

Considerations in linking energy scenario modeling and Life Cycle Analysis

Dan Loughlin, Limei Ran, and Chris Nolte

U.S. EPA Office of Research and Development

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SEPA Foreword

- Objectives of the presentation
 - Describe ORD efforts to develop long-term air pollutant emissions projections
 - Discuss how the tools used in those efforts could be used to support Life Cycle Analysis
- Intended audience
 - Life cycle analysts
 - Emission inventory developers and modelers
 - We assume this audience is familiar with models and terms used in emissions modeling
- Additional contributors
 - EPA Rebecca Dodder, Ozge Kaplan, Carol Lenox, William Yelverton
 - ORISE Samaneh Babaee, Troy Hottle, Yang Ou, Wenjing Shi
 - PNNL Steve Smith, Catherine Ledna
- Disclaimers
 - While the material presented here has been cleared for publication, it does not necessarily reflect the views nor policies of the U.S. EPA
 - Results are provided for illustrative purposes only

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Abbreviations

- AEZ Agricultural Economic Zone
- BAU Business As Usual
- CAMx Comprehensive Air Quality Model with Extensions
- CMAQ Community Multi-scale Air Quality model
- CO₂ Carbon dioxide
- EGU Electricity generating unit
- EPA Environmental Protection Agency
- ESP Emission Scenario Projection method
- GCAM-USA Global Change Assessment Model with U.S. spatial resolution
- GHG Greenhouse gas
- GREET Greenhouse gases, Regulated Emissions and Energy use in Transportation model

- IAM Integrated Assessment Model
- LC life cycle
- LCA life cycle analysis
- MARKAL MARKet ALlocation energy system model
- MOVES MOtor Vehicle Emissions Simulator model
- $O_3 ozone$
- ORISE Oak Ridge Institute for Science and Education
- ORD Office of Research and Development
- PM_{2.5} Particulate matter with diameter smaller than 2.5 micrometers
- PNNL Pacific Northwest National Laboratory
- N nitrogen
- SMOKE Sparse Matrix Operator Kernel Emissions modeling system

• I/O – Input-output



- Part 1. Emission Scenario Projection (ESP) methods and models
- Part 2. Scenarios in Life Cycle Analysis (LCA)

Approach 1: Using the spatial allocation component of ESP to gain insight into the location of LCA emissions

Approach 2: Using ESP to inform LCA inputs

Approach 3: Incorporating LC factors into energy and Integrated Assessment Models (IAMs)



Multi-decadal air pollutant emission projections (e.g., through 2050)

• Real world applications:

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- Benefit-cost analysis
 - evaluating and comparing potential management strategies
- Long-term planning
 - identifying emerging source categories or other environmental issues
 - evaluating the synergies and co-benefits among environmental, climate and energy goals
 - characterizing the robustness of regulations under wide-ranging conditions
- Technology assessment
 - calculating the net environmental impact of new and emerging technologies

- Generating these projections poses many challenges
 - Underlying drivers are complex, interrelated, dynamic, and uncertain
 - Population growth and migration
 - Economic growth and transformation
 - Technology development and adoption
 - Land use and land cover change
 - Climate change
 - Behavior, preferences and choices
 - Policies (energy, environmental and climate)
- Goal

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 Evaluate scenarios defined by internally consistent assumptions to obtain future-year emission inventories

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Part 1. Emission Scenario Projection

• From the emissions modeling perspective



These should reflect the scenario assumptions about the future

Long-term vision

Integrated emission projection system



Inputs

National Emissions Inventory Growth and control factors Temporal profiles Speciation profiles Road network Temperature fields Spatial surrogates



SMOKE/

MOVES



Assumptions

Policies

Population

Part 1. Emission Scenario Projection

Emission Scenario Projection (ESP) v1.0 (2011)

Develop regional-, technology-, pollutant-specific emission growth factors using an energy system model



Inputs **Emissions** processing National Emissions Inventory **Growth and control factors Temporal profiles** SMOKE/ Speciation profiles Road network **MOVES Temperature fields Spatial surrogates**

Loughlin, D.H., Benjey, W.G., and C.G. Nolte (2011). "ESP v1.0: methodology for exploring emission impacts of future scenarios in the United States." Geoscientific Model Development, 4, 287-297.

• ESPv1.0 (2011), cont'd

Application:

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Evaluation of a Business as Usual (Scenario 1) and a 50% CO₂ reduction Scenario (Scenario 2)



	Scenario 1			Scenario 2		
	CO_2	NO _x	PM_{10}	CO ₂	$NO_{\rm X}$	PM_{10}
Electric sector	0.91	0.35	0.61	0.04	0.24	0.41
Industrial combustion	1.51	1.43	1.25	0.99	0.92	0.56
Residential combustion	1.06	1.11	0.95	0.97	1.03	1.06
Commercial combustion	1.66	1.65	1.50	1.21	1.17	0.89
Light duty transportation	1.44	0.24	1.94	0.71	0.11	1.64
Heavy duty transportation	1.62	0.06	0.11	1.57	0.06	0.11
Airplanes	1.76	1.76	1.76	1.76	1.76	1.76
Rail	1.72	1.72	1.72	1.71	1.72	1.72
Domestic shipping	1.35	1.35	1.35	1.35	1.35	1.35

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• ESPv1.0 (2011), cont'd

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Method captured scenario, pollutant, and sector-specific trends

Loughlin, D.H., Benjey, W.G., and C.G. Nolte (2011). "ESP v1.0: methodology for exploring emission impacts of future scenarios in the United States." Geoscientific Model Development, 4, 287-297.

