Energy, environmental and climate assessment with the EPA MARKAL energy system modeling framework

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Abstract

The ***energy system*** is comprised of the technologies and fuels that extend from the import or extraction of energy resources (e.g., mines and wells), through the conversion of these resources into useful forms (e.g., electricity and gasoline), to the technologies (e.g., cars, lightbulbs, and building heating systems) that meet end-use energy demands (e.g., miles driven, lumens for lighting, and watts per square meter for space heating).

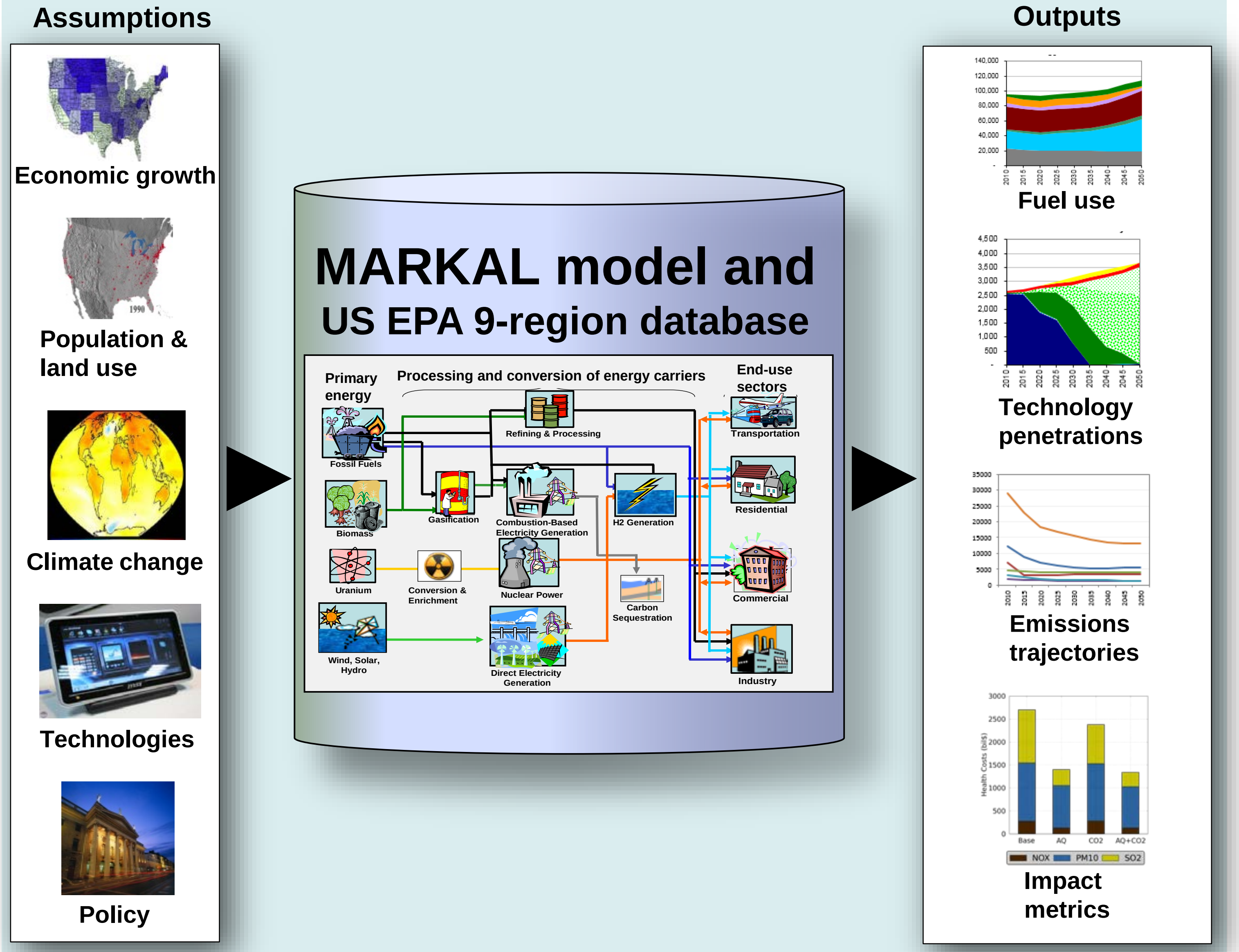
This system is responsible for the vast majority of US man-made emissions of both air pollutants and greenhouse gases (GHGs). ***Many of society's future air quality management and climate challenges will be influenced by how the energy system evolves over the coming decades.***

Factors influencing this evolution include population growth and migration, economic growth and transformation, land use change, technology development and deployment, climate change, and current and future environmental, climate and energy policies. ***Understanding how various factors affect energy demands and the associated emissions is critical if we are to anticipate the resulting environmental challenges and act proactively.***

The U.S. EPA has developed the EPA MARKAL framework, consisting of the MARKAL energy system model and the EPA 9-region MARKAL database. With this framework EPA is examining wide-ranging scenarios of the evolution of the U.S. energy system through 2055. ***The EPA MARKAL framework is providing insights about strategies for simultaneously achieving air, water resource, climate and energy goals.***

In this poster, we provide overviews of EPA MARKAL applications, including: (a) assessing the air and climate pollutant implications of alternative scenarios of the future, (b) estimating the co-benefits and other impacts of potential mitigation strategies, and (c) characterizing multi-pollutant mitigation potential of renewable electricity, energy efficiency, and fuel switching.

