Biofuels have gained increasing attention as an alternative to fossil fuels. The three main motivations for increasing biofuel production include: reducing greenhouse gas (GHG) emissions, decreasing reliance on foreign oil, and stimulating rural development. The Energy Independence and Security Act (EISA) of 2007 established a Renewable Fuel Standard (RFS) that aims to increase the volume of renewable fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022. The RFS imposes volumetric requirements for different types of biofuels based on their GHG emissions and sets an upper limit on corn ethanol of 15 billion gallons from 2015 onwards in order to encourage a transition to advanced and cellulosic biofuels which could reduce GHG emissions by more than 50% compared to gasoline. California’s Low Carbon Fuel Standard (LCFS) which calls for a 10% reduction in the GHG intensity (GHG intensity is a measure of emissions per unit of energy from fuel, usually expressed in carbon dioxide-equivalents i.e. kg CO2-eq per megajoule) of transport fuels by 2020 is another policy that seeks to leverage the GHG reduction potential of biofuels.

The implementation of the RFS and LCFS relies on a life-cycle assessment (LCA) of the GHG intensity of different biofuels. LCA studies measure emissions from the production of biofuel feedstocks, conversion of feedstocks to biofuel in the refinery, distribution to blenders and fuel pumps, and finally tailpipe emissions. A similar process is used to measure emissions from gasoline, from extraction of crude oil to tailpipe emissions. Emissions per unit of biofuel is then compared to gasoline in order to determine whether a particular biofuel meets GHG reduction thresholds (in the case of the RFS) or to calculate how much overall fuel intensity is decreased through the use of biofuels (in the case of the LCFS).

Several recent studies have argued that in addition to the emissions accounted for in the production of feedstocks up to tailpipe emissions, large scale biofuel production induced by current US policies could lead to indirect land use changes (ILUC) in other countries which could cause the release of large amounts of carbon stored in natural vegetation. When these ILUC emissions are taken into account, some studies argue that the GHG mitigation benefits of biofuels could be eroded or even negated and that biofuels create a “carbon debt” with a long payback period. The estimates of this payback period, however, vary widely across biofuels from

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1 Based on the paper, Khanna, M., Crago, C.L. and M. Black, 2011. “Can biofuels be a solution to climate change? The implications of land use change-related emissions for policy,” Interface Focus, 1, 233-247.
different feedstocks and even for a single biofuel across different modeling assumptions. In the case of corn ethanol, this payback period is found to range from 15 to 200 years.

In response to these concerns, the US RFS and California LCFS have included an ILUC factor in their calculation of the GHG intensities of different biofuel pathways. In this policy brief, we discuss the link between biofuel production and land use change, and examine the methods used to measure ILUC, including the assumptions that need to be made. We then discuss whether an ILUC factor should be included in the life-cycle assessment of biofuels and what implications of such inclusion may be for policy. Finally, we discuss whether biofuels can be one solution to climate change, even in the presence of ILUC.

Since biofuel production requires land normally devoted to crop production to be diverted to the production of biofuel feedstocks, large scale production of biofuel in the US could affect world commodity prices as globally traded food/feed crops are diverted to biofuel production. The competition for cropland induced by biofuel production has the inevitable impact of raising world prices of not only the biofuel feedstocks but also of other crops that compete for limited land resources. The increase in world prices could induce crop acreage expansion on native vegetation and forested land in other regions which releases the carbon stored in these ecosystems, leading to ILUCs that also contribute to GHG emissions.

THE GHG INTENSITY OF BIOFUELS FROM ALTERNATIVE FEEDSTOCKS

The extent to which biofuels can mitigate climate change depends on their GHG intensity relative to the liquid fossil fuels they displace. This GHG intensity is sensitive to the practices used for producing the feedstock and the biorefinery heat source. The potential GHG reduction by corn ethanol relative to gasoline can range between 17-59% depending on whether coal or biomass is used as the source of energy for the biorefinery. GHG intensity of biofuels also differs across first and second generation biofuels and the feedstocks used for each. Studies consistently show that second generation biofuels from cellulosic feedstocks, particularly perennial grasses like miscanthus and switchgrass, have significantly lower direct GHG emissions intensity than corn ethanol or gasoline and can reduce emissions by over 88% relative to gasoline. The emissions intensity of sugarcane ethanol is also estimated to be significantly lower than that of corn ethanol.

