Assessing alignment between a top-down LCA model and a bottom-up supply chain model for data gap identification and prioritization

Rebecca Hanes[1], Xiaoju (Julie) Chen[2,3], Alberta Carpenter[1], H. Scott Matthews[2,3]

1. Strategic Energy Analysis Center, National Renewable Energy Laboratory, Golden, CO, USA
2. Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA, USA
3. Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA

Summary

- Two methods for identifying data gaps in a bottom-up model are developed and tested.
- This study uses NREL's Materials Flows through Industry (MFI) bottom-up supply chain model and an input-output life cycle assessment (IO-LCA) model based on a recent EEIO model of the U.S. economy.
- Preliminary results indicate that Approach 2 (below right) provides sufficient information for data gap identification, while Approach 1 (below left) requires additional development to yield valuable insights.

Background: The MFI Tool

- Materials Flows through Industry is a *bottom-up* supply chain modeling tool (Hanes et al., 2017).
- A linear network model is used to quantify energy consumption and greenhouse gas emissions in U.S. commodity supply chains.
- MFI draws on a database of material and energy inputs to manufacturing processes, covering 1,536 processes for 739 commodities.
- This project aims to both identify gaps within the MFI database and provide information on the relative impact of each gap on MFI results.

Background: The IO-LCA Model

- The Input-Output Life Cycle Assessment model is a *top-down* LCA model.
- The data of the economic component of the IO model are from the U.S. Department of Commerce Bureau of Economic Analysis (BEA).
- The energy use in the IO model are from the U.S. Environmental Protection Agency's (EPA) U.S. Environmentally Extended Input-Output (USEEIO) model (Yang et al., 2017) .
- The most recently available inventory of industrial energy (year 2007) was used.

Approach 1: Compare direct energy by sector

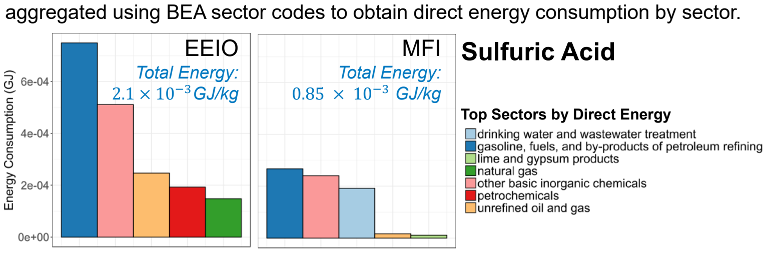
Top-Down Calculation Method
EPA's U.S. EEIO model (Yang et al., 2017)

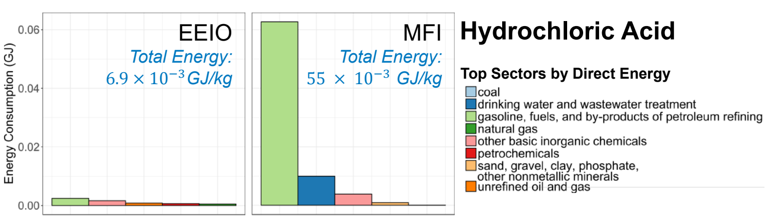
$$x = (I - A)^{-1} f \;\Rightarrow\; D_{\cdot j} = x_j a_{\cdot j} \;\Rightarrow\; E_{\cdot j} = \sum_i d_{ij} b_{\cdot i}$$

- x is total throughput ($) by sector for production of f
- Columns of A are scaled by elements of x to obtain direct ($) inputs to each sector
- Elements of D multiply columns of B to obtain direct use of energy resources (GJ) by sector

Bottom-Up Calculation Method
NREL's MFI tool (Hanes et al., 2016)

MFI-calculated fossil fuel and renewable energy consumption by commodity were aggregated using BEA sector codes to obtain direct energy consumption by sector.





- Differences in energy accounting between models creates difficulty in deriving an "apples to apples" comparison.
- MFI total energy is generally *but not universally* lower than EEIO total energy, contrary to expectations.
- Agreement in energy consumption by sector is variable even among products within the same sector.
- Further study and method development is required for these results to provide information around data gap identification and prioritization.

Approach 2: Compare direct and indirect fuel inputs

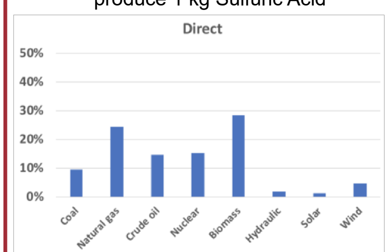
IO-LCA Methodology

$$T = (I + A) f \;\Rightarrow\; g_i = b_i D \;\Rightarrow\; g_{total} = \sum_i g_i$$

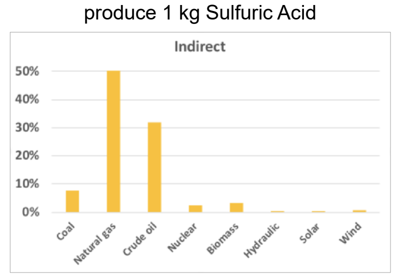
- T: Direct throughput ($) by sector for production of f, based on *economic exchange matrix A*
- Elements of D multiply columns of B to obtain direct use of fuel i for production of f.
- The sum of the direct use fuel i is the total energy consumption for production of f.

IO-LCA Results

Ratios of direct fuel consumption to produce 1 kg Sulfuric Acid



Ratios of indirect fuel consumption to produce 1 kg Sulfuric Acid



$M = g_{total} - TB$ — *Indirect fuel consumption = total – direct*

$r_i = g_i / g_{total}$ — *Ratio = fuel i consumption/ total consumption*

- Direct fuel consumption takes place within the process of interest (sulfuric acid production, in this case) while indirect fuel consumption takes place upstream of that process, such as within electricity generation facilities.
- The IO-LCA results show that biomass is the main direct energy source for producing sulfuric acid, while natural gas is the main indirect energy source.
- Separating direct and indirect supply chain energy consumption will provide additional information on where data gaps exist within the bottom-up MFI dataset, and how impactful each data gap is on energy consumption results.
- Work is ongoing to compare the IO-LCA results, at the sector level, to MFI results at the process level. The level of aggregation in the IO-LCA model is expected to create some difficulties in this comparison.

References

Yang Y., W.W. Ingwersen, T.R. Hawkins, M. Srocka and D.E. Meyer (2017). "U.S. EEIO: A new and transparent United States environmentally-extended input-output model." *Journal of Cleaner Production* (158): 308-18.
Hanes, R. J. and A. Carpenter (2017). "Evaluating opportunities to improve material and energy impacts in commodity supply chains." *Environment Systems and Decisions* 37(1): 6-12.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Advanced Manufacturing Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

International Symposium on Sustainable Systems and Technology
Buffalo, NY, USA
June 26 – 28, 2018
NREL/PO-6A20-71760