• ESPv2.0 (2015)

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Spatially allocate future-year emissions to account for population growth and migration and land use change



Ran, L., Loughlin, D.H., Yang, D., Adelman, Z., Baek, B.H., and C. Nolte (2015). "ESP2.0: enhanced method for exploring emission impacts of future scenarios in the United States – addressing spatial allocation." *Geoscientific Model Development*, *8*, 1775-1787.

• ESPv2.0 (2015), cont'd

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Ran, L., Loughlin, D.H., Yang, D., Adelman, Z., Baek, B.H., and C. Nolte (2015). "ESP2.0: enhanced method for exploring emission impacts of future scenarios in the United States – addressing spatial allocation." *Geoscientific Model Development*, *8*, 1775-1787.

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Part 1. Emission Scenario Projection

• ESPv2.0 (2015), cont'd

Application:

Explore impact of accounting for population migration and land use change on exposure



Emissions show relative increases in counties with moderate population density, but decreases in rural and urban areas.

Ran, L., Loughlin, D.H., Yang, D., Adelman, Z., Baek, B.H., and C. Nolte (2015). "ESP2.0: enhanced method for exploring emission impacts of future scenarios in the United States – addressing spatial allocation." *Geoscientific Model Development*, *8*, 1775-1787.

• Next steps: ESPv3.0?

- Adjust temporal distribution of emissions to capture changing roles of technologies
 - Natural gas transitions to a baseload technology



• Next steps: ESPv3.0?

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- Incorporate integrated assessment model (e.g., GCAM-USA)
 - Adds agriculture, water system, land use, climate impacts



State-level, sectoral emission growth factors

Illustrative results



Italics represent possible additions

Adapted from graphic supplied by PNNL

• Next steps: ESPv3.0?

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• Provide examples of very different alternative scenarios



Electricity production projections for alternative scenarios of the future

Gamas, J., Dodder, R., Loughlin, D.H. and C. Gage (2015). "Role of future scenarios in understanding deep uncertainty in long-term air quality management." *Journal of the Air & Waste Management Association*, 65(11), 1327-1340.

- Also under consideration for ESPv3.0
 - Commercial and industrial land uses within land use modeling
 - Industrial I/O tables

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- translate scenario assumptions to industrial production
- E.g., a transition from conventional vehicles to electric vehicles would result in shifts in output in the metal and chemical industries
- Impact factors estimate 1st order environmental effects of emissions
 - PM_{2.5} mortality costs
 - O₃ mortality costs
 - Crop and timber damage due to ozone
 - Damages from N deposition
- Water supply constraints on the evolution of the energy system
- Wish list for a future version of ESP: ESPvX?
 - Site new emission sources
 - Dynamic road networks with attributes (capacity, speed, travel demand) that interact in land use and population modeling



• One type of Life Cycle Analysis:

Compare the net life cycle impacts of competing technologies

Assumptions

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Future-year electric grid mix **Technology characteristics**

- efficiency
- emission factors

- fuels

Upstream technologies

(e.g., transportation, conversion, manufacturing)

- mix

- efficiency
- emission factors

- fuels

Fuels

- origin (un/conventional)

- composition



Comparison of four technologies

Scope 3 – Manufacturing

D

• One type of Life Cycle Analysis:

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Evaluate impacts over a set of sensitivities (e.g., electric grid mix)



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Part 2. Scenarios and Life Cycle Analysis

- Some limitations
 - Stationarity of system
 - Evaluates impact of the technology, considering fixed set of electric grid and fuel chain assumptions
 - What if adoption of the technology is widespread? Those specific conditions may change
 - Example: Widespread adoption of electric vehicles
 - Expansion of electric sector capacity
 - When calculating the impact of the vehicles, the environmental signature of the capacity expansion may be more appropriate than that of the existing electric sector capacity
 - Reduction in demand for gasoline and diesel in the light duty sector
 - Reduced demand will impact the mix of conventional and unconventional fuels, refinery operations, and biomass production for biofuels
 - Prices of competing fuels
 - Gasoline, diesel, and biofuels prices will be affected, which may result in fuel switching in other sectors
 - Change in energy demands related to manufacture of vehicles
 - shifts from conventional to alternate fuel vehicles, vehicle lightweighting, etc., affect industrial energy demands
 - Typically lack support for evaluating wide-ranging scenarios
 - Models like GREET provide a large set of inputs that could be tweaked
 - However, it may be difficult for users to tweak these in ways that are internally consistent

Approach 1: Using the spatial allocation component of ESP to gain insight into the location of LCA emissions

Energy system modeling could be used to provide insights into where impacts occur

Where?



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Example of spatial information from ESP: Dedicated biomass production for bioenergy, 2050 derived from GCAM-USA results



Illustrative results

Comparison of four technologies

• Approach 2: Using ESP to inform LCA inputs

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Use an energy system or integrated assessment model to develop contextual assumptions



Approach 3: Incorporate LC factors into energy models and IAMs

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Conduct LCA using an energy system model, capturing contextual considerations, cross-sector dynamics, etc.





• ESP methods and tools have the potential to link with LCA Approach 1: Using the spatial allocation component of ESP to gain insight

into the location of LCA emissions

Approach 2: Using ESP to inform LCA inputs

Approach 3: Incorporating LC factors into energy and Integrated Assessment Models (IAMs)

- Additional methods and tools being investigated in ESP should be of use in LCA as well:
 - High-resolution integrated assessment modeling
 - Siting new sources
 - Scenario modeling



Questions?

Contact: Dan Loughlin Loughlin.Dan@epa.gov