The Use of Environmental Life-Cycle Analysis for Evaluating Biofuels

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Life-cycle analysis (LCA), the methodology used to assess the impact of producing biofuels on greenhouse gas emissions (GHG), may lead to flawed policy implications as it assumes that coefficients could be fixed rather than functions of policies and market forces. The methodology needs to be modified to recognize the effects of prices and changes in technology and policy over time. Fuel quality standards that are based on LCA are likely to be more costly than when controlling GHG emissions by carbon tax or a global cap-and-trade scheme.

Processors that convert corn into biofuel may use two sources of energy—energy from coal and energy from natural gas. An increase in the price of natural gas will lead to a switch to coal, which will result in a significant increase in the GHG generation associated with the production of ethanol.

The biofuel industry, which produces liquid fuels mostly from grain, sugar, and oil crops, emerged to a large extent in response to the rising price of fuels and the increased dependence on fossil fuel produced in politically unstable regions. The impetus for the production of biofuel is also its supposed contribution to a slowdown of climate change. Theoretically, net emissions of greenhouse gases (GHG) from biofuels may reach zero because the carbon emitted while burning was sequestered during photosynthesis.

In reality, however, the production of biofuel requires energy (for fertilizer production, transportation and conversion of feedstock, etc.), and this gives rise to net positive GHG emissions, like other fuels. Thus, the more pertinent question is whether biofuels emit less overall GHG than other fuels. The methodology of life-cycle analysis (LCA) has been used to compare the total energy and the net GHG emissions of various biofuels with that of gasoline or other liquid fossil fuels. Proposed policies suggest relying on LCA to regulate the use of various biofuels.

LCA is a systems approach to evaluating the environmental footprint of industrial processes. The goal behind the development of LCA was to quantify the resource and environmental footprint of industrial activities over its entire life cycle from raw material extraction, manufacturing, and use until ultimate disposal. By resource footprint we mean the total physical flow of both extractive resources such as materials, energy, water, etc. and polluting resources like greenhouse gases, criteria air pollutants, toxic chemicals, etc. through the various stages of the life cycle.

Studies that use LCA to analyze corn ethanol have come to widely different conclusions about the net GHG benefits. Farrell et al., through a meta-analysis of several earlier LCA studies, conclude that corn ethanol generates 0.8 units of GHG for each unit it saves. However, Pimentel and Patzek report that all crop-based biofuels generate more GHG than they save. Such differences notwithstanding, all studies ignore carbon emissions due to land-use change induced by biofuels, and this can be substantial, as we will discuss later. Furthermore, existing studies ignore the response of producers to prices and policies that may affect their input use and thus the GHG of biofuel production.

The lack of consensus in the LCA literature highlights some of the methodological challenges associated with computation of LCA. In the following sections, the current status of LCA and the challenges it faces as a tool for policy-making will be discussed. We present initial results of our research, which aims to compare the implications of alternative life-cycle methodologies, to expand these methods by incorporating economic considerations, and assess the implications of using LCA in policy-making.

Different Types of LCA

It is useful to distinguish between aggregate LCA that uses past data to convey the amount of GHG or other energy or pollutants generated on average in producing one unit of output—be it biofuel or other products in the economy—versus specific LCA that assesses, say, the generation of GHG to produce biofuel at a certain facility. Because of heterogeneity among locations in terms of productivity of

Table 1. Sensitivity of Ethanol LCA to Fuel Mix

	Scenario	Kg. of CO_2 Equivalent Offset per Liter of Ethanol	% Change over Baseline
1	Baseline (Farrell et al. *Science* 2006)	0.18	--
2	Net GHG displacement if average biorefinery uses only coal-based energy	0.09	-50
3	Net GHG displacement if average fertilizer production facility uses only coal-based energy	0.07	-61
4	Net GHG displacement if both the average biorefinery and fertilizer producer use only coal	-0.01	-106
5	Net GHG displacement if average biorefinery uses only gas-based energy	0.42	133

corn, energy used to produce fertilizer, and energy sources for processing ethanol from corn, one expects differences in the GHG footprint of ethanol across locations. While we can get a number that will tell us about the GHG footprint of biofuel production in the past, when it comes to the future, things depend on economic and technological conditions. Thus, the outcome of LCA is not necessarily a number *but, rather, a function*.