EPA MARKAL Framework

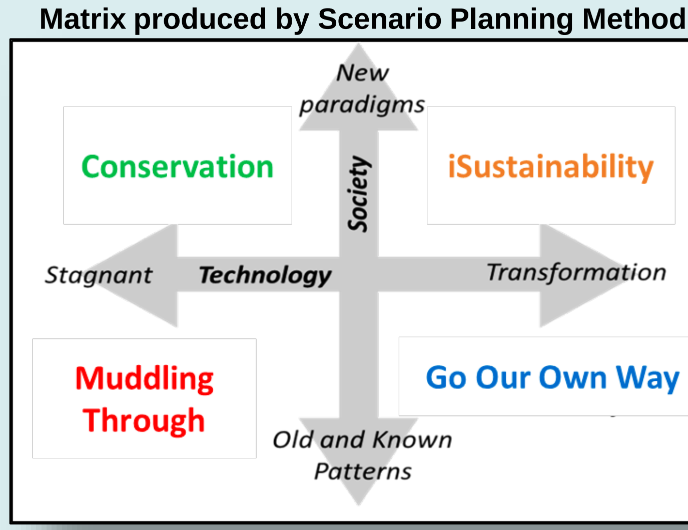


Database development team: Lenox, Dodder, Kaplan, Loughlin

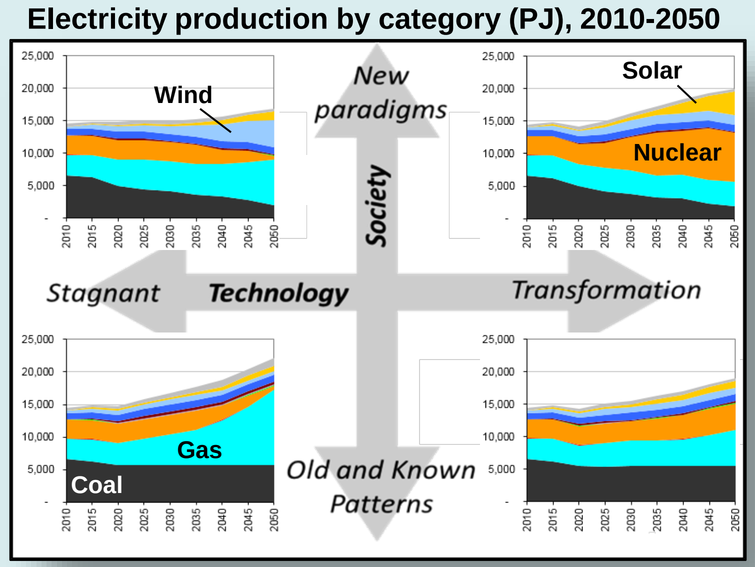
(a) Application: Scenario analysis

- Emission projections can identify challenges and opportunities for future air quality management.
- There are considerable uncertainties in multi-decadal projections, however.
- The Scenario Planning Method (SPM) involves the development of very different realizations of the future intended to encompass key uncertainties.
- Through a workshop and subsequent discussions, we applied the SPM to develop the Scenario Matrix to the right, as well as underlying storylines.
- We implemented each scenario in MARKAL (e.g., electricity production for each is shown below) and evaluated the emission implications (bottom right).

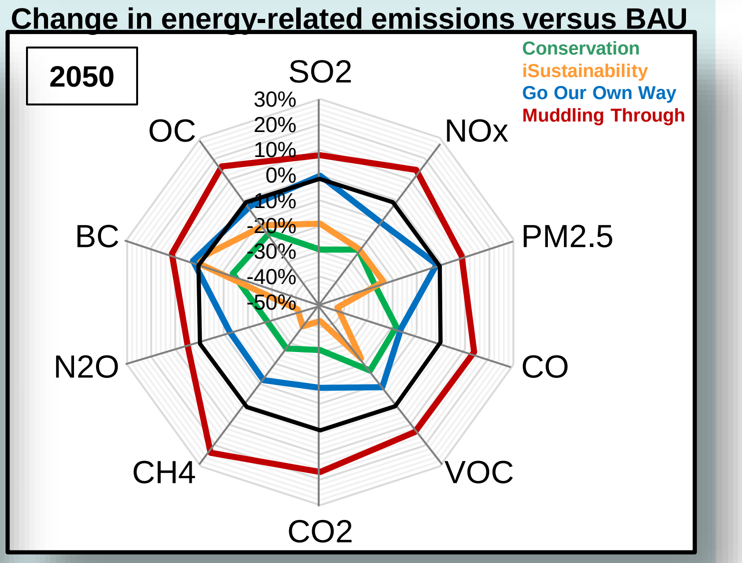
Matrix produced by Scenario Planning Method



