State-Level Energy and Emissions Projections from GCAM-USA

Steven J. Smith*, Catherine Ledna
Joint Global Change Research Institute
College Park, MD

*Also Department of Atmospheric and Oceanic Science
University of Maryland
ssmith@pnnl.gov

USEPA 2017 International Emission Inventory Conference

August 19, 2017

With contributions from:
Wenjing Shi, Yang Ou, Christopher G. Nolte, Daniel H. Loughlin, Gokul Iyer
Outline

- Introduction to Integrated Assessment Models
  - Wide variety of IAMs

- GCAM Overview
  - Flexible, technologically detailed (for an IAM), global -> regional model

- GCAM-USA Overview
  - US State-level detail
  - Example applications (that don’t involve air pollutants)

- Air Pollutant Emissions in GCAM-USA
  - Methodology and Data Sources
  - Comparison to EPA Inventories
  - Example analysis - RPS

- Questions

Please ask clarifying questions during the talk!
What is an Integrated Assessment Model (IAM)?

IAMs are research tools that integrate human and natural systems.

- IAMs provide insights that would be otherwise unavailable from disciplinary research.
- IAMs focus on interactions between complex and nonlinear systems.
- IAMs are not substitutes for disciplinary research or more detailed modeling.

IAMs are also science-based decision support tools.

- IAMs support national, international, regional, and private-sector decisions.
IAMs – “Big Picture” Analysis With “Just Enough” Detail

- IAMs were designed to provide strategic insights
  - Not designed to model very fine details (unemployment, electrical grid operation, daily oil market price paths)

- IAMs are:
  - Global in scope
  - Generally include all anthropogenic sources of emissions
  - Include some representation of the climate system

- However, there is significant variation across models as to their:
  - Spatial resolution (countries to regions to global)
  - Inclusion of gases and substances
  - Energy system detail
  - Representation of agriculture and land-use
  - Economic assumptions and technological change
  - Degree of foresight
  - Sophistication of the climate model component

- There is a big difference between highly-aggregated IAMs used for cost-benefit analysis (and social-cost of carbon estimates) and higher-resolution IAMs used for analysis of system dynamics such as GCAM (which does not produce a social-cost of carbon)
The Global Change Assessment Model (GCAM)
The Global Change Assessment Model
The Global Change Assessment Model

32 Region Energy/Economy Model

- GCAM is an open-source, global integrated assessment model
- GCAM links Economic, Energy, Land-use, and Climate systems (and now Water)
- Typically used to examine the effect of socioeconomic scenarios, technology, and policy on the complex system that links economy, energy, agriculture, land-use, and climate

283 Agriculture and Land Use Regions

- Technology-rich model (for an IAM)
- Emissions of carbonaceous aerosols, reactive gases, sulfur dioxide, ozone precursors, and 16 greenhouse gases
- Runs through 2100 in 5-year time-steps
- Documentation available at: wiki.umd.edu/gcam

233 Water Basins

- Also a GCAM Community Listserve and an annual GCAM community meeting
Technology Competition: Logit Choice Model

A Probabilistic Approach

\[ \text{share}_i = \frac{\alpha_i \text{cost}_i^\sigma}{\sum_j \alpha_j \text{cost}_j^\sigma} \]

- Economic competition among technologies takes place at many sectors and levels.
- Assumes a distribution of realized costs due to heterogeneous conditions.
- Market share based on probability that a technology has the least cost for an application.
  - Avoids a “winner take all” result.
  - “Logit” specification.
    - Relative and absolute cost technology choice models implemented.
The Global Change Assessment Model

**ENERGY SYSTEM**
- Energy Supply
  - Coal, Gas, Oil
  - Renewables
  - Electricity
  - Hydrogen
- Energy Demand
  - Transportation
  - Buildings
  - Industry
- Energy Markets
  - Fossil fuel prices
  - Electricity prices
  - Hydrogen prices
  - Bioenergy prices
- Other Markets
  - Emissions Permits
  - Portfolio Standards

**CLIMATE SYSTEM**
- Fossil and Industrial Emissions
- Land Use and Land Use Change Emissions
- Land Use & Land Cover
- Concentration, forcing calculations
- Other things (aerosols, sea level, ...)

**ECONOMY**
- Regional GDP
  - Agricultural Demand
    - Crops
    - Livestock
    - Forest Products
  - Agricultural Supply
    - Crops
    - Livestock
    - Forest Products
    - Bioenergy

**AGRICULTURE AND LAND USE**

**Resource Bases**

**Energy Conversion Technologies**

**Energy Demand Technologies**

**Labor Force**

**Labor Productivity**

**Agricultural Technologies**

**Land Characteristics**
The choice among modes of transportation in the passenger sector is a function of the **cost** of travel, the **time** it takes, and **income**.
- Vehicles are also vintaged

*Similar level of detail for freight transport*
GCAM USA
GCAM-USA: Overview

- GCAM-USA is a version of GCAM with sub-regional detail in the United States.
- GCAM-USA is a full, global integrated assessment model (IAM).
- It is actively being used to explore energy-water-land interactions.

See bibliography at end of this talk

Part of an overall trend in our work to add greater spatial and sectoral detail (where needed)
GCAM-USA Detail

► Socioeconomic projections are input at state level
  ■ Population
  ■ GDP (as labor productivity growth)

► Energy transformation at state level
  ■ Electricity generation & Refining by state
  ■ Full electricity (and CO₂ storage) trade within modified NERC regions

► Renewable and carbon storage resources at state level
  ■ Wind, Solar (central PV, rooftop PV, solar thermal), geothermal
  ■ Carbon storage

► Energy final demands at state level
  ■ Buildings: representative commercial & residential building in each state
  ■ Transportation: passenger & freight with detailed technologies
  ■ Industry: aggregate energy demands (process model in progress)

*Not modeled at the state level*

■ Fossil Resources/Fossil resource production
■ Agricultural demand (USA total) & supply (10 agro-economic zones AEZ)
Future Water Consumption

2095 Water withdraw for Electric Generation

- Reference scenario water withdraw where the prevalence of closed-loop cooling increases over time for electric generation.
- Withdraw rates are up to ~10 km$^3$/yr larger at the state level under a “frozen cooling technology” scenario.

Water demands, integrated into the model, allow analysis of sensitivity to assumptions including policy options.

Work incorporating water supply and demand in prep.

Population is not the only factor driving water consumption.

Increases in the prevalence of closed-loop cooling technologies reduce water demands over time relative to a frozen tech scenario.

Shifts in electric generation technologies also change water demands.

Fig. 2. Population percent change in 2095 from 2005 vs. water consumption percent change in 2095 from 2005.

A more detailed representation of the U.S. at the 50 state level, embedded within the global model allows for improved modeling of issues such as the impact of changing climate on US building energy consumption.

Recent and In-Progress Improvements

- **Harmonization to EIA’s Annual Energy Outlook**
  - Follows similar trend other than overestimate in 2015
  - Will be corrected with calibration year updated to 2015

- **Air pollutant emissions updates**
  - (see next slides)

- **Electricity load segments**
  - Generation segments: peak, sub-peak, intermediate, baseload

- **Detailed Industrial Energy Model**
  - ~12 sectors and ~8 services (boilers, process heat, electro-chemical, feedstocks, etc.)
  - Brings industry sectors into similar level of detail as buildings and transportation

- **Natural gas supply and infrastructure**
  - State supply curves. Natural gas trade/transport between states

- **More detailed regional representation of land-use change**
  - Better aligned with water basins/states

- **Energy-Water-Land interactions**
  - Water demand, supply and associated markets

- **New Technologies**
  - Offshore Wind (collaboration with Z. Cramer)
Air-Pollutant Emissions in GCAM-USA
State-level criteria pollutant emissions

In collaboration with EPA ORD, air pollutant emissions in GCAM-USA have been updated.

