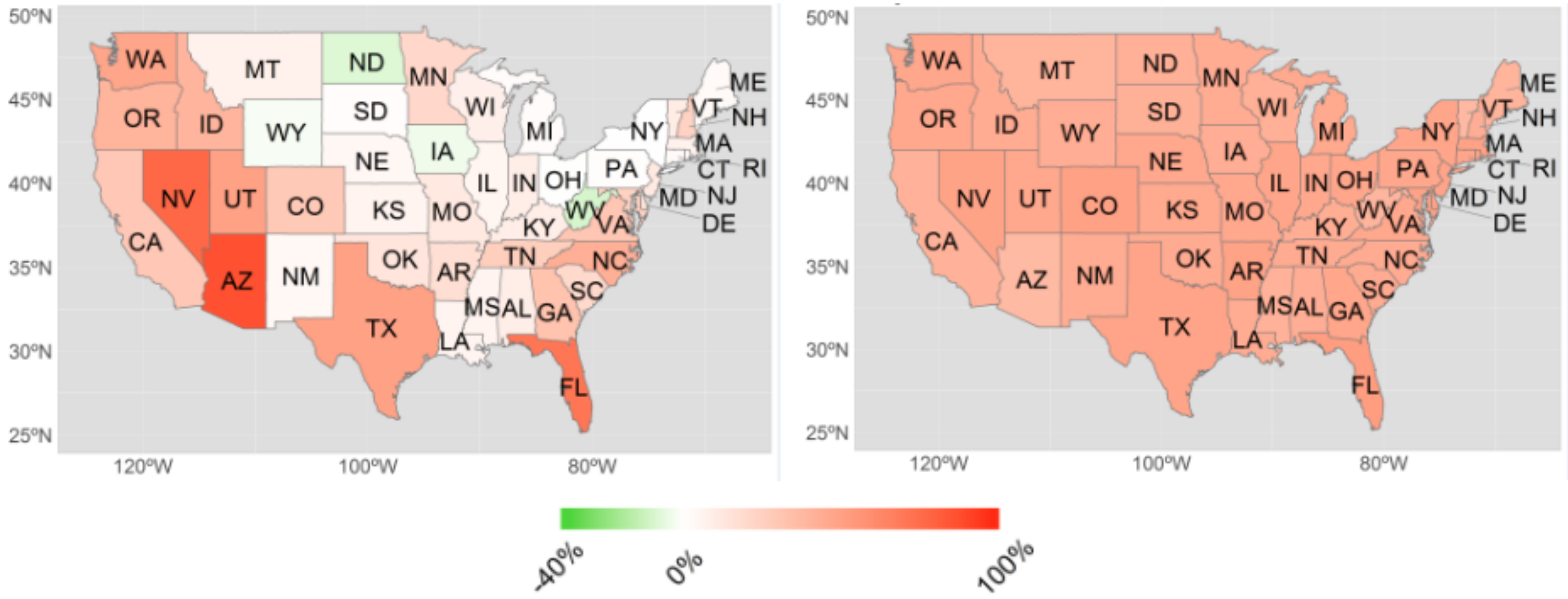
What challenges to air quality could arise if the U.S. experiences high population growth?



