Energy Policy journal submission

Analysis of iLUC impacts under LCFS policy: Exploring impact pathways and mitigation options

Research Highlights

- The stand-alone RFS case causes the most land use change relative to the baseline
- An LCFS policy tends to reduce grain use for biofuels, relative to the RFS
- An LCFS results in less land use change, especially in Africa and Latin America
- Imposing iLUC values or increasing the stringency of the LCFS reduces LUC more
- Yield gains reduce LUC in Africa, whereas direct land policies work best for LAC
Analysis of iLUC impacts under an LCFS policy: Exploring impact pathways and mitigation options

1. Introduction

As global energy resources become increasingly scarce in the face of growing energy demand for transport fuel and other productive uses, many countries have begun to turn to the possibilities that biofuels from renewable resources could offer in supplementing their domestic energy portfolio. North America has taken a leading role in biofuels consumption, worldwide, and is followed by Latin America and the European Union (IEA, 2008). While both Brazil and the US represent over 90 percent of the world’s ethanol production, the US has overtaken Brazil as the world’s leading producer of ethanol, since 2004, while the majority of the world’s biodiesel production is concentrated within the EU (IEA, 2008). Besides the desire for energy independence, a big policy motivation for biofuels production has also been to reduce greenhouse gas (GHG) emissions from fossil fuels, especially in the European Union. The actual GHG emissions savings, however, depends heavily on the production pathway, and is a source of active debate and research.

A great deal of the current debate on the environmental impact of biofuels arises from discussions about the size of market-induced land use change (LUC) caused directly and indirectly by the growth of biofuels production in OECD countries (Searchinger et al., 2008). The discussion of indirect effects from the US biofuels policy come in addition to other critiques of the Renewable Fuel Standard and its tendency to favor the domestic production corn ethanol.
over other feedstocks, and the tariff barriers which hinder the importation of Brazilian ethanol, causing economic inefficiencies and welfare losses (De Gorter and Just, 2007) as well as sharp increases in world maize prices that lead to increases in staple food prices and malnutrition for poor consumers in the developing world (Runge and Senauer, 2008; Rosegrant et al. 2008), such as during the 2007-08 food price ‘crisis’ (Headey and Fan, 2010). Even though the US domestic biofuels policy is not believed to be the most important factor in the more recent rises of food prices that followed the global 2009 recession, there is still a great deal of urgency in the minds of researchers and policy advocates towards addressing the carbon ‘leakages’ that are caused by the design of the policy, and to enhance its environmental sustainability through the adoption of measures more akin to California’s low carbon fuel standard, which goes much farther to incentivize the reduction of carbon intensity within the pool of transportation and other domestic fuels (Sperling and Yeh, 2010).

In this paper, we focus on how policy could mitigate LUC effects that could arise from biofuels production growth in the US, rather than trying to derive the ‘best’ measurement of LUC associated with specific biofuel feedstocks – which is still subject to intense academic debate. By looking carefully at the supply response of key agricultural producers, we gain insight into which crops and regions are likely to contribute the most to LUC and the kinds of policies that could offset those tendencies. We quantitatively illustrate the pathways through which LUC effects are propagated from the domestic markets of the biofuel-producing country, such as the US, through international market linkages that cause conversion of land area in regions outside the US. We have based our quantitative framework upon linkages that have built between two economic, multi-market equilibrium models – namely, the ‘Biofuels and Environmental Policy Analysis
Model’ (BEPAM) and the ‘International Model of Policy Analysis and Agricultural Commodity Trade’ (IMPACT). The BEPAM model (Chen et al. 2011) is the ‘driver’ of land use change, through its simulations of US domestic biofuels policies and their trade impacts over time, while the IMPACT model (Rosegrant et al. 2001, 2009) actually simulates the pathways of international indirect land use change, and the potential strategies for its mitigation. Although there is still considerable debate over the best analytical framework within which to quantify indirect land use change impacts – we have chosen the IMPACT model because of its medium-to long-term perspective, the ease with which we could couple it to a detailed model of the US energy and agricultural market (BEPAM), and the detailed product and spatial coverage that it gives for the developing world – where most of the indirect impacts of biofuels growth in OECD countries will be felt. Given that we do not have a complete accounting of land use cover, at this stage of our analysis, and cannot fully quantify the way in which agricultural land use expansion causes conversion of other land uses, with resulting loss of natural cover and carbon sequestration – we do not provide any direct measurement of the GHG emissions implied by our scenario results. This will be incorporated into future work, beyond this study, as our data coverage for the key environmentally-sensitive regions improves.

Notwithstanding, we employ a simple conceptual framework to illustrate the basic components of agricultural production and market dynamics that underlie the iLUC effect, and use the quantitative, model-based analysis to highlight the entry points relevant to policy intervention and to assess the potential for iLUC mitigation. We recognize that the results of the quantitative assessment depend on some key modeling assumptions, which differ across different categories of economic models – such as assumptions on yield potential on newly cultivated land, the
responsiveness of yield to price changes, the spatial representation of trade, and other issues (see Witzke et al, 2010, Edwards et al, 2010). In a later section of this paper we address the limitations of the quantitative analysis in this study, as well, and its implications for our results. Much of the debate over the iLUC effect of biofuels, in terms of its size and specificity to particular biofuels production pathways, relates to some of the quantitative uncertainties in the modeling, and speaks to the need to think through and guide the use of quantitative (and even qualitative) impact assessment techniques within the policy design process itself (Nassar, 2011).

While we cannot fully resolve all the uncertainties regarding the location, magnitude and timing of indirect land use changes, driven by biofuels growth, we provide a wide range of illustrative experiments that help to narrow the attention of future research efforts and policy analysis on the issues that really matter to environmental sustainability and human well-being.

