A CRITICAL EVALUATION OF THE CARBON INTENSITY METRIC

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Overview

The common practice of rating fuel sources by their lifecycle carbon intensity (CI) (e.g. grams CO_2-equivalent per Megajoule, kilograms of CO_{2e} per million Btu, etc.) misaligns carbon abatement policies when a fuel's carbon emissions are measured in terms of delivered energy (e.g. the gasoline delivered to a vehicle) rather than in terms of useful energy (e.g. the energy that actually turns the wheels and propels the vehicle forward). The primary purpose of this project is to demonstrate that omitting the delivered-to-useful energy conversion stage has a heterogeneous effect on carbon intensity depending on the fuel, time period, region, and carbon policy. While our focus is on fuels in the transportation sector, the results are broadly applicable.

Background

Carbon intensity (CI) estimates are increasingly important components of regulatory frameworks that seek to reduce the carbon content of the fuel supply, such as low carbon fuel standards (LCFS) and renewable fuel standards (RFS). Carbon intensities are categorized on a "pathway" basis – each separate energy resource that is delivered to an end user will have its own carbon intensity value, typically measured in CO_{2e} per unit of delivered energy[1]. Examples of fuel pathways and associated carbon intensities in California's LCFS include: average Midwest corn ethanol with 80% dry mill, 20% wet mill (95.66 $gCO_{2e}/MJ_{delivered}$); conventional gasoline (99.18 $gCO_{2e}/ MJ_{delivered}$); natural gas via pipeline (67.70 $gCO_{2e}/ MJ_{delivered}$); and average California electricity mix (124.10 $gCO_{2e}/ MJ_{delivered}$).

In policies such as the LCFS, implicit incentives arise because of the ratio of one fuel's carbon intensity to another. For fuel providers, these ratios have real associated dollar values and so should be measured as accurately as possible to provide the intended incentive. Because end-use efficiency varies across technologies that provide the same service, a discrepancy arises between actual lifecycle emissions and CI as measured at the delivered energy stage. For example, an electric vehicle can drive roughly twice as far per unit delivered energy than an equivalent-sized gasoline vehicle. Thus, even though electricity may have a higher carbon intensity than gasoline in terms of CO_{2e} per delivered energy, it generates lower lifecycle CO_{2e} per vehicle-km. This simple example illustrates that it is essential to measure CI as close along the energy supply chain pathway to the service metric as possible.

Ultimately, if these two pathways were rated on their carbon intensity alone, the policy would incentivize the higher carbon pathway. The designers of California's LCFS recognized this issue and corrected carbon intensities based on end use efficiencies using an "Energy Efficiency Ratio (EER)" – the ratio of the delivered to service efficiency of a fuel relative to gasoline. The LCFS uses two EER factors – the CI values of electricity and hydrogen pathways are divided by 2.5 and 3.0, respectively (CARB, 2009).

We argue here that a more comprehensive and accurate carbon intensity indicator would take into account the delivered to useful energy conversion for all fuels and would be both region- and time-period-specific in order to incorporate spatial and temporal heterogeneity in this conversion stage. We demonstrate this effect using fuels within the transportation sector in 14 world regions.

Methods

We compare carbon intensity values based on delivered, $CI\_{delivered}$ (grams $CO_{2e}/MJ_{delivered}$), and useful CI_{useful} (grams CO2e/vehicle km or tonne-kilometer) energy, using the Global Change Assessment Model (GCAM). GCAM is a long-term, global, technology rich, partial-equilibrium model developed and maintained by Pacific Northwest National Laboratory. As an integrated assessment model, it links representations of global energy, agriculture, land-use, and climate systems. GCAM models through the year 2100 at the resolution of 14 world regions. The model

[1] Analysts sometimes refer to carbon intensity as CO_2 per dollar of GDP. Here, carbon intensity is strictly defined as CO_{2e} per unit energy.

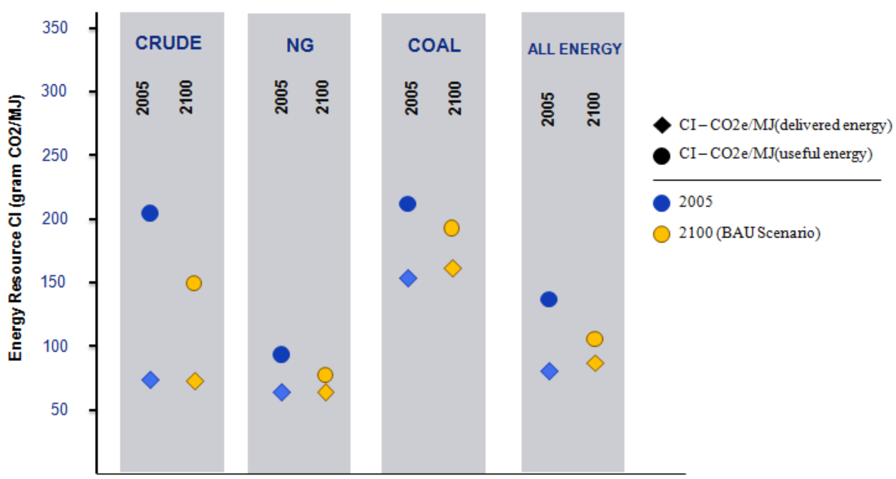
calculates equilibria in 5-year time steps in all regional and global markets for energy goods and services in three end-use markets – industry, buildings (commercial and residential), and transportation. It also includes a reduced-form climate model that tracks sixteen greenhouse gases and criteria pollutants, including CO_2, CH_4, N_2O, and SO_2 (Brenkert et al. 2003).

Together with colleagues at PNNL, we recently (January, 2013) updated GCAM's transportation sector to include: (1) detailed base year data, (2) improved cost projections, (3) and multiple size classes of vehicles, including 2-&3-wheelers, which are an important mode of transportation in some developing countries. This level of detail enables us to track non-linear changes in the final energy transformation (delivered energy to useful energy) in ways that other global energy models cannot. More information on GCAM's transportation module can be found in Kim et al. (2006) and Kyle et al. (2011).

Results (preliminary)

Figure 1 demonstrates how, when measured on a delivered energy basis (diamonds), crude and natural gas have nearly the same carbon intensity and that this $CI_{\_delivered}$ does not change appreciably between 2005 and 2100. However, when measured on a useful energy basis (circles), the two fuels have markedly different carbon intensity values and change at different rates over time. This figure uses business as usual assumptions about technology growth and a model run without any carbon policy. It is illustrative of the patterns which we will investigate in the regional heterogeneity and temporal evolution of delivered to useful energy efficiencies across energy carriers and under varying carbon policies.

Figure 1: CO_{2e} per unit delivered (diamonds) and useful (circles) basis.



Conclusions

Forthcoming

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