Change in state population (%) relative to 2015

GCAM-USA Reference Case Population

SSP5 Population

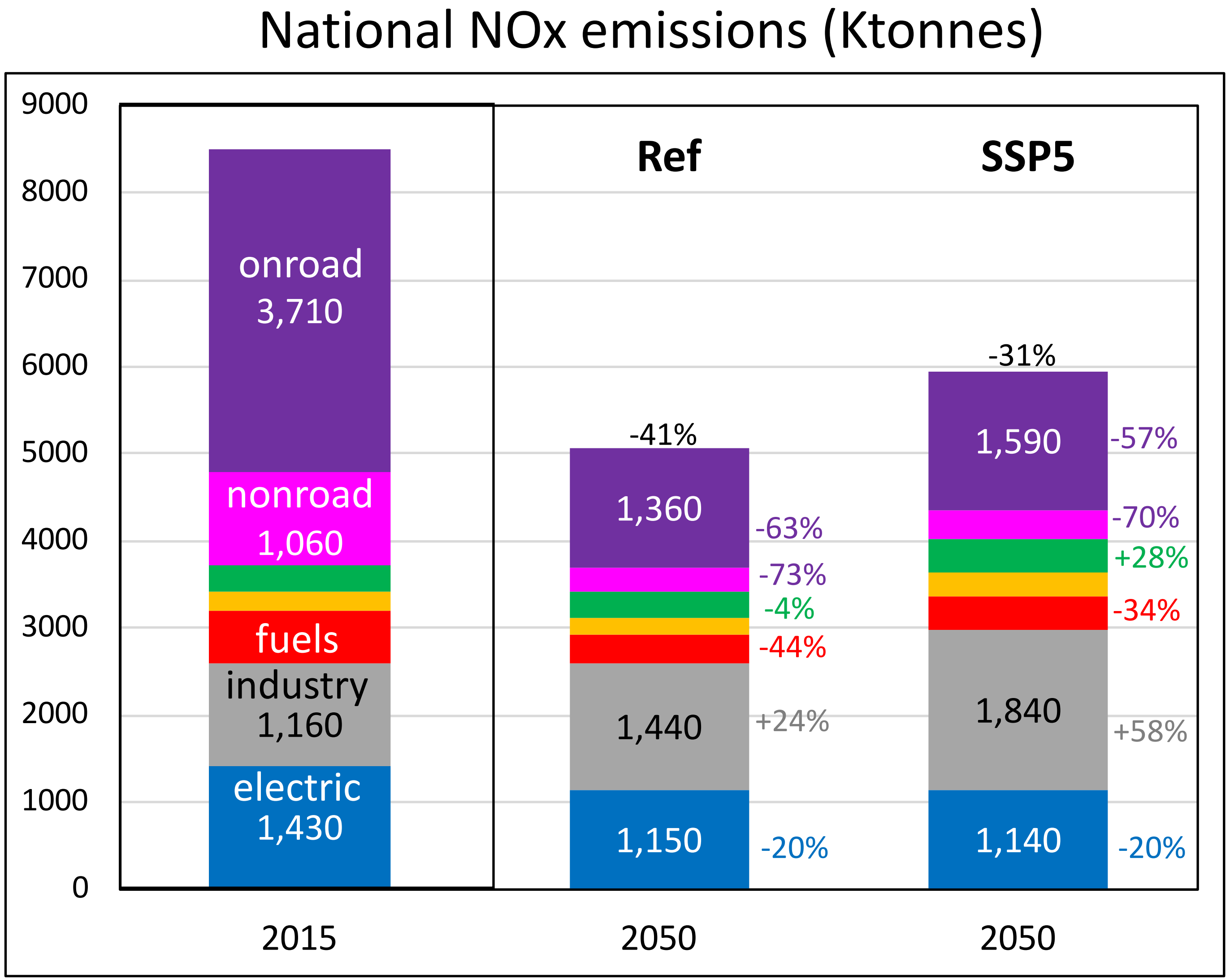


SSP5 population projection from derived from Jones and O'Neill (2016)

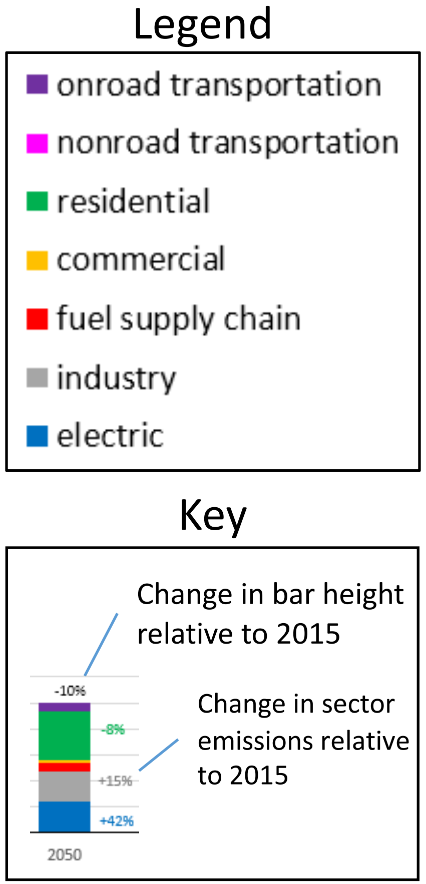
Examining alternative population growth scenarios

Population growth 2015-2050:

Ref: 24%
SSP5: 46%



Illustrative results



Observation: Emissions from some sectors are more closely correlated to population growth than others.

