Insights into future air quality:
Analysis of future emissions scenarios using the MARKAL model

Julia Gamas\textsuperscript{1}, Dan Loughlin\textsuperscript{2}, Rebecca Dodder\textsuperscript{2} and Bryan Hubbell\textsuperscript{1}

\textsuperscript{1} U.S. EPA Office of Air Quality Planning and Standards
\textsuperscript{2} U.S. EPA Office of Research and Development

14\textsuperscript{th} Annual CMAS Conference, UNC-Chapel Hill, October 5-7, 2015
Objective of this presentation

We describe a scenario-based approach for projecting future pollutant emissions. The scenarios are used to characterize regional emission trends through 2050. The scenarios are also demonstrated in the context of evaluating pathways for achieving a multi-pollutant emission reduction target.

Intended audience

The material presented here is intended to be of interest to modelers who develop and evaluate projections of future-year emissions.

Disclaimers

Modeling results are provided for illustrative purposes only.

The scenario implementation is a work-in-progress, and future results may change.

While this presentation has been reviewed and cleared for publication by the U.S. Environmental Protection Agency, the views expressed here are those of the authors and do not necessarily represent the official views or policies of the Agency.
1. Introduction
2. The Future Scenarios Method
3. Scenario Implementation
4. Illustrative Results
   - How different are the scenario results?
   - What are the long-term emission trends and how do they differ by region?
   - How can we use the scenarios to test a (hypothetical) policy?
5. Conclusions
6. Next steps
1. Introduction

- **Drivers of future pollutant emissions (and thus air quality) are uncertain. Examples include:**
  - Population growth and migration
  - Economic growth and transformation
  - Technology development and adoption
  - Climate change
  - Consumer behavior and preferences, and
  - Policies (energy, environmental, climate, ...)

- **Given these uncertain drivers, are there steps that we can take to:**
  - understand a range of future conditions that may occur,
  - anticipate conditions that may limit the efficacy of air quality management strategies, and,
  - develop management strategies that are robust over a wide range of future conditions?
We applied the **Future Scenarios Method** to develop scenarios that inform air quality management decisions.

**Future Scenarios Method steps:**

- Interview internal and external experts
- Select the two most important uncertainties and develop a scenario matrix
- Construct narratives describing the matrix’s four scenarios

Note: In this application, we developed a 2x2 scenario matrix. The method is adaptable, however, and could be used to develop more or fewer scenarios.
2. Future Scenario Method, cont’d

This is the resulting Scenario Matrix:

Conservation is motivated by environmental considerations. Assumptions include decreased travel, greater utilization of existing renewable energy resources, energy efficiency and conservation measures adopted in buildings, and reduced home size for new construction.

Sustainability is powered by technology advancements, and assumes aggressive adoption of solar power, battery storage, and electric vehicles, accompanied by decreased travel as a result of greater telework opportunities.

Muddling Through has limited technological advancements and stagnant behaviors, meaning electric vehicle use would be highly limited and trends such as urban sprawl and increasing per-capita home and vehicle size would continue.

Go Our Own Way includes assumptions motivated by energy security concerns. These assumptions include increased use of domestic fuels, particularly coal and gas for electricity production and biofuels, coal-to-liquids, and compressed natural gas in vehicles.
3. Scenario Implementation

- The scenarios were implemented in the MARKet ALlocation (MARKAL) energy system model with EPA’s US nine-region database.

- MARKAL details:
  
  - **Name**: MARKet ALlocation model
  - **Dataset**: EPAUS9r_14 database
  - **Resolution**: U.S. Census Division
  - **Temporal**: 2005-2055, 5-yr steps
  - **Sectoral resolution**: electric, residential, commercial, industry, transportation, resource extraction
  - **Outputs**: energy-related technology penetrations, fuel use, emissions, and water demands
  - **Solution**: linear programming with perfect foresight
  - **Runtime**: 30 min-1 hour on desktop PC

*Note: The Clean Power Plan is not yet represented in EPA MARKAL*
3. Scenario Implementation, cont’d

- Implementation of the scenarios continues to be a learning process

- Early approach:
  - Developed highly detailed narratives
  - Constrained MARKAL to follow the detailed narratives
  - Advantage:
    - The scenarios differed considerably with respect to projected technology penetrations and air pollution emissions
  - Disadvantage:
    - The scenario assumptions were hard-coded, leaving the model little freedom to respond to a policy or other “shocks”
    - Scenarios have to be re-implemented in each new MARKAL database version

- Current approach:
  - Step back from the detailed narratives and focus on underlying drivers
  - Let the model drive the narratives
  - Layer the scenarios on top of the current base case
Current approach

- **Axis:** Technological transformation or stagnation
  
  **Lever:** technological availability and cost

- Only considered technologies that are competitive today without subsidies

- No electric vehicles
- No IGCC
- Conservative wind and solar costs

- Electric vehicles achieve cost parity with conventional
- Wind and solar costs follow optimistic cost projections
3. Scenario Implementation, cont’d

- Current approach
  - **Axis:** Social transformation and behavioral change
  
  **Lever:** hurdle rates to reflect scenario-specific preferences

Prefer:
- Renewable
- Environmental- and climate-friendly
- Local
- Energy efficient

Avoid:
- Advanced technologies
- Infrastructure changes req’d
- High capital cost

Prefer:
- Renewable
- Environmental- and climate-friendly
- Energy efficient
- Advanced technologies

Avoid:
- Advanced technologies
- Energy efficient
- Infrastructure changes req’d
- High capital cost
3. Scenario Implementation, cont’d

- **Current approach**
  - **Axis:** Social transformation and behavioral change
  - **Lever:** end-use energy demands

Passenger vehicle demands reduced to reflect telework

Historic trends of increasing travel per person and increasing house sizes continue

Passenger vehicle demands reduced to reflect telework
New homes larger to accommodate home offices
4. Illustrative Results

How different are the scenario results?