The direct and indirect land use change effect of biofuels also differs considerably across feedstocks. Perennial grasses or energy crops like miscanthus and switchgrass are relatively higher yielding than other biofuel feedstocks and have the potential to sequester significantly large amounts of carbon on previously cultivated land. They can also be grown productively on low quality marginal lands. Thus, the direct land use change from existing uses, either crop production or marginal pastureland, to perennial grasses, can make biofuels from these grasses a net sink of carbon rather than a source of carbon. The ILUC effect of cellulosic biofuel from energy crops is also likely to be low because a unit of this biofuel requires much less land than a unit of corn ethanol since ethanol yields of energy crops could be much higher than those of corn-based ethanol even after considering the co-products produced by the latter. Moreover,

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2 First generation biofuels here refers to existing conversion technologies such as fermentation of sugars and starches to produce ethanol (derived from commodity food crops such as maize, sugarcane, wheat and sugarbeet) and methyl esterification of vegetable oils to produce biodiesel (derived from commodity crops such as oilseed rape/canola, soy and palm oil). Second generation refers to advanced biofuel technologies such as lignocellulosic ethanol (derived from crops residues or dedicated energy crops such as energycane, switchgrass, miscanthus, short rotation coppice species).
these grasses are more likely to be economically viable on marginal land because of its lower opportunity costs relative to other cropland; hence they are much less likely to displace food/feed production and adversely affect world market prices as compared to food crop based biofuels.

Cellulosic biofuels can also be produced from crop or forest residues, which would have negligible ILUC effects since they are a by-product of other production activities. A commercial technology to produce second generation biofuels from cellulosic feedstocks is currently not available. The process of converting these feedstocks to biofuels is currently significantly more expensive than first-generation biofuels. These costs can be expected to decline with up-scaling of production from pilot scale to industrial scale, learning by doing and cumulative experience. Government policies, like biofuel mandates and investment subsidies that stimulate investment in the production of cellulosic biofuels can play an important role in accelerating their production and lowering costs of production in the future.

MEASURING THE ILUC EFFECTS OF BIOFUELS

An assessment of the ILUC effect on GHG emissions is important for determining the extent to which biofuels are reducing global GHG emissions from transportation fuels, which is one of the objectives of US biofuel policy. However, unlike direct emissions that can be physically measured or calculated using process-engineering methods, the ILUC effect of biofuels can only be determined using economic models that can simulate the change in behavior of economic agents in response to higher world prices of food/feed crops and biophysical models that can be used to quantify the GHG effects of land use changes. Economic models capture changes in the prices, production and consumption in relevant markets such as: fuel, agriculture, and forestry. Some models which have a spatial representation of land use can map where production changes are likely to occur given prices. These economic models are linked with biophysical models that simulate carbon sequestration in vegetation and soils and can be used to calculate the impact of land use changes on GHG emissions.

The estimates of ILUC obtained by existing studies have a very wide range. Prins et al. (2010) report that estimates for different types of biofuels vary from 15 to 240 g CO₂ per MJ (grams of carbon-dioxide per mega-joule). The differences in estimates are due to different modeling frameworks, and different modeling assumptions. Even for a single biofuel, ILUC estimates using a particular model could vary. For example, Plevin et al. (2010) find that the ILUC factor for corn ethanol ranges between 10-340 g CO₂ per MJ depending on model assumptions. To put this in context, note that the carbon intensity of gasoline is estimated to be 94 g CO₂ per MJ and that the direct carbon intensity of corn ethanol is estimated by many studies to be about 60 g CO₂ per MJ on average; this can vary with the method and fuel used to produce the corn ethanol. The wide variation in estimates suggests that the measurement of ILUC is uncertain and depends on the models used, as well as assumptions made about the determinants of ILUC discussed above. To illustrate the challenges in estimating the ILUC effect, we describe some of the key assumptions made in different models and the sensitivity of their results to these assumptions about parameters and policy scenarios.

Policy Simulation: One of the reasons that different studies obtain different ILUC values is because they are simulating different levels of the policy shock that is stimulating biofuel production. The magnitude of the ILUC effect of a biofuel depends on the design and "ambitiousness" of the policy that is driving biofuel production. For example, a larger biofuel mandate will likely lead to a greater reduction in cropland and food exports in
the US, thus having a larger effect on world commodity markets, and leading to a greater ILUC effect. Searchinger et al. (2008) simulate an increase in corn ethanol production of 15 billion gallons, above the reference case which already projects almost 15 billion gallons of corn ethanol. Thus, the implied total biofuel production is 30 billion gallons. This policy mix is likely to lead to fewer exports of corn and a larger corn price increase, resulting in a higher ILUC effect than studies by Hertel et al. (2010) and Tyner et al. (2010) that simulate an increase of only 13.25 billion gallons of corn ethanol production between 2001 and 2015.

**Yield Responsiveness:** The amount of additional cropland that is brought into production in the US and other countries as crop prices increase due to biofuels depends on how productive the cropland is, and on the rate of growth of productivity. The lower the productivity of the marginal cropland brought into crop production in the US and other countries and the slower the assumed rate of growth of yields in these countries, the greater the amount of land that needs to be converted to meet demand for food and fuel. These productivity parameters are important in predicting global land use changes due to biofuel production, and are likely to differ among countries, and within countries depending on location; however there are very few empirical estimates of these parameters.

Searchinger et al. (2008) estimate that it would take 167 years before the GHG savings from replacing gasoline with corn ethanol will be able to offset the initial release of carbon from land use change. They assume yield increases are offset by reduction in productivity due to expansion of production on new cropland. Even a small increase of 1% in the assumed rate of growth of yields reduces this “payback” period to 31 years (Dumortier et al. 2009).

**Land Available for Conversion:** Models also differ in the land that is considered to be available for conversion to cropland. Some models restrict land conversion to managed cropland, pastureland and forests while other models allow unmanaged (virgin) grasslands and natural forests to be converted to cropland if the revenue from crop production is less than the cost of accessing, developing and operating on that land. Since most unmanaged areas are rich carbon stores, allowing for conversion of unmanaged natural areas to cropland leads to a higher ILUC effect (a seven-fold increase according to Melillo et al. (2009)) of biofuels compared to a scenario that only allows more intensive use of existing management. Searchinger et al. (2008) assume that 36% of new cropland in the US for corn ethanol production comes from forest. Eliminating the potential for deforestation in the US reduces their payback period for corn ethanol from 167 years to 141 years.

**Ease of Land Conversion:** The assumption in many models is that there is a cost associated with converting one land use to another, and costs increase as more land is converted. For example, converting pasture or forest land to cropland requires expenditures. In addition, as more land is converted, the greater the conversion cost is because the land that is first converted are those that are relatively easy to access and convert. As demand for land increases, farmers may need to convert tracts of land that are far from roads or are less suitable for crop production. The data on how “easy” it is to shift from one land use to another and how costly it is to do so varies by location and evidence to support values used in current models is limited. Modelers often times use a parameter called “elasticity of substitution” to measure the ease of shifting from one land use to another. Al-Riffai et al. (2010) find that an increase in this elasticity of substitution between crops or between cropland and pasture by 50% reduces the ILUC effect of biofuel policy in Europe by 30% because the ease of converting land from one use to another reduces the need to bring in less productive new land.
Time Horizon: Estimation of the effect of ILUC on the GHG intensity of biofuels requires comparing the one-time release of carbon from converted areas like forest and grasslands at the time of conversion with the annual reduction in GHG emissions from the displacement of gasoline by biofuels. The net impact depends on the length of the time horizon assumed for the comparison. If one assumes that biofuels have a long time to pay off the initial carbon debt, the overall GHG intensity of biofuels will be lower. In contrast, if the payback period is short, the GHG intensity of biofuels will be larger. Studies differ in the time horizon they use for estimating the ILUC effect. The US Environmental Protection Agency uses a 30 year time horizon for calculating the ILUC factor used in the RFS. Hertel et al. (2010) find that assuming a 30 year time horizon for corn ethanol production results in a 50% lower ILUC factor compared to that with a 20 year time horizon.

In addition to these factors, the ILUC effect will vary with the feedstock being considered and with the co-products of biofuels, with the nature of the price transmission mechanism in the world market, and GHG intensity of the biofuel production process. Additionally, most models focus on a supply side analysis of a biofuel production/price shock, assuming that the additional biofuels can substitute for gasoline on an energy-equivalent basis. This ignores bottlenecks due to lack of infrastructure to distribute biofuels and the inability of the current vehicle fleet to accommodate its use and can over-predict the effect of a policy shock on biofuel production. We now discuss the implications of these uncertain ILUC effects for the design of policy to induce the appropriate mix of biofuels.

POLICY IMPLICATIONS OF INDIRECT LAND USE CHANGES DUE TO BIOFUELS

The presence of an ILUC effect on the GHG impact of biofuels raises the question of how government policies should be designed to respond to it and which policies should take it into consideration. In particular, should the ILUC effect be incorporated in the design of all policies that encourage biofuel production, such as the RFS and LCFS or also in the design of broader policy initiatives, such as an economy-wide cap and trade policy?

In an ideal setting where all polluters across the globe can be held accountable for their actions, all polluters should be penalized for the GHG emissions they generate, including those due to changes in land use decisions that could cause carbon stored in soils and vegetation to be released. Economic theory shows that the penalty (or carbon price) for a unit of GHG emission is the “marginal social damage” of that unit of GHG emissions. ILUC is a problem of "emissions leakage" that occurs when domestic emissions reductions are offset by increases in emissions abroad as emission-generating activities move to other countries that do not regulate their emissions. In order to address this leakage problem, a global carbon price for emissions generated by fossil fuels, industrial activities, and land use change is necessary. However, policy choices become less clear in settings where (a) only a subset of polluters can be penalized for their GHG emissions and/or (b) the policies to control GHG emissions are not targeted directly at GHG emissions but are quantity mandates or technology standards like the RFS and LCFS, respectively.

In the case of (a) even if some countries reduce their emissions due to the carbon penalty, those who don’t face a penalty could still freely emit GHGs . Worse, if the carbon penalty in one part of the globe causes higher commodity prices, un-penalized producers could increase crop production in a manner that raises overall global emissions. In (b) the GHG reduction benefit is just one of the policy objectives. Although increased biofuel production oftentimes advances all biofuel policy objectives, there could be instances, such
as in the case of ILUC where society has to make trade-offs in the extent to which the social goals of energy security, rural economic development and GHG mitigation are met through biofuels.

In the case of (a) and (b) a more careful cost-benefit analysis is needed to determine the appropriate policies to deal with GHG emissions and the extent to which ILUC should be factored into policy design. The multiple motivations for biofuels suggests that we need to be more cautious in including an ILUC factor in the design of policies and that the cost of ILUC may be significantly overestimated because it disregards the contribution of biofuels to other social goals.

ILUC is not the only market-mediated effect that occurs with biofuel production. Large scale production of biofuels is also expected to lower fossil fuel prices by decreasing gasoline demand; this would offset some of the reduction in fossil fuel caused by biofuels. Additionally, anticipated lower gasoline prices in the future could create incentives for fossil fuel producers to increase extraction volumes to convert the proceeds into investments in capital markets that offer higher yields. In addition, policies like the LCFS that promote biofuels and limit the use of higher GHG intensive fossil fuels like oil tarsands in the US could divert those fuels to other countries like China. Thus leakages of GHG emissions are not limited to those due to ILUC alone and including an ILUC factor in the RFS and LCFS ignores the other leakages associated with biofuel production. Accounting for only some market driven indirect effects would be arbitrary and accounting for all of them would make policy design even more complex and cumbersome than it already is.

To the extent that an ILUC factor can act as “pseudo-carbon tax” on land use emissions and encourage a shift towards biofuels with a lower ILUC effect, a case could be made for its inclusion in the GHG intensity measure of biofuels. However, given the wide range of ILUC estimates obtained by recent studies, determining the “right” ILUC factor to include in regulations is likely to be controversial. Given the modeling uncertainties in determining an ILUC factor due to its dependence on a choice of model, on a particular set of assumptions and a particular policy mix, any factor chosen to capture ILUC effects for policy implementation will be subjective. A review of the literature shows that the ILUC effect is positive but the exact magnitude is policy and baseline specific and that it depends on assumptions that often have little empirical support. Setting an ILUC factor too high could prevent innovation in the biofuel industry.

Given the differences among modeling approaches it is unlikely that estimates will converge to a single number. At best, economic models should be used to provide probability distributions of the ILUC factor that reflect the uncertainties inherent in the assumptions that underlie it. While this is useful to obtain an understanding of the GHG mitigation potential of biofuels, it may not be particularly useful for designing policies such as a carbon tax or an LCFS which needs to be based on simple estimates of ILUC. Such estimates need to be guided by a cost-benefit analysis that considers the multiple economic and environmental objectives motivating biofuel production.

**CAN BIOFUELS BE A SOLUTION TO CLIMATE CHANGE EVEN IF ITS PRODUCTION LEADS TO ILUC?**

The answer to this needs to take into account the type of biofuel being considered, because the direct and indirect land use change-related GHG intensity of biofuels differs across the feedstocks used. Biofuel produced from non-edible high-yielding grasses is likely to have a lower impact on land use and crop prices than biofuel produced from corn. Moreover, the design of government policies used to support biofuels play a critical role in determining whether or not biofuels can
mitigate climate change. Firstly, these policies need to encourage biofuels from feedstocks that have a much larger potential to reduce GHG emissions (including indirect land use effects) compared to liquid fossil fuels. Secondly, these policies need to be accompanied by land use policies in the biofuel producing countries that prevent conversion of natural vegetation and forests to energy crops and practices that ensure that the soil carbon sequestered by these energy crops is maintained permanently. Thirdly, biofuel production needs to be accompanied by sustainability standards for fuel blenders in the US and EU that would create incentives for them to ensure that domestic and imported biofuels are produced in environmentally sustainable ways. Fourth, sustainability standards and land use management policies are needed in regions where ILUC could occur to reduce incentives for conversion of natural lands to produce crops displaced by biofuels. In addition to appropriate government intervention, market based pressures for sustainable land use practices could also play a role in making biofuels a solution for climate change mitigation. The effectiveness of these market driven pressures for products produced using sustainable methods of production depends on how widespread they are, on consumer willingness to pay premium prices for such products, and the credibility of sustainability certification standards.

SUMMARY

The ILUC effects of biofuels cannot be measured through direct observation because it is difficult to isolate the impact of biofuels from all other factors that cause land use changes in a country. Thus, estimates of ILUC have to be based on models of economic behavior and international trade and are sensitive to modeling and policy assumptions. Any choice of an ILUC factor for implementing regulations is likely to be a subjective decision. Moreover, the benefits of including ILUC in policy implementation are questionable. A more effective approach to address ILUC would be through international agreements to regulate global carbon emissions and to encourage sustainable land use practices globally.
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