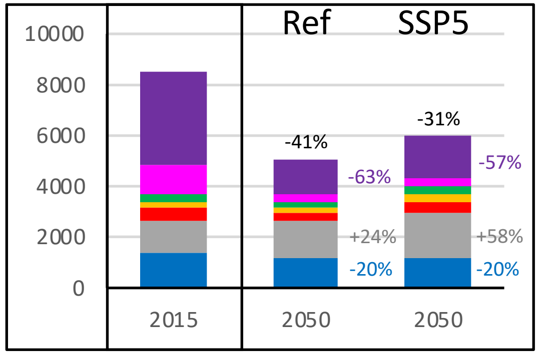
Examining alternative population growth scenarios

Population growth 2015-2050:

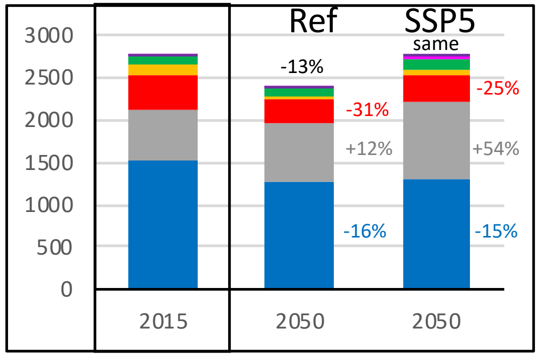
Ref: 24%

SSP5: 46%

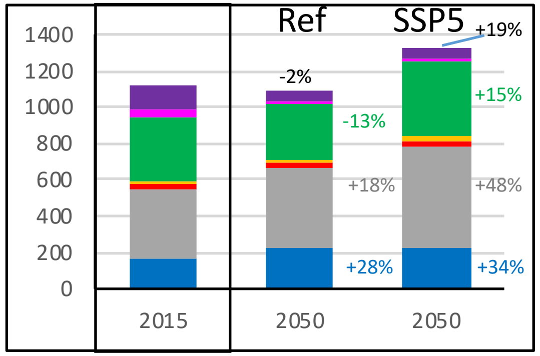
NOx (Ktonnes)



SO_2 (Ktonnes)



$PM_{2.5}$ (Ktonnes)

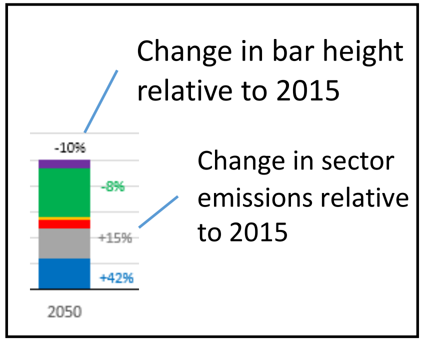


Illustrative results

Legend

- onroad transportation
- nonroad transportation
- residential
- commercial
- fuel supply chain
- industry
- electric