Electricity production by category (PJ), 2010-2050



Change in energy-related emissions versus BAU

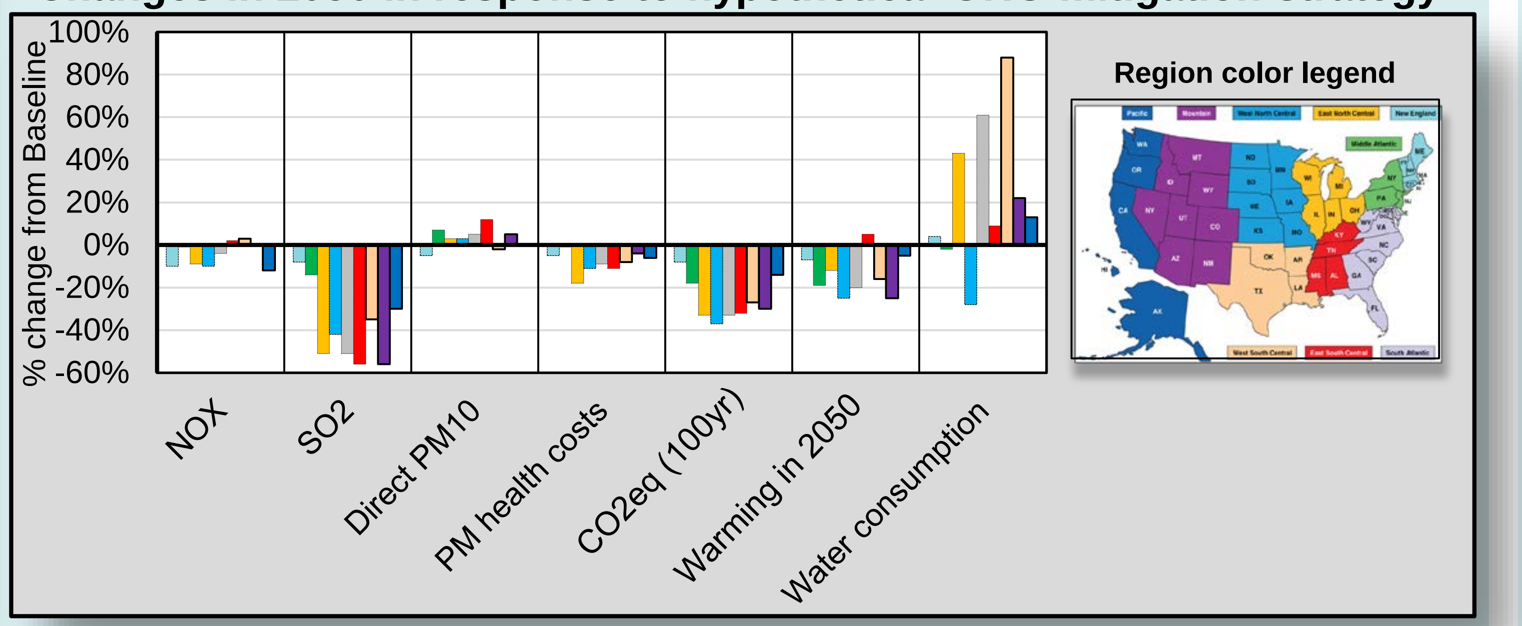


Research team: Gamas, Dodder, Loughlin, Hubbell

(b) Application: Assessment of co-benefits

- The goals of reducing air pollution, mitigating global climate change, and meeting societal water and energy demands are inextricably linked.
- For example, combustion of fossil fuels results in emissions of air pollutants, short-lived climate forcers, and greenhouse gases. Further, water withdrawals for electricity production are greater even than from agriculture.
- Measures taken to reduce a single pollutant thus can have a wide range of impacts, including the co-benefit of reductions of other pollutants. In some instances, disbenefits can occur.
- MARKAL allows us to assess the implications of technological and fuel pathways, and even to identify pathways that meet air, climate and water goals simultaneously.
- Below, we show a range of responses to a hypothetical GHG mitigation strategy.