To elaborate on this point, note that businesses pursue profits, and their selection of technologies and input use varies according to economic conditions. Processors that convert corn into biofuel may use two sources of energy—energy from coal and energy from natural gas. An increase in the price of natural gas will lead to a switch to coal, which will result in a significant increase in the GHG generation associated with the production of ethanol.

Sensitivity of LCA Calculation to Assumptions

The conclusion of Farrell et al., that on average each liter of corn ethanol produced in the United States displaces 0.18 kilograms of CO_2 equivalent, is based on the assumption that the average conversion facility derives 60 percent of input energy from coal and 40 percent from natural gas. We performed a sensitivity analysis of their model to various assumptions about the relative mix of coal and gas-based energy input to corn conversion and fertilizer production. The results are shown in Table 1.

In the extreme case when both biofuel refineries and fertilizer production shift entirely to coal, there is a net increase in GHG emissions from using corn ethanol compared to gasoline. On the other hand, if, say, in response to a carbon tax the average facility shifts entirely to natural gas, then there is a 133 percent increase in the estimated life-cycle GHG benefit.

This illustrates the fact that the average biofuel's life-cycle footprint is a function of the technology and other input choices of the average producer whose behavior is ultimately influenced by the economic conditions. Thus, LCA numbers are not an outcome of assumptions about technology but also implicit assumptions about behavior and economic conditions. Thus, if government policies and economic conditions are expected to lead to the introduction and adoption of wind power in a biofuel-producing region, then the estimated GHG from the biofuel production are likely to decline. Similarly, LCA studies should be able to assess the gains associated with farm policies that induce adoption of yield-increasing technologies in production of feedstock for biofuel production (improved varieties, precision farming methods, etc.).

Land-use Effects and LCA

LCA was developed to assess the environmental impact of industrial processes, and one of the challenges with regard to biofuels is adapting this technique for agricultural systems. Production of biofuels may either directly or indirectly induce conversion of land from one form of use to another. When biofuel is produced by converting rangeland to farmland, the *direct* land effect is the resulting decrease or increase in carbon sequestration in soil and above-ground biomass. When lands that provided corn for food are converted to biofuels production, the reduced supply of corn will increase corn prices and will lead to expansion of corn acreage, and this extra land has an *indirect* effect on the GHG emission associated with the biofuels production.

A recent study by Fargione et al. finds that producing biofuels by converting forests or rangeland releases 17 to 420 times more GHG than the reduction these biofuels would provide by displacing fossil fuels. Searchinger et al. conclude that if ethanol is produced from switchgrass grown on what was previously corn land, there is a net increase in carbon emissions for up to five decades before there is net sequestration due to global expansion of agricultural land. A closer look suggests that estimating emissions from land-use change is complex for several reasons. The GHG contribution of the cleared biomass depends on how it is managed. This contribution may be smaller when the cleared trees are used to generate power, thus replacing fossil fuel, or converted to products like furniture than when they are burned outright. The indirect effects are complex and depend on interaction among several markets, innovations in new technologies, and government policies.

Our research considers alternative methods to adapt the LCA method to incorporate land-use changes. The allocation of the initial emissions of land conversion across time will affect the LCA. Emissions will be the highest in the first year when land is cleared but, clearly since this land will produce fuel for several years, one approach is that the emissions should be annualized over the productive time horizon of the land. Since the indirect effect depends on complex economic factors, their incorporation into LCA requires incorporating general equilibrium effects in LCA.

General Equilibrium Effects and LCA

The introduction of biofuel in the United States has expanded total corn acreage but reduced corn available for food. The expanded corn acreage may take land away from wheat, which may move into previously unfarmed land. In Brazil, grazing activity displaced from the Cerrado region by sugarcane expansion may encroach into the Amazon, although sugarcane may not be cultivated in the Amazon. Thus, when one considers the overall effect of producing biofuel on a large scale on net GHG emissions, the indirect land-use effect has to be taken into account. However, calculation of these effects is tricky.