Key



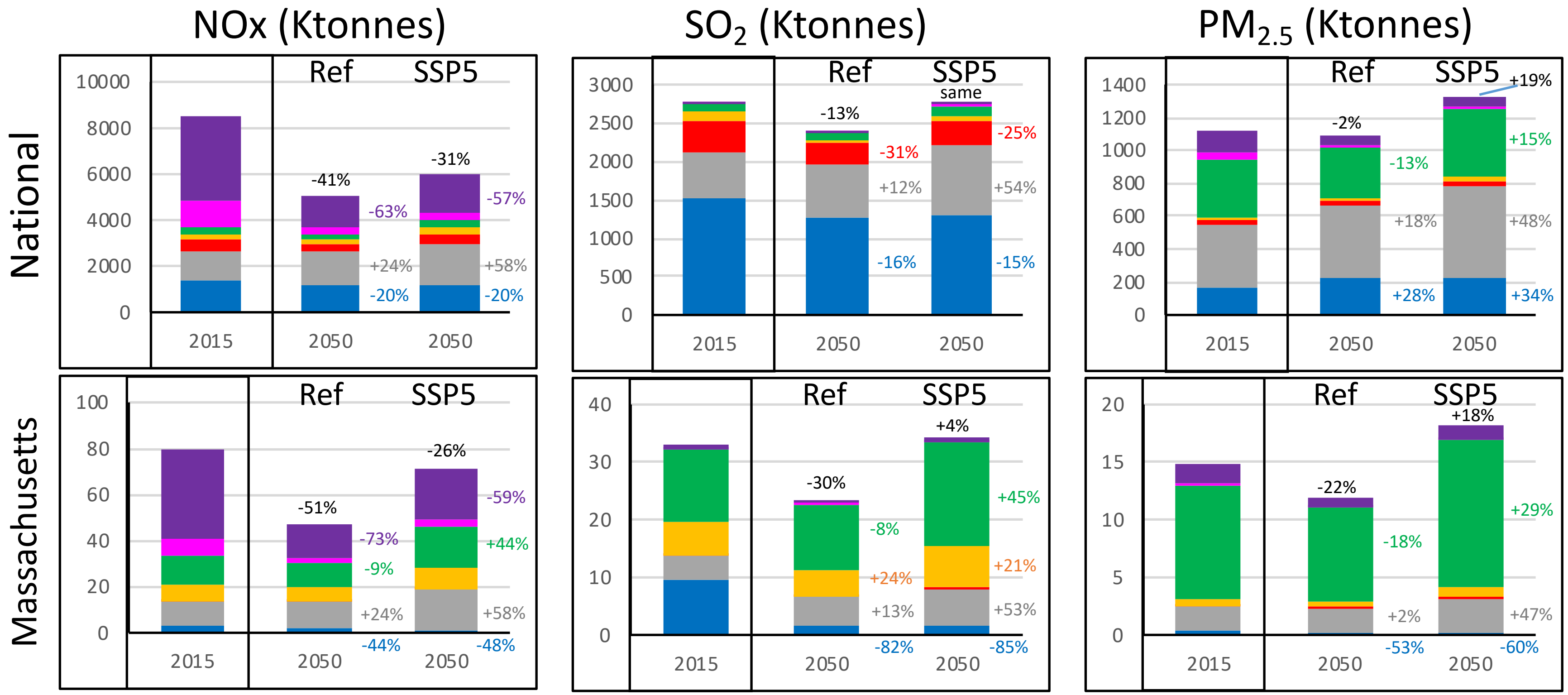
Observation: Emission response to greater population growth is different by pollutant and sector

Examining alternative population growth scenarios

Population growth 2015-2050:

Ref: 24%
SSP5: 46%

Ref: 7%
SSP5: 48%

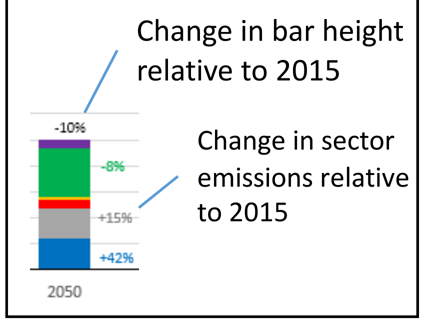


Illustrative results

Legend

- onroad transportation
- nonroad transportation
- residential
- commercial
- fuel supply chain
- industry
- electric

Key



Observation: In MA, sectoral contributions are very different than national values. Also, electric sector emissions are inversely correlated with increased population growth because of RGGI.