Changes in 2050 in response to hypothetical GHG mitigation strategy

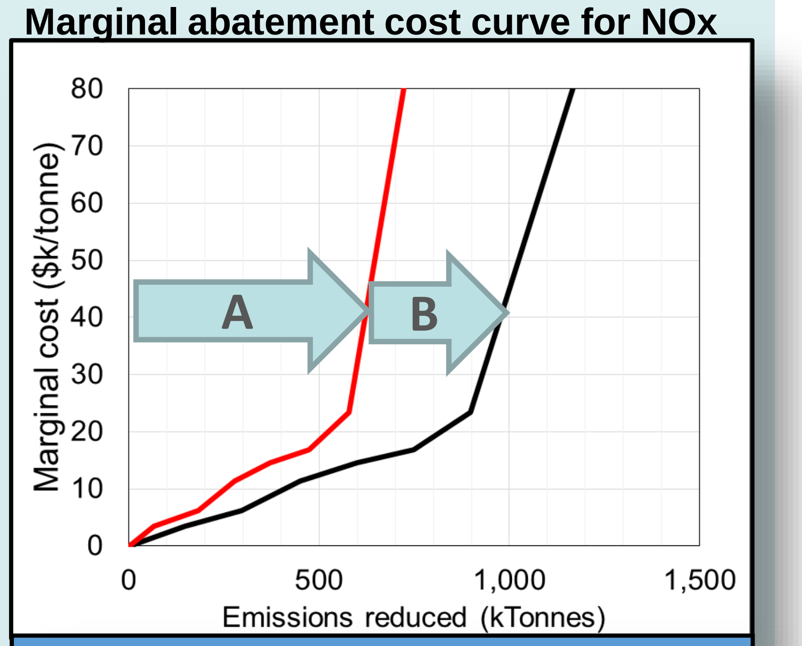


Research team: Loughlin, Nolte (Former: Capps, Pinder, Akhtar)

(c) Application: Control strategy development

- Control strategies for air pollutants traditionally involve measures that modify the combustion process to reduce pollutant formation (e.g., low NOx burners) or remove pollutants from the exhaust stream (e.g., catalytic converters).
- Control strategies can also include renewable electricity, energy efficiency, and fuel-switching (RE/EE/FS).
- Limited tools are available for evaluating the cost-effectiveness of RE/EE/FS, however.
- By representing the full U.S. energy system, MARKAL facilitates examination of RE/EE/FS, both individually and in combination with traditional controls.
- In the figure to the right, the red line is a Marginal Abatement Cost Curve (MACC) that traces out the cost of reducing each additional unit of NOx emissions in the U.S. in 2035 using traditional controls.
- The black line traces out the MACC when both RE/EE/FS and traditional controls are considered.
- For a given marginal cost, the distance between the curves (B) indicates that additional reductions achievable view RE/EE/FS.
- With MARKAL, we can generate regional MACCs and identify the most cost-effective RE/EE/FS given regional conditions.

Marginal abatement cost curve for NOx



A: Reductions from controls for $40k/tonne or less
B: Additional reductions achievable from renewable electricity, energy efficiency & fuel switching

Research team: Loughlin, Kaufman, MacPherson, Lenox, Hubbell

Selected publications using EPA MARKAL

Akhtar, Pinder, Loughlin & Henze (2013) GLIMPSE: a rapid decision framework for energy and environmental policy. *Environ Sci Technol, 47*(21).

Balash, Nichols & Victor (2013) Multi-regional evaluation of the U.S. electricity sector under technology and policy uncertainties: Findings from MARKAL EPA9rUS modeling. *Socio Econ Plan Sci, 47*(2).

Brown, Henze & Milford (2013) Accounting for climate and air quality damages in future U.S. electricity generation scenarios. *Environ Sci Technol, 47*(7).

Cameron, Yelverton, Dodder & West (2014) Strategic responses to CO2 emission reduction targets drive shift in U.S. electric sector water use. *Energ Strat Rev, 4*.

Lenox, Dodder, Gage, Kaplan, Loughlin & Yelverton (2012) *EPA U.S. nine-region MARKAL database: Database documentation*. (Report EPA600/B-13/203).

Loughlin, Benjey & Nolte (2011) ESP v1.0: methodology for exploring emission impacts of future scenarios in the United States. *Geosci Model Develop, 4*(2).

Loughlin, Kaufman & Macpherson (2015) Characterization of regional marginal abatement cost curves for NOx that incorporate control measures, renewable energy, energy efficiency and fuel switching. In *Proceedings of the Air & Waste Management Assoc Ann Mtg*.

Loughlin, Yelverton, Dodder & Miller (2012) Methodology for examining potential technology breakthroughs for mitigating CO2 and application to centralized solar photovoltaics. *Clean Technol Environ Pol, 15*(1).

Rudokas, Miller, Trail & Russell (2015) Regional air quality management aspects of climate change: Impact of climate mitigation options on regional air emissions. *Environ Sci Technol*.