2. Pathways of global land use change

In this section, we will describe the pathways through which land use changes can be induced through policy-driven changes in the production of biofuels. These land use changes (LUC) can occur either domestically – within the country in which the biofuels are being produced – or in international markets, outside the domestic sphere of direct policy influence. In this paper, we are focusing on the international dimensions of LUC, since they are the most difficult to predict or control – and pose the greater challenge to policy design that is concerned with the mitigation of these effects. We begin our exposition by, first, presenting a conceptualization of LUC and the key components that drive it – followed by an empirical example that better illustrates the dynamics of these key linkages.
2.1 Conceptualizing LUC impacts

In this sub-section, we present a simplified conceptual framework to show the linkages between biofuels, agricultural markets, and the area and yield responses that are relevant for direct and indirect environmental impacts. We build on this conceptual framework, later in the paper, through a quantitative, empirical framework that helps to show the effectiveness of alternative strategies to mitigate global LUC.

To begin with, we present a graphical illustration of how domestic and international markets -- and the producing and consuming agents that underlie them -- interact with each other and lead to changes in production behavior that, in turn, induce indirect land use change.

Figure 1: Linkages relevant to LUC impacts
Figure 1 shows a schematic, in which the domestic expansion of biofuel production induces effects in local markets for agricultural goods, and results in ‘spillover’ effects into international markets through trade. The responsiveness of domestic supplies to meet increased demand is critical to determining the magnitude of these spillovers. We can translate the visual conceptualization in Figure 1 into one of a very simple supply and demand balance for a country

\[ Q_S + M = Q_D + E \]  \hspace{1cm} (0.1)

Where \( Q_S \) and \( Q_D \) stand for the quantity of production and consumption, respectively, of a particular commodity at any particular point in time. \( M \) and \( E \), on the other hand, are the imports and exports of that commodity into and from that country, respectively. We note that while we neglect the removal or addition of goods into stocks for simplicity, in this formulation, it might be important for some commodities. We can re-arrange this expression so that the difference between imports and exports is expressed as a net quantity of exports (\( NetE = E - M \)) that can take on either a positive (if exporting) or negative (if importing) value at any point in time. So we can re-write (0.1), so that it appears as

\[ Q_S = Q_D + NetE \]  \hspace{1cm} (0.2)

and we can re-write it further to represent the changes that would be required in terms of both supply, demand and the level of net exports, in order to maintain a balance

\[ \Delta Q_S = \Delta Q_D + \Delta NetE \]  \hspace{1cm} (0.3)

Where the symbol \( \Delta \) denotes the change in the quantity. This relationship suggests that any increase in the exports of a good from the country, would have to be met by either an increase in
production, or through the reduction in demand. Either of these effects would be consistent with an increase in the price ($\Delta p$) of that good – in which case the producers would be encouraged to supply more of the good to the market, and the domestic consumers of that product would be discouraged from additional purchases, due to the higher cost of the good. Even though we have not made the role of price explicit in this very simple formulation – it clearly serves as a way of making the supply and demand adjustments that are necessary to meet a certain level of exports to an external market – or to make the importation of goods to satisfy local consumption levels possible.

If we place this supply and demand balance within the context of international markets and trade, then we can see how regions with producers, consumers, importers and exporters could be connected through market linkages – where the exports from one region represent the imports into another. If we take just two ‘regions’ – that of the US and the ‘Rest-of-the-World’ (RoW) -- then we can connect their supply and demand balances through trade, as shown below (Figure 2).

**Figure 2: Domestic and international market adjustments through trade**

\[
\Delta Q_3^{US} = \Delta Q_D^{US} + \Delta NetE^{US}
\]

\[
\Delta Q_3^{RoW} = \Delta Q_D^{RoW} + \Delta NetE^{RoW}
\]
Where the arrow denotes the movement of goods – which (within the context of this paper) could be a biofuel feedstock, or another agricultural good that is displaced by the production of a biofuel feedstock within the US. If all the additional demand for biofuels feedstock can be met domestically – then no direct imports would be needed. However, there still could be effects on international markets if levels of exports from the domestic market have to be reduced, in order to accommodate this additional demand. We can decompose, further, the change in production that occurs within either of these regions, so that it represents either a change in production area – or the productivity per unit area (i.e. yield), as is shown below.

\[ \Delta Q_s = \Delta y \cdot A^\text{current} + y^\text{new} \cdot \Delta A \]  \hspace{1cm} (0.4)

Here, the change in production (\( \Delta Q_s \)) is met through either increasing yield (\( \Delta y \)) on land that is currently under cultivation (\( A^\text{current} \)), or through expanding cultivation to new area (\( \Delta A \)) such that it achieves a new level of per-unit productivity (\( y^\text{new} \)) that is either equal to or (most likely) lower in yield potential. This presumes that the better-quality land has already been exploited, leaving more marginal areas remaining for future use. The extent of this effect is under debate in the literature, as the approaches to quantifying it can differ.

These two pathways of adjustment define both the intensive (\( \Delta y \)) and extensive (\( \Delta A \)) margins of production, along which agricultural producers tend to move, when responding to market signals or environmental changes. In regions with limited, scarce or costly land – producers tend to intensify their production, through raising the level of productivity per unit land (i.e. increasing yield) – whereas, regions with more abundant land (or costlier or scarce productivity-enhancing inputs) will tend to rely on extensification (i.e. land expansion) to increase their production.
If we look beyond just a single commodity, and consider the fact that multiple commodities are competing for the same resources within a country or region – primarily that of land – then we might have to consider a constraint where the expansion of land by competing commodities is limited by the total amount of land available ($\bar{A}_{total}$), such that the following expression would apply in the case of two goods

$$A_{current} + \Delta A_1 + \Delta A_2 \leq \bar{A}_{total}$$

(0.5)

Which we could generalize to the case of many goods ( indexed by $i$ ) to be

$$A_{current} + \sum_i \Delta A_i \leq \bar{A}_{total}$$

(0.6)

And which implies that as some goods expand in area, the production area of other goods might have to decrease – in particular, when this constraint becomes binding in some regions. Here, we focus on land, even though other factors of production, like labor and capital-intensive inputs, could also be limited and need to be rationed and allocated through their own price-responsive markets. The reason for this constraint to become binding can vary from the limitations of regional land markets or actual physical availability or suitability. In IMPACT we do not model land markets, and impose this constraint on the basis of physical availability of suitable land. Whether or not the reduction of production area for other goods that are ‘crowded out’ by the expansion of a particular commodity (like a biofuel feedstock crop) results in the actual decrease
of production levels would be determined by the ability to compensate for lost area with higher yield ($\Delta y$), which would vary depending on the crop and the country.

The ability of area to expand or yield to increase, as a means of increasing domestic production and supply, is relevant to the direct land use changes that occur within the biofuel-producing region or in neighboring regions. As price signals and changing levels of trade propagate through international markets, then the responses of other regions to these influences will also determine the level of land use changes that are therefore generated indirectly. We should emphasize, here, that land use changes are occurring within both the domestic and the international domains – although the focus of this paper is more specifically on the discussion of international effects of such knock-on land use adjustments. This is done in a similar vein to the study of Edwards et al. (2010) which evaluated the land uses occurring in the ‘Rest-of-the-World’ due to European and US policy. Later on in the paper, we discuss particular strategies that could be applied to offset or mitigate the (actual or risk of) occurrence of biofuel policy-driven LUC. These strategies relate to how biofuel-driven changes in the agricultural landscape result in adjustments on either the intensive or extensive margins of adjustment and the role that agricultural technology plays in improving the productivity of agricultural crops – thereby creating a greater incentive for producers to move along the intensive margin of production (rather than the extensive margin) and, thereby, offset the occurrence or risk of LUC effects. We will contrast the effectiveness of productivity-focused technological interventions with other mitigation options, and discuss their place in policy design.
It is not easy to see exactly how the individual components of supply, demand and trade fit together with actual biofuel-related policies within the US, from this simple illustration. Therefore, in the next section, we use an empirical, quantitative framework to highlight the nature of these market-based linkages, and illustrate the pathways through which international land use change is driven, as a result of shocks induced by policy-driven changes in the levels of US biofuel production.

### 2.2 Analytical approach to quantifying LUC impacts

Building on a conceptual framework for how heterogeneity in production systems could matter for iLUC, we use the results of numerical experiments with a global partial equilibrium model for trade in agricultural commodities (the International Model for Policy Analysis of Agricultural Commodities and Trade, or IMPACT) to illustrate promising policies to mitigate global LUC. The key elements in the model that we explore are the exogenous growth rates for crop yield and productivity, and the ability of the model to expand production into grassland or other non-agricultural land use types.

We base our simulations on IFPRI’s IMPACT model (Rosegrant et al., 2001), which has been applied to a number of biofuels-related studies (Msangi et al., 2007; Rosegrant et al., 2006, 2008), and use it to explore some alternative policy-based scenarios. The IMPACT model is a partial equilibrium agricultural model for crop and livestock commodities, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes/meals, sugar/sweeteners, and fruits and vegetables. It is specified as a set of 115 country and regional sub-models, within each of which supply, demand, and prices for agricultural commodities are determined. IMPACT contains four categories of commodity demand – food, feed, biofuels feedstock, and other uses. The model therefore takes into account the growth in demand for the feedstock commodities for
biofuel production and determines impact on prices and demand for food and feed for those same agricultural crops. The utilization level of feedstock commodities for biofuel depends on the projected level of biofuel production for the particular commodity, including maize, wheat, cassava, sugarcane, and oilseeds, as well as commodities such as rice, whose demand and supply is influenced by the price of biofuel feedstock crops. Figure 3, below illustrates the key modeling components that interact with exogenously-specified drivers of socio-economic and environmental change, within the IMPACT modeling framework.

**Figure 3: Schematic of modeling components in IMPACT**

The simulation of US energy policies was driven by the BEPAM model (Khanna *et al.*, 2010; Chen *et al.*, 2011; Khanna *et al.*, 2011), a detailed national model of agricultural and energy markets for the US, and which represents the economic and environmental impacts of a change in US domestic biofuels policy in terms of changes in fuel consumption, oil imports, national biofuels production and blending. The BEPAM model also tracks the changes in agricultural crop production levels that are driven either by changes in the use of crops for first-generation
biofuels technology, or by the competition of these crops for land as the production of dedicated energy crops like miscanthus and switchgrass is increased. While most of the land allocated to dedicated energy crops will be marginal in quality, there may be some resource allocation tradeoffs with cereals or other annual crops that could have implications for their production and exports from the US. A key output of the BEPAM model that is used to drive the international agricultural price, production and land use effects that are simulated by the IMPACT model is that of total net exports from the US into international markets. The BEPAM and IMPACT models are, in effect, connected through international trade, such that changes in domestic policy of biofuels result in a different pattern of agricultural production and exports from the US, that are then felt on the world market. The schematic of this linkage is shown in Figure 4 below.

Figure 4: Linkages between the IMPACT and BEPAM models
As is shown above, the international land use change effects that arise from changes in US domestic biofuel policy is simulated by the IMPACT model, whereas the BEPAM model simulates the biofuel-driven land use change effects that occur within the US. As will be discussed in greater detail, later in the paper, there are some limitations with the ‘soft’ linkage between the two models, as full integration with simultaneous feedback of price effects was not possible within the timeframe of the project. There are also some differences in the behavioral response of international trade flows to world and US domestic market prices between the models, as well as in the treatment of price expectations by agricultural producers over the projection horizon. Notwithstanding these limitations, however, the combination of these two models and their market components still serve to define the total global environmental effects on land use that are of such concern to many researchers looking at the long-term sustainability of US biofuel policies. Table 1, below, summarizes the key aspects of US and international market effects that are captured by each of the models within our linked framework.
Table 1: Summary of market interactions covered in BEPAM and IMPACT linkage

<table>
<thead>
<tr>
<th></th>
<th>BEPAM model</th>
<th>IMPACT model</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Oil price effects</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>US Fuel consumption growth</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>US Biofuel production growth</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>US Exports/Imports</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>World price changes</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>(ag commodities)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traded volumes on world</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>markets (ag commodities)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ag commodity consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>RoW</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ag commodity production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>RoW</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Ag crop yield changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>RoW</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Ag crop area changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>RoW</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Note: both models are recursive-dynamic and project over the 2007-2035 period

In the next sub-section, we illustrate how the outputs of the BEPAM model drive the effects of agricultural land expansion that are observed within the IMPACT model simulations.
2.3 Drivers of iLUC across scenarios

Following from the analytical scheme that was just presented, we now show the way in which changes in agricultural net exports from the BEPAM model are manifested within the IMPACT simulations as agricultural land expansion (or contraction) in various regions of the world, outside of the US.

The baseline case that we take from the BEPAM model is based on the “Techno-Realistic” scenario in which the projected level of advanced biofuels from ligno-cellulosic and other advanced, next-generation conversion technologies (Khanna et al., 2011) that are produced under the ‘Renewable Fuel Standard’ (RFS) program is not sufficient to meet the levels mandated by the 2007 Energy Independence and Security Act (EISA), and can only achieve the lower levels of advanced biofuels that are projected by the US Energy Administration in their energy outlook (AEO) projections (EIA, 2010). We refer to this case as ‘RFS_AEO’. The reference case that we choose for illustrating the effect of no explicit government biofuels policy is called the ‘business-as-usual’ (BAU) case, in which agricultural exports from the US – as simulated by the BEPAM model to 2030 – are at their maximum levels, given that there is no competition for food and feed uses on the US domestic market, as a result of aggressive first-generation, corn-ethanol biofuel production growth.
From the baseline simulations of the model, we can already see the implications that growth in demand for agricultural goods between 2007 and 2030, and the corresponding increase in supply have for change in land used by agriculture over time. Table 2 below shows the cumulative change in total crop area in various regions of the world, over the projections of the model from 2007 to 2030.

**Table 2: Cumulative change of total crop area outside the US based upon the BEPAM baseline case**

<table>
<thead>
<tr>
<th>Region</th>
<th>Chg in Physical Area 2007-2030 (million ha)</th>
<th>Share of cumulative area change occurring by 2015</th>
<th>Share of cumulative area change in cereals</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. Asia minus China</td>
<td>6.5</td>
<td>48%</td>
<td>-1%</td>
</tr>
<tr>
<td>China</td>
<td>4.7</td>
<td>91%</td>
<td>-56%</td>
</tr>
<tr>
<td>S. Asia minus India</td>
<td>2.5</td>
<td>56%</td>
<td>-1%</td>
</tr>
<tr>
<td>India</td>
<td>-3.2</td>
<td>69%</td>
<td>125%</td>
</tr>
<tr>
<td>SS Africa</td>
<td>51.4</td>
<td>41%</td>
<td>31%</td>
</tr>
<tr>
<td>Latin Am &amp; Cbnn</td>
<td>23.0</td>
<td>44%</td>
<td>19%</td>
</tr>
<tr>
<td>Brazil</td>
<td>9.1</td>
<td>42%</td>
<td>13%</td>
</tr>
<tr>
<td>E. Europe &amp; C. Asia</td>
<td>2.2</td>
<td>141%</td>
<td>27%</td>
</tr>
<tr>
<td>M. East &amp; N. Africa</td>
<td>1.5</td>
<td>56%</td>
<td>43%</td>
</tr>
<tr>
<td>Developing</td>
<td>88.7</td>
<td>47%</td>
<td>17%</td>
</tr>
<tr>
<td>High Income</td>
<td>-6.2</td>
<td>12%</td>
<td>66%</td>
</tr>
<tr>
<td>World</td>
<td>82.5</td>
<td>50%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Source: IMPACT model projections

In these results, we have illustrated the ‘front-loaded’ nature of the agricultural area changes that occur in the IMPACT model, for the ‘rest-of-the-world’ – in which a greater share of the
cumulative crop area changes occur within the first half of the projection period, than in the latter half. This is especially true for regions in East and South Asia, which tend to have relatively limited areas of land in which to expand agriculture and thereby begin to ‘run out’ of additional cultivable area at a shorter point in the time horizon compared to other regions in Latin America and sub-Saharan Africa which still have considerable area over which to expand in the medium-to long-term future. Later in the paper, we will discuss what this means in terms of the potential for mitigating land use change through alternative policies, whose effective impact and the time period in which it can be felt is especially relevant.

The BEPAM model was run over a number of alternative scenarios, described in Khanna et al. (2011) which conform to both the ‘Techno-Realistic’ case, in which the biofuel volumes projected of by the Annual Energy Outlook of 2010 (EIA, 2010) targets of the 2007 are not fully met in the implementation of the RFS policy – as well as to a more ambitious ‘Techno-Optimistic’ case in which the EISA targets can be realized in the implementation of the RFS program (referred to as the ‘RFS_EISA’ case). The simulation of these alternative cases was also combined with the implementation of a hypothetical nationally-implemented low carbon fuel standard (LCFS), in which policy offsets a standard to reduce the overall average fuel carbon intensity (AFCI) by 15-20% relative to baseline levels (i.e. LCFS15 and LCFS20), over the period 2007 to 2030 – or the policy can be more aggressive in meeting environmental goals, so as to target a 20% reduction in AFCI over that same period (i.e. LCFS20). The incentivization of carbon reduction in the fuel mix was also simulated under a carbon pricing policy (combining with the RFS_AEO case). They also simulated the effect of imposing an ‘iLUC factor’ on certain biofuels feedstocks used to meet the RFS + LCFS15 scenario. The sensitivity of the model results to the magnitude of the iLUC factor was tested, and they draw from both the average
value (‘avg iLUC’\(^1\)) derived by the US Environmental Protection Agency for the implementation of the RFS2 policy (EPA 2010), as well as from twice that value\(^2\), or from an alternative value that includes those emissions from land use changes as well as the additional emissions caused by intensification of chemical input use in agriculture (average iLUC effect including all international effects\(^3\)).

We summarize these cases for the reader, below, in Table 3 – which should help to clarify the definition of the scenarios, as well as how they are labeled in the result tables and graphs which will follow in the rest of the paper.

**Table 3: Summary of BEPAM scenarios linked to IMPACT model simulations**

<table>
<thead>
<tr>
<th>Description</th>
<th>Techno-Realistic</th>
<th>Techno-Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business-as-usual (BAU)</td>
<td>RFS_AEO</td>
<td>RFS_EISA</td>
</tr>
<tr>
<td>RFS_AEO</td>
<td>RFS achieves&lt; EISA goals</td>
<td>RFS meets EISA blending goals</td>
</tr>
<tr>
<td>RFS_AEO + LCFS15</td>
<td>RFS_AEO w/ LCFS 15% CI reduction target</td>
<td>RFS meets EISA goals w/ LCFS 15% reduction target</td>
</tr>
<tr>
<td>RFS_AEO + LCFS15 + CO(_2) price</td>
<td>RFS_AEO w/ LCFS15 and carbon pricing</td>
<td>RFS meets EISA goals w/ LCFS 20% reduction target</td>
</tr>
<tr>
<td>RFS_AEO + LCFS15 + avg iLUC</td>
<td>RFS_AEO w/ LCFS15 and either the average or twice the average EPA ILUC factor</td>
<td></td>
</tr>
<tr>
<td>RFS_AEO + LCFS15 + 2x avg iLUC</td>
<td>RFS_AEO w/ LCFS15 and the iLUC factor accounting for int’l ag input use intensities</td>
<td></td>
</tr>
<tr>
<td>RFS_AEO + LCFS15 + int’l iLUC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{1}\) This value represents an average or median of the range generated by Monte Carlo analysis on land cover types and emissions factors within the EPA study for international LUC only.

\(^{2}\) Although this is sizable, this still does not reach the upper end of the iLUC uncertainty for most feedstocks.

\(^{3}\) Although we could argue that the term ‘iLUC’ already embeds international dimensions into it, we use the label ‘international’ to distinguish the way in which this factor was derived, taking input use intensity in international agricultural expansion as an induced indirect effect, into account.
These scenario definitions describe the policy drivers and technological assumptions that are used within the BEPAM model to cause different levels of biofuel production and consumption, as well as changes in agricultural crop production and consumption that cause export changes from that are then interacted with the IMPACT model. In this paper we do not consider the RFS_AEO + low-stringency LCFS (of 10% AFCI reduction over 2015-30), since Khanna et al. (2011) found this to collapse to the RFS_AEO case, in terms of simulated outcomes.

2.3.1 Effect of policy scenarios on the volume of agricultural exports

In Figure 5, below, we reproduce the effect of alternative US renewable energy policies (as defined above) on the level of net exports of major export commodities generated by the BEPAM model, across the various policy scenarios defined by Khanna et al. (2011).
Figures 5a and 5b: Change in US exports from business-as-usual case under alternative scenarios (cumulative trade volume over 2007 – 2030)
From Figure 5, we see that (relative to the BAU case) the principal cereal crops (wheat and maize) see large decreases in their export levels from the US, under the RFS-only scenario, which are then moderated by the other variants of the LCFS implementation. In particular, the addition of an LCFS offsets the reduction of maize, soybean and meal exports due to both the cases where the RFS-A(EO) and RFS-E(ISA) are implemented alone. Adding an iLUC factor to the LCFS case further offsets these reductions relative to the RFS-AEO case (Figure 5a), while increasing the stringency of the LCFS policy has a similar effect (Figure 5b). The by-products of soybean crush, like meal and oil products, see less of a change in total trade volume, compared to that of soybeans itself – and cotton, other coarse grains and rice undergo relatively small shifts in exports across these cases.

2.3.2 Effect of agricultural export reductions on changes in world crop areas

In order to better understand how the changes in net exports from the US that are simulated by the BEPAM model, under various scenarios, might affect the land use outcomes for the rest-of-the-World that is simulated by the IMPACT model, we illustrate the effect of changes in US net exports on total agricultural land use change in various regions of the world. For greater clarity in describing the ‘pathway’ of land use impacts coming from market-mediated effects, we apply commodity-specific US exports reductions to each feedstock, one-by-one.

Figure 6, below, shows the changes that are simulated in IMPACT, in terms of total change in physical area under agricultural cropping activities (added cumulative across the projections horizon of 2007 to 2030), that are generated as a result of a uniform percentage decrease in US exports across a variety of important agricultural food, feed and fiber commodities.
Comparing the effects of these export reductions on cumulative crop area expansion across the various regions, we see that the effects of some commodity export changes have an additively cumulative effect at the global level—such as those for cotton, sorghum and wheat—whereas others have opposite land use change impacts across regions, which tend to offset each other when summed to the global level—like for maize, soybean and other coarse grains. On a regional-level, changes in soybean exports have significant implications for crop area change in Latin America (and Brazil, in particular), whereas sorghum has the largest impact in sub-Saharan Africa and wheat has the biggest effect in the Europe and Central Asia regions. While most commodities cause an overall increase in cumulative crop area expansion—there are some, like other coarse grains, which drive a decrease in cumulative expansion of agricultural area as their export levels from the US decline. This is due to the fact that a relatively low-yielding coarse grain (like oats or barley) is likely to intensify in yield rather than extensify in area, in order to
boost its production in response to a US export decrease, thereby saving land in the process of
growing to meet a shortfall of coarse grains on the market. This is also seen to be true for
soybeans, in a number of regions – although the overall effect at the global level is seen to be a
slight increase in cumulative change of total cultivated area.

It should be noted by the reader, however, that these results show the effects of what
would happen if a trade shock of similar magnitude were to happen for each of the commodities
shown. In reality – not all of these commodities will be affected equally, under a particular
policy scenario coming from the BEPAM model.

2.3.3 Effect of policy scenarios on changes in world crop areas

The combination of these two effects – that of the effect of a policy on the change in trade
volumes (Section 2.3.1), and the effect of a unit of trade volume change on land use change in
other parts of the world (Section 2.3.2) – combine to give the total change in cumulative
agricultural crop area that lead to the indirect land use effects that we can measure from the
BEPAM-driven US domestic biofuels policy scenarios. This also takes into account the cross-
commodity effects coming from both the BEPAM and IMPACT models, that are inherent in
policy-driven shocks, that would be missed if we only considered the one-at-a-time commodity
trade shocks shown in Figure 6.

In Figure 7, below, we see the combined effect of these scenarios on the cumulative
change in agricultural crop area simulated by IMPACT, for various regions of the world.
Figures 7a and 7b: Change in total crop area from business-as-usual case under alternative simulated biofuel scenarios (cumulative change in crop area over 2007 – 2030)
From this figure, we see that the RFS-AEO and RFS-EISA scenarios cause the greatest deviation in total agricultural area change from the baseline case, as would be expected – given their emphasis on the use of food-based agricultural crop feedstocks. All other alternative scenarios, give lower changes in total cumulative crop area change, relative to the baseline case, and show variation across alternative levels of stringency of the LCFS policy and imposition of other policy measures. The biggest agricultural land use impacts are seen for developing regions like Sub-Saharan Africa and Latin America, which have tended to have higher historical levels of agricultural expansion compared to other regions (MEA, 2005). Even though there are some offsetting agricultural land use decreases from Asia, Europe and other high income regions, the overall global effect is an effective increase in agricultural harvested (and physical) area.

The effects shown in Figure 7 juxtapose a business-as-usual case generated by the BEPAM model against alternative US fuel policies, including the existing RFS policy. To provide a clearer picture of how the alternative low-carbon-focused policy scenarios differ from the RFS-AEO policy is given by Figure 8 below, which shows the difference in cumulative total crop area changes relative to the RFS-AEO policy (by itself).
In this figure, we see that the reduction in total agricultural area change relative to the RFS-AEO policy for sub-Saharan Africa and Latin, increases as the LCFS policy is combined with the RFS and as more conservative (i.e. higher) iLUC values are imposed with the LCFS policy. For Asia and Europe, however, there is a greater cumulative agricultural area change as these same policies are added to the RFS, within the BEPAM simulations. The change in cumulative agricultural area expansion, relative to the baseline case, becomes smaller, however, as we
combine the LCFS policy with a higher stringency level, and with an additional carbon price policy, at the ‘base’ level of CI reduction for the LCFS policy.

In the same figure and focusing on the four bars on the left (RFS-AEO+LCFS15, RFS-AEO+LCFS15+ILUC, 2xILUC and w/intl ILUC), we see that doubling the iLUC ‘risk’ factor from the average value taken across various studies results in greater reductions of agricultural area expansion in Africa and Latin America, and slightly higher expansion in Asia and Europe – resulting in an overall global decrease in cumulative agriculture area expansion.

There is not much of a difference, however, between applying the ‘average’ iLUC factor and the value that was derived to represent the ‘risk’ to international indirect land effects, as was applied in the EPA analysis – although we do see that applying the international value leads to slightly greater decreases in cumulative agricultural area expansion than just the EPA value.

In order to understand the effect of increasing the stringency of the LCFS policy on top of the case which tries to fully meeting the RFS blending targets (i.e., the RFS-EISA case), we look at the changes in cumulative agricultural area expansion, relative to the RFS-E case, shown in Figure 9, below.
In this figure, we see that increasing the stringency of the LCFS policy – such that the reduction of carbon intensity of the base fuel mix is increased to 20%, over the 15% value used for the ‘RFS-EISA+LCFS15’ case while still moving towards compliance with the RFS-EISA blending targets – results in a greater reduction in cumulative agricultural area expansion in sub-Saharan Africa and Latin America, with opposite effects for the Asia region. The impact on sub-Saharan Africa and Latin America can be understood by combining the insights that came from looking at the effect that the alternative policies have on US exports (in section 2.3.1), and the effect of those net export changes on crop area changes in the various regions (in section 2.3.2). Since the decreases in US exports of maize, soybean, wheat and meals (relative to the BAU case) have the
Effect of decreasing area expansion in sub-Saharan Africa and LAC, and the US exports of all of these commodities do in fact decline when greater stringency is applied on the LCFS policy – we, therefore, have a relatively strong decrease in area expansion, relative to the RFS-AEO case for SS Africa and LAC.

Based on these assessments of policy impacts on land use change in various regions of the world – as simulated through the BEPAM-IMPACT linkage – we see the general ranking of effects that is summarized in Table 4, below, where area growth decreases are denoted by “-“, whereas increases are indicated by a “+” – both of which are shown to vary in degree.

**Table 4: Summary ranking of the ‘additionality’ of various policies over the RFS in terms of total LUC impacts across regions**

<table>
<thead>
<tr>
<th></th>
<th>SS Africa</th>
<th>L. America</th>
<th>S. Asia</th>
<th>E. Asia</th>
<th>Europe &amp; C. Asia</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LCFS</strong></td>
<td></td>
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<td></td>
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<tr>
<td>low stringency/ RFS-</td>
<td></td>
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<td></td>
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<tr>
<td>AEO</td>
<td>[ - - - ]</td>
<td>[ - ]</td>
<td>[ + ]</td>
<td>[ ++ ]</td>
<td>[ ++ ]</td>
<td>[ - - ]</td>
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<tr>
<td>high stringency/RFS-</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EISA</td>
<td>[ - - - ]</td>
<td>[ - ]</td>
<td>[ + + ]</td>
<td>[ +++ ]</td>
<td>[ +++ ]</td>
<td>[ - - ]</td>
</tr>
<tr>
<td><strong>iLUC risk factor</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>low value</td>
<td>[ - - - ]</td>
<td>[ - ]</td>
<td>[ + ]</td>
<td>[ ++ ]</td>
<td>[ ++ ]</td>
<td>[ - - ]</td>
</tr>
<tr>
<td>high value</td>
<td>[ - - - ]</td>
<td>[ - ]</td>
<td>[ + + ]</td>
<td>[ +++ ]</td>
<td>[ +++ ]</td>
<td>[ - - ]</td>
</tr>
</tbody>
</table>

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While this is not a precise ranking, it provides a rough characterization of the relative impact that changing various ‘policy levers’ within the US, in terms of the design of domestic biofuel policy, has on various regions of the world – with the sub-Saharan Africa region being the most responsive. In the next section, we discuss the alternative ways in which indirect land use change could be mitigated, and show how these mitigation options differ according to the regions on which – and the pathways through which – they are applied.

3. Mitigation of global land use change

In this section we will now explore, more directly, the pathways that are available to attenuate the effects of biofuel expansion on the environment, and which act to reduce global LUC. Given the design of our analytical framework, we explore the possible strategies for mitigating global LUC through the specific market-mediated pathways that connect the policy-driven results of the BEPAM to the simulated outcomes of the IMPACT model. There are a number of mitigation strategies that relate to actions that can be taken within the context of US policy and the way in which biofuel feedstock selection, production, and processing are carried out within the supply chain of US ethanol or biodiesel. Other strategies apply more to the behavior of agents who are external to the US supply chain, but who are causally-linked to US domestic biofuel production through market-based linkages. We discuss possibilities for mitigation within a variety of settings, but focus on those which can be specifically and quantitatively addressed within our chosen modeling framework.

3.1 Available options for iLUC mitigation

The mitigation of indirect land use change, resulting from expansion of biofuel production – or that of any other agro-industrial enterprise – can only be accomplished through the avoidance,
attenuation or mitigation of those same drivers that were described in section 2 of this paper, and which are mediated through national and international agricultural markets. As Witcover and Yeh (2011) discuss, there are essentially 3 types of strategies that can be exploited to mitigate indirect land use change: (a) those that are aimed at incentivizing measures that reduce LUC exclusively within the biofuel supply chain itself (such as through the choice of feedstock), (b) those strategies which provide incentives that avoid LUC both within and outside the biofuel supply chain (such as emissions credits and offsets) and (c) those strategies that can extend beyond the biofuel supply chain. Examples of strategies that fall under category (c) include those measures which take pressure off the land base by enhancing yields, and those which tend to protect carbon stocks and avoid the conversion of land that would otherwise release large amounts of carbon.

In effect, the strategies that fall under category (a) can be modeled directly within the BEPAM modeling framework, since that model deals specifically with the selection and production of first- or second-generation biofuel feedstocks and their processing and marketing for domestic consumption (or export). Therefore, all of the measures that might be taken to reduce the risk of LUC or mitigate its occurrence are addressed within the range of policy measures that are embedded in its scenario-based simulations – and its effects on US net exports are then fed into the IMPACT model to show the effects on global LUC. Those mitigation strategies that fall under category (c) and relate to the behavior of agents outside of the US biofuel supply chain, on the other hand, fall within the scope of the IMPACT model, which addresses the effects of agricultural producers in outside the US, who are connected to US agricultural and biofuel production through market-based linkages. Even though category (b) also partly deals with agent behavior outside the US, it is neither addressed by the modeling done
within BEPAM nor IMPAC, and is not represented in the quantitative illustrations given in this paper.

Referring back to our conceptualization of iLUC linkages, in section 2, we recall the decomposition of production changes along the intensive (Δy) and/or extensive (ΔA) margins of adjustment, such that \( \Delta Q_r = \Delta y \cdot A^\text{current} + y^\text{new} \cdot \Delta A \). Therefore, the mitigation strategies that we will illustrate, that fall under the (c) category relate directly to these dimensions of agricultural production adjustment. In particular, we will address changes along the intensive margin (Δy) through technology-driven increases in crop yield, whereas adjustments along the extensive margin of production (ΔA) would have to be addressed through policies that directly limit or incentivize the avoidance or reduction of area extensification – particularly in those regions where the natural land cover is high in stocks of carbon (or species biodiversity) and whose conversion would have significantly negative environmental consequences.

### 3.2 Limitations and uncertainties

There are a number of limitations in our study, that arise from difficulties in obtaining key types of data, as well as from overall challenges in modeling and resolving some uncertainties about behavioral response and concrete, bio-physical linkages to the environment. While we will address a number of these issues in further iterations of this work – some will continue to remain in doubt due to the state of the current literature on indirect land use change and lack of agreement on how best to model some important effects.

As we have pointed out before – we have not discussed actual GHG emissions (in terms of CO₂-equivalent tonnages) that are associated with the agricultural area expansions that we have simulated in this study. An obstacle standing in the way of doing this, at this stage of the
work, is that of being able to fully describe the types of agricultural and non-agricultural land
cover patterns that are in each spatial unit of the global model, and how the ag and non-ag land
uses might compete and crowd each other out, over time, as the supply-side adjusts to increasing
demand side pressure for food, feed, fuel and fibre products. The calculation of GHG emissions
depends on the ability to quantify the ‘stocks’ of carbon embedded within each type of land
cover – so that the release or further sequestration of this carbon can be calculated with area
shifts. While we have done this for specific sub-regions, we have not achieved global coverage
in this work.

On the modeling side, we have also illustrated how a ‘soft’ linkage between BEPAM and
IMPACT can provide a view to how changes in US policy and market conditions can directly or
indirectly affect other parts of the global agricultural economy and the environment. Given the
size and importance of the US within the global context, a ‘harder’ link would have been more
desirable, as it could have provided a more realistic set of feedbacks between the models, and
helped to highlight specific commodity-level effects which are highly dynamic within a very
‘globalized’ international market economy. The numerical challenges of simultaneously linking
and simulating the models was considerable, and could not be resolved in time for this round of
work – but will be further explored in future expansion and examination of these scenarios and
policy issues. In addition to this, further sensitivity analysis around some key parameters that
drive the results of the linked BEPAM-IMPACT model will also be carried out.

We also recognize that there is an inherent inconsistency between the iLUC factor that is
introduced into the analysis, through the BEPAM scenarios, and the land use change generated
by the linkage to IMPACT – but which is not necessarily consistent with the implicit behavioral
response embedded in the policy-imposed iLUC factor itself. In this paper, we do not attempt to
come up with a single iLUC number that’s associated with a particular fuel path, given the inability to resolve a number of issues regarding model-based uncertainties and methodological issues that lead to differences across the iLUC effects calculated by different models. Despite the fact that iLUC is, itself, an endogenous outcome of the quantitative analysis and the particular model used to generate it, and its estimates – including those used to derive an ‘iLUC factor’ – depend on a number of embedded model assumptions, we do insert an iLUC number into some of our simulations (through the BEPAM model), so that we can evaluate the iLUC factor in policy design as a ‘policy lever’ that can mitigate potential international agricultural (and other) land use change.

Some research efforts have been underway to try and understand the differences between models and types of iLUC effects that they generate, and we summarize a set of results, as an illustration of this, in Table 5, below.

**Table 5: LUC effects in different models**

<table>
<thead>
<tr>
<th>(land use change in hectares per toe of biofuels)</th>
<th>US ethanol</th>
<th>EU ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>maize</td>
<td>wheat</td>
</tr>
<tr>
<td>IMPACT model</td>
<td>0.12</td>
<td>0.22</td>
</tr>
<tr>
<td>AgLink model</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>FAPRI model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTAP model</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>LEITAP model</td>
<td>0.86</td>
<td></td>
</tr>
</tbody>
</table>

Source: Witzke et al., 2010
These results are drawn from a recent comparison study by Witzke et al. (2010), which tried to subject various models to biofuels shocks in order to illustrate (and understand) the differences in impacts on land use change among them. Among the many factors that underlie these differences are those of basic model structure, since some of the models are partial-equilibrium in nature (like the IMPACT, AgLink, FAPRI models) and focus mainly on agricultural markets and consumption, whereas other models take all interactions within the economy into account (like GTAP and LEITAP) and bring all markets (including input markets for labor, capital and chemical inputs) into equilibrium, with respect to the behavior of the agents within the economy. Some differences come from the way in which the by-products of biofuels are handled – which offsets the decrease in feed demand when grain or oilseeds are used for biofuel feedstock production, as is illustrated in the linkages on the LHS of Figure 1. Other differences come from the variation of parameter values used for key behavior relationships, such as the response of area or crop yield to price, which differ according to the particular form of the functional relationship that’s embedded in the model (linear versus non-linear, etc.). The differences in how models handle trade also affects these results – as some models have a detailed bilateral representation of trade flows, such as in the GTAP models, versus a ‘pooling’ of total net trade from all countries within an integrated world market, as is the case with many partial-equilibrium models. Indeed, there is a constellation of possible influences that could lead to these differences, which have been discussed in more detail by other authors (Edwards et al., 2010; Nassar et al. 2011) than we are able to do in this short paper. It is worth bearing these differences of measurement in mind when deciding how best to carry out ex ante environmental assessments of biofuels, and how to use them within the process of policy design or implementation.
4. Conclusions

In our paper, we have tried to evaluate a possible array of variants of US domestic fuel policies in terms of likely locale and magnitude of international land use change, using the BEPAM-IMPACT modeling framework. The policy variants include sensitivity analysis of one mitigation strategy – inclusion of an ‘iLUC factor’ – within a policy design that includes an LCFS in addition to the existing RFS policy. We also examine a number of interventions in addition to the RFS that are targeted at areas outside the US, in order to gain a sense of how these measures compare in their ability to reduce the risk of GHG emissions-increasing global LUC. Results show that adding an LCFS to an existing RFS policy provides considerable benefits in terms of reducing international LUC effects of the policy. Including an iLUC factor as well provides further gains, although with diminishing returns as the iLUC factor is increased. This combination of policy provides more land savings than a ‘Techno-Optimistic’ scenario that involves fuller compliance with the RFS plus a more stringent LCFS.

Our study suggests that the use of an iLUC factor, while not addressing all the dimensions or array of incentives that drive international land use change and land cover conversion, still serves as an effective policy tool that can accompany a national low-carbon fuel standard that seeks to incentivize the reduction of carbon intensity in the national fuel pool. Choice of ILUC factor must deal with the uncertainty in its measurement; as input into that decision, this modeling work provides some information on how the magnitude of any ILUC factor may influence actual LUC effects of the policy. Challenges remain as to how a national policy could directly facilitate the investment of resources for overseas agricultural development.
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programs. Still, they can provide incentives for blenders to source their renewable fuel supplies from vendors that have certified, low-carbon intensity feedstock and fuel production practices.

We do recognize that no single intervention is likely to achieve the overall goal of reducing global LUC that is induced by biofuels growth. Adopting a ‘menu’ of options that can help policymakers maintain an acceptable level of LUC risk, given the uncertainties in measuring this effect, and in so doing allow a pathway for more efficient and innovative producers to develop their technologies further and lay the groundwork for better next-generation fuels in the future. Given that energy and food markets are (and will continue to be) strongly and inextricably linked – it pays to have productivity and efficiency improvements happening within both – since both markets would benefit from greater flexibility and lowered volatility. Within a highly-globalized and fast-changing environment any gains made in the near-term could open the way for greater gains and benefits to be realized in the future – either on the food or the fuel side.

References


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