- Calibrated to NEI 2011 emissions at the state-level
- Emission factors (EFs) incorporate impact of on-the-books regulations (CSAPR), new source performance standards (NSPS2), MACT requirements, consent decrees, etc. for new capital stock

Data sources:
- Industrial fuel consumption: derived from EPAUS9r2014 MARKAL energy modeling framework
- Refineries: GREET (which was developed from EPA inventories and approximates the effects of NSPSs)
- Light- and heavy-duty vehicle: Mobile Vehicle Emissions Simulator (MOVES)

- Add emission factors for fuel/technology combinations not represented separately in NEI or other inventory data

Part of this process have been evaluating/updating other GCAM assumptions so as to better model energy-system dynamics over 1-3 decade time horizons.

Funding for this work provided by the US EPA Office of Research and Development.
Comparison With EPA Inventories

In general, GCAM-USA projections are now similar to EPA regulatory inventories.

Because these projections includes only policies currently in place, some emissions can ultimately increase in the long-term as energy demands or other drivers increase over time.

Comparison With EPA Inventories

Emissions match well for most sectors/fuels.

Some emission differences due to differences in the underlying energy projection or sector definitions.

Comparison With EPA Inventories

Emissions match well for most sectors/fuels. Some emission differences due to differences in the underlying energy projection or sector definitions.

State level comparison

Figure shows a “quality metric” that is equal to 2 when both base-year and 2025 values match EPA’s inventories for that state.

There are larger differences at the state level. State level energy projections have not been harmonized. Emissions agree better in CSAPR states since electric sector emissions are required to match IPM modeled values through an emissions market within the model.

Analysis: Air Pollution Co-benefit of Efficiency and Renewable Energy Measures

Analysis examining the impact on state pollutant emissions due to a renewable energy standard requiring that specified percentage of new generation be supplied by renewable power (wind, solar, biomass, geothermal).

This leads to various analysis set-up choices and additional questions.

- **Applied RPS constraint at the grid region level (roughly equal to NERC regions).**
  - From a modeling standpoint, this is a clean set-up since model freely trades electricity within a grid-region.
  - Question: what would differing state level RPS standards mean in the context of interconnected AC grids where net state-level electricity import/export is generally not zero?

- Might renewable portfolio standards ultimately be set high enough that existing capacity would be either prematurely retired or under-utilized? (Set-up in this analysis assumes not.)

- Results are often in a context of relatively low projected growth in electricity demand
  - Often this implies relatively low levels of new capacity addition.
Electricity System Projections

System size varies between states.

**Elec.Total.EJ 2030** (Generation)

- Scenario
  - 40% new renew
  - Reference

Electricity demand decreases too much in these results – something we are fixing.

**Elec.Total.New.EJ 2030**

Under a region-wide RPS, generation shifts (although shifts are modest in this case).

Preliminary Results
Renewable Generation

Elec.Renew.New.EJ 2030

scenario
- 40% new renew
- reference

New builds of renewable capacity increase

Criteria pollutant emissions decrease, although change is small in this case

Assumptions for biomass (both transformation side and end-use) can impact these results.

Preliminary Results
GCAM-USA is a flexible modeling tool that can now be applied to energy and air pollution analysis at the state level.

At the national level, air pollution projections agree well with regulatory inventories. As with any model, results at finer scales are increasingly sensitive to assumptions and model behavior.

- State level air pollutant emissions show larger differences at this level.

This tool does not replace the need for more detailed modeling

- Regulatory impact analysis often requires more detailed tools that consider the system “as it is now” and might evolve in the near-term.

- GCAM-USA can be a useful tool to allow flexible analysis with multiple scenarios with different driver (e.g. Population, Shi et al. in prep), technology (Ou et al. in prep), or policy assumptions.


The End

Contributions from:

Wenjing Shi, Yang Ou, Christopher G. Nolte, Daniel H. Loughlin