What are the long-term emission trends and how do they differ by region?

How can we use the scenarios to test a (hypothetical) policy?
4. Illustrative Results, cont’d

How different are the scenario results?

Electricity production by aggregated technologies

- **Conservation**
  - Solar
  - Wind
  - Hydro
  - Geothermal
  - Municipal Solid Waste
  - Biomass w/CCS
  - Biomass
  - Nuclear
  - Oil
  - Natural Gas w/CCS
  - Natural Gas
  - Coal w/CCS
  - Coal

- **iSustainability**
  - Solar
  - Wind
  - Hydro
  - Geothermal
  - Municipal Solid Waste
  - Biomass w/CCS
  - Biomass
  - Nuclear
  - Oil
  - Natural Gas w/CCS
  - Natural Gas
  - Coal w/CCS
  - Coal

- **Muddling Through**
  - Solar
  - Wind
  - Hydro
  - Geothermal
  - Municipal Solid Waste
  - Biomass w/CCS
  - Biomass
  - Nuclear
  - Oil
  - Natural Gas w/CCS
  - Natural Gas
  - Coal w/CCS
  - Coal

- **Go Our Own Way**
  - Solar
  - Wind
  - Hydro
  - Geothermal
  - Municipal Solid Waste
  - Biomass w/CCS
  - Biomass
  - Nuclear
  - Oil
  - Natural Gas w/CCS
  - Natural Gas
  - Coal w/CCS
  - Coal

Capacity for Technology Transformation
4. Illustrative Results, cont’d

How different are the scenario results?

Most demand growth met with natural gas. Coal remains in all scenarios. The cost of lifetime extensions is low, and the fuel is inexpensive.

- Growth in renewables
- Relatively high electricity demands
- Major increase in nuclear
- Limited natural gas

Coal remains in all scenarios. The cost of lifetime extensions is low, and the fuel is inexpensive.
4. Illustrative Results, cont’d

How different are the scenario results?

Light duty vehicle technologies

Conservation

E85

Electric

Muddling Through

Conventional

Hybrids & plugin hybrids

Go Our Own Way

Capacity for Technology Transformation

Capacity for Societal Transformation
4. Illustrative Results, cont’d

How different are the scenario results?

Light duty vehicle technologies

From 2020 all vehicles are electrified

Demand levels off

Increased demand

Uses domestic fuels but makes them stretch further

E85

Conventional

Electric

Hybrids & plugin hybrids

Demand levels off
**4. Illustrative Results, cont’d**

**What are the long-term emission trends?**

Existing regulations are relatively robust in locking in downward trends for criteria pollutants.

The range of CO₂ emissions across the scenarios is considerably greater than that of the other pollutants.

Note: The Clean Power Plan is not represented in these results.
Circles represent MARKAL baseline values. The boxes represent the range of values over the four scenarios.

Regional trends are similar to national trends, although baseline reductions and range can differ substantially from one region to another.

Contributing factors include existing technology stock, access to renewables, energy trade with neighboring regions and fuel-switching within and across sectors.
Hypothetical policy goal:
- Using each of the scenarios as an alternative baseline...
- Introduce target to reduce national energy system NOx, SO2 and PM emissions by 50% from 2015 levels by 2035

Questions:
- Is this target feasible for all of the baselines?
- From which sectors would the reductions come for each baseline?
- Are there common technological strategies across scenarios?
4. Illustrative Results, cont’d

What can we learn testing a policy with the scenarios?

Examining NOx

Sectoral NOx emissions (kTonnes)

The quantity of reductions needed differs considerably from one scenario to another.

Hypothetical emission target
Scenario-specific pathways for reducing NOx, SO\(_2\) and PM

Change in sectoral NOx emissions (kTonnes) in 2035

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Electric</th>
<th>Industrial</th>
<th>Commercial</th>
<th>Residential</th>
<th>Transportation</th>
<th>Resource Supply</th>
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<tr>
<td>MARKAL baseline</td>
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Change in electricity production by fuel (PJ) 2035

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<tr>
<th>Scenario</th>
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<th>Wind</th>
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<td>Go Our Own Way</td>
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<td>Muddling Through</td>
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Change in industrial fuel use (PJ), 2035

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Electric</th>
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<th>Coal</th>
<th>Petroleum</th>
<th>Gas</th>
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Illustrative Results, cont’d

What can we learn testing a policy with the scenarios?
5. Conclusions

• Diverse scenarios have been successfully defined, implemented, and applied as alternative baselines in a hypothetical case study

• The revised implementation (which focuses on drivers and not detailed narratives)
  – Yields very different results from one scenario to another
  – Allows the scenarios to respond to stimuli in unique ways

• Observations include
  – Existing pollutant regulations perform relatively robustly for reducing NOx and SO\textsubscript{2} across the scenarios
  – There is more variability in CO\textsubscript{2} across the scenarios (without considering the Clean Power Plan)
  – For the hypothetical policy case
    • the quantity of reductions needed differed considerably from one scenario to another
    • fuel switching to natural gas in electricity production and industry played a central role for all of the scenarios, although complementary measures differed
6. Next steps

- Integrate land use and economic components into the scenarios
- Continue to explore potential applications
- Examine classes of policy options to explore robustness across the scenarios
- Iteratively refine the scenario representations
Questions?

Contact information:
Julia Gamas, U.S. EPA, OAQPS - gamas.julia@epa.gov
Dan Loughlin, U.S. EPA, ORD – loughlin.dan@epa.gov

For more information on the scenarios: