Integration of life cycle emissions from power generation into the Global Change Assessment Model (GCAM)-USA

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Overview

A primary goal of our research is to evaluate the net emission impacts of alternative energy system scenarios. Understanding both the combustion and life cycle emissions associated with electricity generation thus is important. We integrate life cycle emission factors (EFs) for electricity production into the U.S. version of the Global Change Assessment Model, GCAM-USA. The resulting model can estimate not only electric sector emissions from combustion, but also emissions from the associated fuel extraction, processing, transportation, and powerplant construction activities. An advantage of using GCAM-USA in life cycle analysis (LCA) is that it accounts for state-specific conditions, such as existing technology stock and stock turnover, access to renewable resources, and state- and region-specific energy and environmental policies. Thus, our approach has the potential to improve upon LCA methods that use static, national average EFs.

Methods

GCAM, a technology-rich integrated assessment model, is used to explore the interactions among energy, water, agriculture and land use, economy, and climate systems. The model operates at a global scale, with 32 energy-economic regions, and over a time horizon from 1990 to 2100 (PNNL 2018a). GCAM-USA is derived from GCAM, but includes state-level resolution for the US energy system (PNNL 2018b). EPA has modified GCAM-USA by harmonizing its emission factors with EPA estimates and by adding representations of air pollution regulations and emission controls. The resulting model has been applied to several air quality management applications, including estimating future emissions (Shi et al., 2017) and evaluating the air quality co-benefits associated with low-carbon electric sector pathways (Ou et al., 2018). Here, we use the EPA-updated GCAM-USA to evaluate nitrogen oxides (NOx) life cycle emissions associated with electricity production. NOx is a precursor to tropospheric ozone, a principle component of photochemical smog.

The life cycle EFs for NOx for various types of power plants are drawn from recent studies (Argonne 2016; EIA 2016; Carreras-Sospedra et al., 2015; Skone et al., 2010a, 2010, 2013, 2014; Draucker et al., 2010a, 2012; IPCC 2011). The LCA factors represent four stages: 1) fuel extraction and processing, 2) fuel transportation, 3) fuel combustion in power plants, and 4) power plant construction. These LCA factors are multiplied by GCAM-USA estimates of electricity generation, providing state- and technology-, and stage-specific NOx emissions. GCAM-USA also produces combustion-related emissions endogenously, allowing us to compare the estimates of both methods.

Emission projections from 2010 to 2050 for Texas are evaluated and compared. Texas is chosen because it is subject to the Cross-State Air Pollution Rule (CSAPR), which imposes a state-level electric sector cap for NOx and sulfur dioxide (SO_2) emissions. Our expectation is that these caps would result in the application of pollutant controls in the model, reducing combustion-related EFs. Thus, the endogenously-estimated combustion emissions from GCAM-USA could be expected to be lower than those calculated using national-average LCA EFs.

Results

We found that LCA emissions from electricity production from coal and natural gas dominated those of other technologies. For coal plants, we found that LCA emissions for stages 1, 2, and 4 were several orders of magnitude lower than combustion emissions. This result occured whether combustion NOx estimates were endogenous or developed using LCA factors. Furthermore, our expectation on the effect of CSAPR was verified: endogenously-estimated NOx from combustion was significantly lower than when the LCA combusion EFs were used. The discrepancy was traced to coal-fired power plants, which applied additional emission controls in response to the CSAPR.

LCA results for natural gas technologies produced a very different result. The LCA stage with the largest NOx emissions was stage 1, fuel extraction and processing. Signficant emissions were also produced in stage 2, fuel transportation. Both of these stages are not regulated by the CSAPR. The primary sources of stage 1 and 2 emissions are the high NOx-emitting natural gas-powered compressors that are installed in wells and across natural gas transmission pipelines.

Conclusions

Incorporating LCA EFs in GCAM-USA improved our ability to quantify upstream emissions related to electricity production. By comparing LCA emissions to those of analogous GCAM-USA sectors, we also were able to identify source categories for which GCAM-USA emission estimates could be improved. At the same time, we believe that the GCAM-USA-produced electric sector combustion emissions would be an improvement over those often used in LCA analyses. Advantages include their ability to incorporate factors such as existing technology stock and stock turnover, access to renewable resources, and state- and region-specific policies.

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