Historically, increased price of food has induced innovations and investments that increased productivity and slowed expansion of agricultural acreage. If rising food prices reduce barriers and accelerate introduction of new high-yield varieties, the land expansion resulting from higher food prices is likely to decline. By lowering gasoline use, biofuels can delay the production of fuels from dirtier sources like tar sands and coal. However, technological lock-in into certain types of biofuels may also hinder development of cleaner alternative fuels.

Table 2. Simulation of Effect of Carbon Tax on Net GHG Emissions from U.S. Corn Ethanol

Carbon Tax ($/Ton)	5	10	15
Percent Increase in Relative Coal Price	17%	35%	57%
Percent Change in Net GHG Benefits per Liter of Ethanol	117%	228%	383%

Such intricate linkages call for careful interpretation of current LCA numbers. If one conducts LCA on activities that are done on a relatively small scale or products with small markets, then general equilibrium effects can be ignored. However, if an aggregate LCA is considered, then the secondary effects associated with change in prices have to be taken into account.

When conducting a general equilibrium analysis to assess the aggregate GHG impact of biofuel, especially when looking at the future, one has to recognize that this effect depends on policies. Introduction of policies that will invest in research to improve the productivity of biofuel and the efficiency of processes that convert them to fuels, or policies that will enhance adoption of biotechnology of similar productivity-enhancing technologies in traditional agriculture, may lower the impact of biofuel on GHG.

LCA as a Policy Tool: Application of the Low-Carbon Fuel Standard (LCFS) in California

When used as a regulatory tool, LCA can be used to develop policies that would permit fuels below a threshold value for net carbon emissions to be sold in a market, while keeping others out. The LCFS is a first-of-a-kind policy adopted by California, which stipulates GHG emissions per unit of fuel to be below a maximum value which is set to decline over time. This is expected to lead to an introduction of different blends of fuels that will meet GHG standards. LCA indicators, if calculated correctly, can aid the implementation of such a standard. It will also have significant regulatory costs because, to do it right, one will have to trace all the processes that were involved in generating certain fuels and to calculate the GHG emissions.

The uncertainty in calculating the LCA indicators notwithstanding, such a policy is prone to gaming when implemented regionwide or nationwide as opposed to being worldwide. The end result may be reallocation of existing clean and dirty fuels between the various regions, depending on the level of regulation. However, when the region imposing the policy is a large player in the market, this can indeed improve the environmental quality of the average fuel mix.

An alternative approach is to impose a carbon tax where one pays for the carbon content of the fuel they burn. However, since the drawback here is that the upstream carbon associated with transporting gasoline from the Middle East to California or producing biofuel is not taxed, LCA can be used to calculate a more accurate carbon footprint for the fuel at the point consumption. On the other hand, a global carbon tax that pervades all industries and their activities worldwide obviates to a large extent the need for a complex, dynamic general equilibrium LCA. Nevertheless, an LCA model that is a function of prices can be useful in predicting the changes in GHG emissions resulting from a carbon tax.

In Table 2 we simulate the effect of a carbon tax on the relative price of coal with respect to natural gas, which in

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turn can be expected to induce a shift toward greater use of natural gas and lesser use of coal by the ethanol-processing industry. Since gas is a less carbon intensive fuel compared to coal, this shift will on average increase the GHG benefits per liter of ethanol.

Conclusion

Biofuels are being introduced with the aim of enhancing energy supply and reducing GHG emissions. The impact on the former is clear, while that on the latter is uncertain. LCA, the preferred method today for estimating the latter, has become an important tool in the design, implementation, and measurement of policy impacts toward biofuels. Our conclusion is that LCA is a construct that is valuable but prone to misuse and to errors.

Our analysis suggests further methodological development such as the inclusion of price effects, dynamics of carbon emissions and technological change, general equilibrium effects, and a distinction between marginal and average effects before it is employed as a decision-making tool by policy makers. Policy makers should also consider non-GHG environmental impacts that would result from biofuels which has not received much attention in the LCA literature. We also believe that fuel quality standards based on LCA are likely to be more costly than controlling GHG emissions by a carbon tax or a global cap-and-trade scheme.

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For more information, the authors recommend:

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