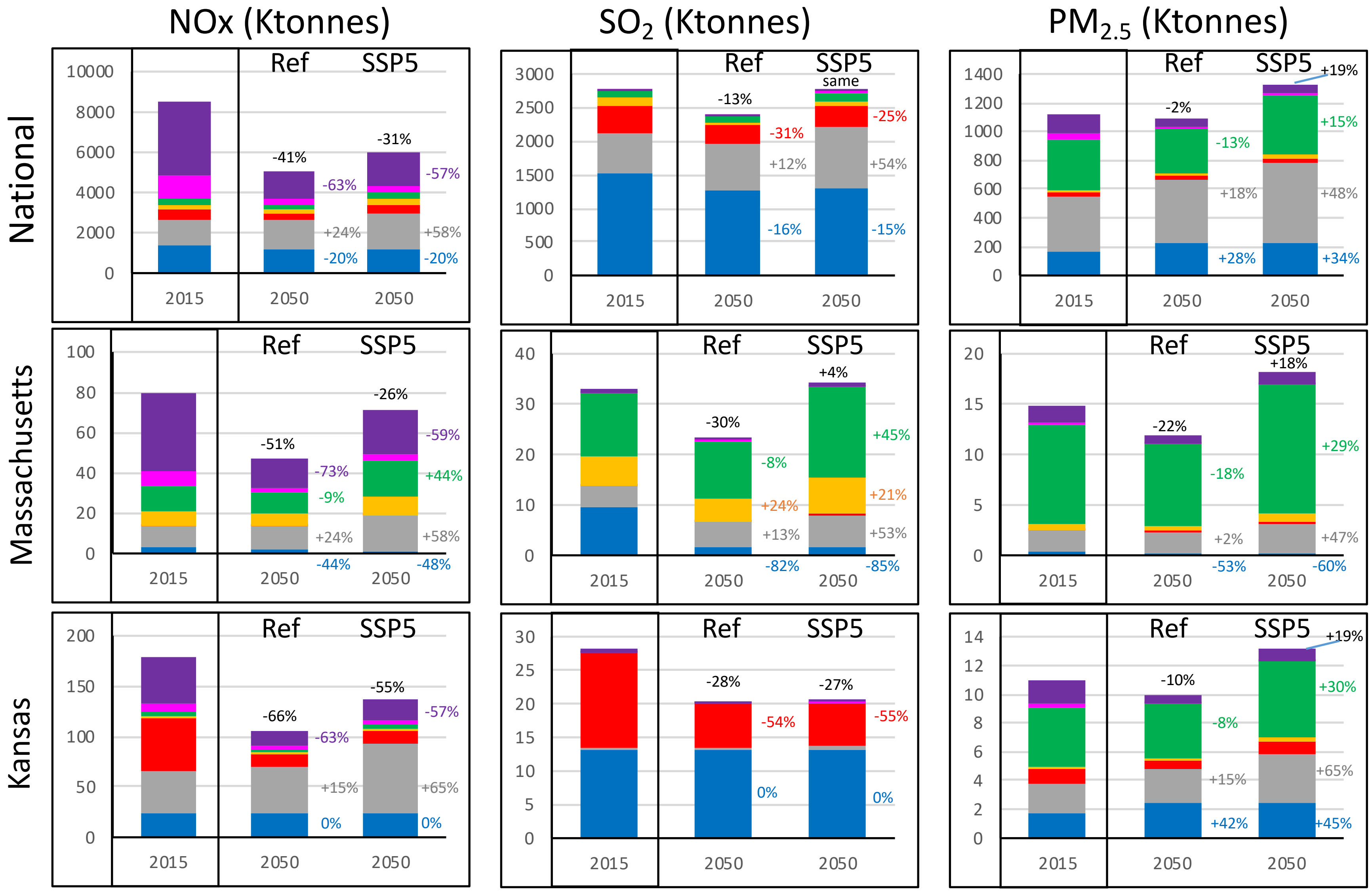
Examining alternative population growth scenarios

Population growth 2015-2050:

National — Ref: 24% SSP5: 46%

Massachusetts — Ref: 7% SSP5: 48%

Kansas — Ref: 6% SSP5: 45%



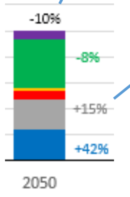
Illustrative results

Legend

- onroad transportation
- nonroad transportation
- residential
- commercial
- fuel supply chain
- industry
- electric

Key

Change in bar height relative to 2015



Change in sector emissions relative to 2015

Observation: States with different sectoral contributions can have very different responses (e.g., SO_2 in MA and KS)

Examining alternative population growth scenarios

For the scenarios that we modeled:

- Nationally and in the states that we examined, the reference case trend is for reductions in NOx, SO_2, and $PM_{2.5}$ by 2050
  - Electric and onroad sector NOx and SO_2 trended down as a result of regulations
  - Industrial source emissions tended to increase
- The SSP5 scenario (with high population growth) leads to emission increases for some pollutants and sectors
  - Industrial sources and residential sources led much of this growth
  - Electric sector regulations that cap NOx and SO_2 in much of the country limited the electric sector response to population growth
  - For onroad transportation, reductions from emission standards have a much greater impact than population growth
- Direct $PM_{2.5}$ emissions are particularly responsive to population growth
  - This response and how it could be mitigated are of interest for protecting future air quality

Additional considerations and next steps

Considerations

- Explicit inclusion of the Cross-State Air Pollution Rule and the Regional Greenhouse Gas Initiative allows us to capture important dynamics of cap-and-trade programs that approximation via emission factors (EFs) alone would not
- New Source Performance Standards mean that future-year EFs may be much lower than base-year EFs
  - Capital stock turnover is therefore very important
  - Emissions trends may not be smooth
- Some priorities for future GCAM-USA development to support our applications
  - Renewable Portfolio Standards – to capture the effects of these state-level policies on electric sector capacity additions
  - Industrial sector update – to differentiate by industry and technology, which can provide a fuller picture of emission changes over time
  - Time slices – to more fully capture seasonal factors (e.g., how natural gas is used, seasonal profile of emissions) and diurnal factors (e.g., electric vehicle charging profiles, solar power output)
  - Water supply module – to understand how water limitations affect energy and agricultural choices
  - "Blueprints" for how to implement energy efficiency, conservation, and other policies

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Ongoing activities

- Internal development activities
  - GLIMPSE graphical user interface
    - Add additional policy levers to the "Scenario Builder"
    - Make the "Enhanced Model Interface" more robust
  - Impacts
    - Addition of Life Cycle factors to more fully understand the implications of energy decisions across all stages (e.g., manufacturing and construction, fuel extraction, operation, decommissioning and end-of-life management)
    - Continue to improve air pollutant health impact factors, and potentially expand to additional pollutants (e.g., ozone) and to location-specific estimates (e.g., at monitoring sites)
  - Analytics
    - Automate LDMI approach to explore endpoints such as emissions, technology penetration, and energy use
    - Improve queries to more directly meet the needs of air quality managers

Next steps

- Starting in the late winter, we will work with several states within EPA's Region 3 (which includes DE, MD, PA, VA, WV) to tailor GLIMPSE to their needs
  - Workshop to identify use cases and functionality requirements
  - Implementation of additional policy levers into GCAM-USA and GLIMPSE
  - Develop documentation for GLIMPSE
  - Provide training and support relevant applications
  - Technology transfer of GLIMPSE to state partners

Questions?

Please feel free to contact me at
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GLIMPSE development activities

Improvements to GCAM-USA:

Regulatory representations:
- Cross-State Air Pollution Rule
- Corporate Average Efficiency Standards
- State-level Renewable Portfolio Standards
- Regional- and state-level GHG reduction goals

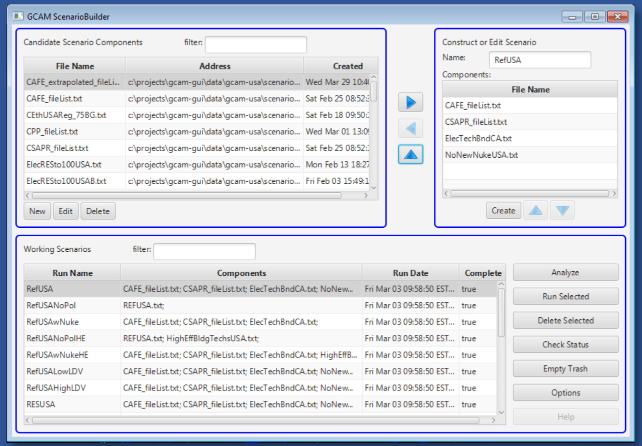
Emission factors from EPA models:
- IPM, MOVES, NONROAD
- Calibration with EPA emission inventories

Air pollution controls for industrial sources:
- U.S. EPA Control Measures Database

Environmental impact factors:
- Water demands
- Air quality – PM mortality health costs

Graphical interface

Scenario Builder facilitates setup and running:



Enhanced visualization and analysis tools: