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Biofuels and Indirect Land Use Change

White paper: Challenges and opportunities for improved assessment and monitoring.

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WINROCK INTERNATIONAL

Winrock International aims to support the development of effective policies and voluntary standards for biofuels by increasing the evidence base and knowledge transfer for indirect land use change and building capacity among standard-setting groups and policy-makers for monitoring sustainability.

This White Paper addresses current approaches to assessing iLUC. It focuses on data requirements and potential collection methods that could improve modeling efforts and identifies potential ways to improve the assessment, quantification and verification of iLUC.

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1. PURPOSE OF THE PAPER

This White Paper summarizes the issues surrounding indirect land use change (iLUC) and identifies ways to address weaknesses and areas of controversy in current approaches to modeling iLUC and potential iLUC mitigation options. It specifically identifies data requirements and potential collection methods that could improve modeling efforts and identifies potential ways to improve the assessment, quantification and verification of iLUC.

Section two of the paper discusses the concept of iLUC and Section three describes the challenges associated with attempting to estimate the magnitude of iLUC and the causality of changes solely attributed to biofuels. Section four provides an overview of the current approaches to modeling iLUC and describes some of the key areas of controversy in critiques of such approaches. Section five identifies potential improvements to iLUC assessment and quantification that could be used to a) improve modeling estimates for improved quantification of iLUC, b) improve knowledge of the relative contribution of biofuels to iLUC and c) better assess the relative risk of biofuels contributing to iLUC in geographic settings. Section six briefly discusses the opportunities and challenges associated with potential mitigation options and section seven sets out the steps needed to practically address iLUC.

2. WHAT IS iLUC AND WHY IS IT IMPORTANT?

Indirect land use change can be viewed as the “trickle down” land use change effect that results when market forces create increased incentives for producers to convert land from one use to another. If market signals cause production in one location to shift from a food crop to a biofuel feedstock, for example, then other land elsewhere will be converted to the original crop to meet food demand[1]. The conversion from food crop to biofuel feedstock on the original parcel of land is a Direct Land Use Change (dLUC), while the conversion of other land elsewhere to the food crop to fill the supply gap is an iLUC resulting from increased biofuel feedstock production.

The concept of indirect land use change arises because artificial boundaries must be drawn around ‘a biofuel’ to calculate the GHG emissions associated with the production of this product. It is the same concept as market-mediated leakage effects discussed in Clean Development Mechanism protocols and methodologies. Therefore, what is attributed as an indirect land use change associated with biofuel expansion (e.g. land use changes in Paraguay) is actually a direct land use change associated with some other driver somewhere else. The results of a life cycle analysis (LCA) for a given biofuel will differ depending on whether only the direct impacts are considered or whether the indirect impacts are also taken into account. When biofuel policies refer to the “land use change effect”, this is meant to be considered as the sum of all of the direct and indirect effects of the production of biofuels. Greenhouse gas emissions that occur when converting land are often the main impact discussed, but other effects of these land use changes include impacts on biodiversity, water use and water quality as well as social impacts. These impacts could negate positive effects that biofuels are intended to deliver.

While direct land use change may be monitored, iLUC is a global, market-driven phenomenon that by definition is not observable directly. While it is possible to detect land cover changes in multiple locations, **assigning causation for global land use changes to a single driver, i.e. expanding biofuel production, with a high degree of confidence is unlikely.**

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[1]There may be offsets from any increase in yield on existing land already under production. This assumes that original demand for the product will be maintained.

Nevertheless, models have been developed that attempt to quantify iLUC. They simulate variables associated with land use changes (such as crop prices) and attempt to isolate impacts that may be associated with biofuel demand increases.

3. CHALLENGES IN ESTIMATING iLUC

Current approaches to estimating indirect land use change caused by biofuel expansion use economic models based solely on economic principles, conversion being driven by changes in crop prices. Price change as a driver is relied upon by modelers because the expected response of farmers and other economic agents to prices can be modeled. However, assigning causality through such an approach is challenging (**see Box 1**).

Furthermore, there are considerable limitations in basing land use models on economic principles alone. There are several other potentially significant factors that also influence what land use change takes place and where it occurs. Among these drivers are politics, land use policy, biophysical constraints on the types of land use a given hectare will support, location features (e.g., infrastructure, proximity to population centres), and agriculture policy and risk management. These factors are described here.

Box 1: Correlation vs. Causality

Observing correlations is relatively simple but assessing causality is a challenge. If, for example, biofuel demand has increased the price of corn by US$1 per bushel which cascades through the rest of the commodity markets and increases the price of yams in Africa an equivalent amount and the area of yam cultivated in Africa. How do we know that we wouldn't have had the same level of acreage increase with only a US$0.50 increase in the price of corn due to a change in other factors such as access to capital, lack of infrastructure to deliver inputs, access to markets, and price controls?

Political Interactions

A trend identified and described in The Economist (2009) illustrates the ways in which political interactions among countries can influence land use decisions. Countries that normally import food from world food markets are instead choosing to outsource farm production to other countries that have land to spare. They grow their crops abroad and ship them back, decreasing their reliance on the world food markets. In return, land-rich (but capital-poor) countries receive the capital that they need to stimulate their economies. In Sudan alone, South Korea and the United Arab Emirates (UAE) have signed deals for 690,000 and 400,000 hectares, respectively, and Egypt has secured a similar deal here. An official in Sudan, Africa's largest country for Arab governments (traditionally known as the 'breadbasket of the Arab world') says his country will set aside roughly a fifth of its cultivated land for Arab governments. Export bans and taxes, such as those instituted on Ukrainian and Indian wheat exports, also play a role in persuading many food-importing countries that they can no longer rely on world food markets for basic supplies.

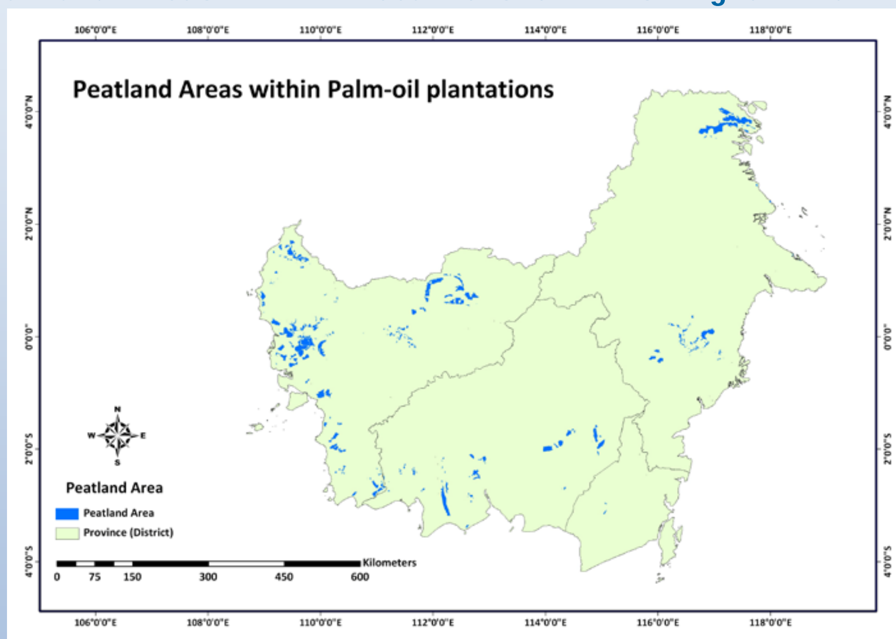
Land Use Policy

Land use policy may dictate where land use change occurs, independent of economic or geophysical factors of the land. In Indonesia, for example, land concessions have been granted for palm oil according to national and provincial land use planning maps that are drafted by the government every five years. It is therefore unnecessary to use models to forecast where production will occur, because geographic locations of oil palm concession areas have already been pre-determined. However, there is evidence that palm oil concessions are not designated in areas that will minimize GHG or other environmental impacts. Using a 2004 land cover map and ancillary spatial data from Wetlands International, Winrock (2009) found that some concessions are located in forested areas as well as wetlands/peatlands. In Kalimantan alone, Winrock estimated that approximately 1.6Mha of oil palm concessions are on forested land and more than 880,000 ha are in wetland areas where peat depth exceeds 50 cm[2] and where GHG emissions would be substantial (**see Box 2**). Based on calculations stated in Edwards et al (2010), cultivation of 224,000 hectares of peatland/wetland could be significant enough to negate biofuel GHG savings[3]. Other potentially suitable areas appear to be available that avoid the loss of high carbon stock land (Winrock, 2009).

Box 2: Land Use Change and the Growth in Oil Palm in Indonesia

Existing data on locations of future palm oil growth is likely to provide better data on GHG emissions than those predicted in models. Oil palm concessions in Indonesia can be mapped against land cover characteristics – Figure A illustrates peatland areas within existing oil palm concessions.

Figure A: Peatland Areas within Locations of Existing Oil Palm Concessions.



Many existing oil palm concessions are located on wetlands and/or forested areas, but other areas within the concessions appear uninhibited by such criteria. In the main oil palm growing regions, the areas within current concessions that are not wetlands or forested are Jambi – 292,760 ha, Riau – 337,595 ha, Kalimantan – 1,137,860 ha. There are substantial areas outside concession areas that have potential (Winrock, 2009a). However, key data limitations on land rights or highly biodiverse areas (other than protected areas) limit the robustness with which such conclusions around sustainability can be made.

Agricultural Policy and Risk Management

The influence of agricultural support payments on land use decisions must be considered and the extent to which they have been included in models for all regions of the world is not clear. Many subsidies are indirectly linked to changing land use such as low interest rates in Brazil for agricultural loans and fertilizer subsidies and power subsidies at the processing level in China. Others are more explicit, such as those in the US that include marketing loan benefits, crop insurance, and disaster

[2]These areas may overlap and therefore are not additive.

[3]2.4% (Edward's estimate) of the EU biofuel demand of 27Mtoe results in 648,000toe biodiesel. If this all came from CPO from peatland, the area of peatland converted would be 224,000 ha. This assumes the ratio of tonne biodiesel; to toe is 1.07 that 1ha produces 3.5tonne CPO and 2.7tonne biodiesel. (Winrock, 2009a).

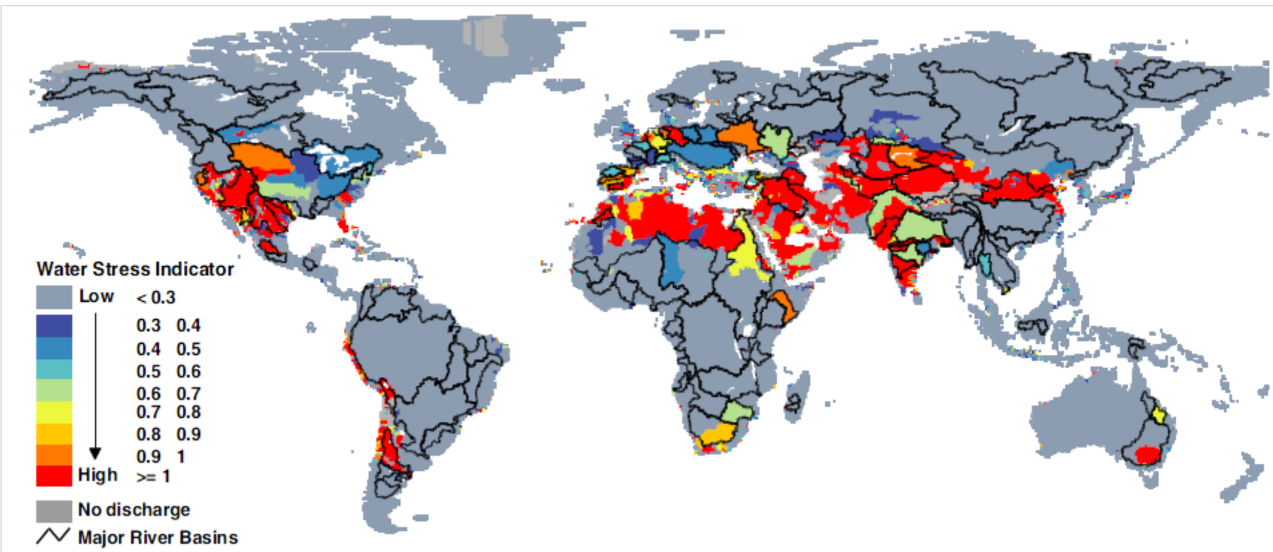
payments. These subsidies can help protect crop farmers from very low prices and yields, which enable farmers to maintain the production of certain crops even when market prices alone would suggest a switch to a different crop or a different land use altogether. Support payments also influence whether yields are increased or new land is brought into production. For example, producers in the US can increase their eligibility for these programs by converting grassland to crop production. Newly converted land is eligible for marketing loans and crop insurance.

Natural Resources

Availability and quality of water is one of the most critical parameters for agricultural expansion and without this check, the location and size of land changes predicted in models are somewhat theoretical. Analysis that reviews Global Climate Change (GCC) models shows the impacts of climate change on most of the developing world are significant reductions in agricultural productivity while experiencing substantial population growth and food demand (Cline, 2007). Water availability is key to this mismatch.

A high level view of water stress indicators in basins throughout the world is illustrated in **Figure 1**.

Figure 1: Water Stress Indicators Including Environmental Water Needs (closed basins in red).



Source: SIWI, 2006

Because of various limitations on rainfed land, many authorities believe that the majority of additional food production will have to come from irrigated land, and therefore the expected increase in the production and use of biofuels in the coming years would add to this requirement. Impacts will be more pronounced for local and regional water resources. Costs of irrigation and water storage systems vary widely by type and location. Molden (2007:117) estimates that US$ 414 billion will be required for irrigation and storage by 2050 just to meet additional food demands. This estimate does not consider all the other domestic, industrial and environmental demands on water resources. Water availability and relative costs of production will further influence decisions on land use.

Other issues that impact land use and land cover change include:

- Location/infrastructure: Access to markets (e.g. distance to towns, roads etc) is key to land use change and it is not clear how this is assumed in many models. Some models that use agroecological zoning to establish a land supply curve may miss this critical issue.
- Business models. For example, if a soybean farmer has financial interest in a soybean crushing plant, he won't simply change crops as modeling would suggest.
- Currency and exchange rates. Devaluation of a country's currency can lead to attractive investment potential from other regions and a weak currency assists in export competitiveness.
- Labour availability or the availability of mechanization that reduces labour requirements.
- Technological innovation. For example, the availability of new crop varieties that are salt or heat tolerant and that can increase productivity while reducing fertilizer and water requirements may make production possible in areas where it was not possible without such innovations.

4. AN OVERVIEW OF CURRENT ECONOMIC APPROACHES TO MODELING iLUC

iLUC models have attempted to isolate the impacts of biofuel expansion (for US or EU policy purposes) on land use changes mainly over a simulated 20- to 30-year timeframe. The area of land ultimately impacted by biofuel crop production will be affected by changes in market prices for particular commodities as well as producers' responses to these changes, as reflected by what and how much they decide to grow.

All models follow a similar approach to simulate land cover/ land use changes and subsequent GHG emissions. A baseline scenario is chosen to reflect current forecasts against which an alternate policy scenario is assessed. The policy scenario includes biofuel demand additional to that of the baseline. The market response to the additional biofuel demand is determined by model assumptions related to the impact of increases in commodity prices on crop yields, crop area changes for those commodities, and resultant total commodity supplies. The resulting area and type of land use change that takes place, and the associated carbon stock changes, are used to quantify the indirect impacts of biofuels on GHG emissions. **Table 1** provides an overview of the different modeling approaches taken to date.

Table 6: Summary of modeling approaches used to date.

Approach	Examples (see Notes)	Approach	Strengths	Weaknesses
Partial equilibrium	FASOM*, FAPRI-CARD*	Concentrates on a particular economic subsection All other variables are treated as exogenous (not dependent or linked to changes in model)	Capable of including detailed biophysical land use characteristics	Lack of adequate coverage of linkages between agri-food markets and general economy, linkages to factor markets, and possible links to other political, cultural and technological issues. Can't handle complex dynamics of global land use
General equilibrium	GTAP* (and modifications thereof)	Aims to represent the global economy and interactions between	Provides a theoretical basis for estimating which lands will be	Incapable of properly capturing dynamic changes in global agricultural sector

Approach	Examples (see Notes)	Approach	Strengths	Weaknesses
		different sectors Top-down model that links general equilibrium theory with real data	converted to crop production Can accommodate trade regimes and estimate impacts	
Combined PE & GE	EPA approach for RFS*	Static model: change in biofuel demand is modeled by moving from a baseline crop demand to the target biofuel policy crop demand in a single step	International applicability Ability to assign land-use types to land-use changes Accounts for specific trade arrangements for agriculture around the world	Concerns about applicability of Armington elasticity factors Level of detail is coarse, for example for land cover types, which compromises accuracy of resulting carbon emissions Lacks transparency Not flexible to dynamic changes in the global agricultural sector
Descriptive - causal	E4Tech* ICONE*	Uses cause and effect logic to describe events	Transparent Easily replicable Not reliant on price elasticities to derive impacts, but on historic trends and expert market projections Can be spatially explicit if conducted at sub-national scales (ICONE) which improves estimates of carbon stocks	Relies on projecting past trends into the future and validating results Doesn't assign a probability to different scenarios

*Notes: FASOM - The Forest and Agricultural Sector Optimization model. The model depicts the allocation of land in the US, over time, to competing activities in both the forest and agricultural sectors. The model initially was developed to evaluate welfare and market impacts of alternative policies for sequestering carbon in trees but also has been applied to a wider range of forest and agricultural sector policy scenarios[4]. FAPRI-CARD - The Food and Agricultural Policy Research Institute and Center for Agricultural Development Model examines and projects the area, production, usage, stocks, prices, and trade for wheat, corn, barley, and sorghum for several countries and regions of the world [5].The GTAP model (Global Trade Analysis Project) was developed by a global network of researchers and policy makers conducting quantitative analysis of international policy issues[6]. The EPA used FASOM results to estimate lifecycle greenhouse gas (GHG) emissions produced by the domestic agricultural sector and FAPRI-CARD results are used to estimate lifecycle greenhouse gas (GHG) emissions produced by the international agricultural sector[7]. E4Tech developed a descriptive-causal approach to determine a range of iLUC impacts as an alternative to modeling approaches[8]. ICONE has also undertaken a specific approach to assessing iLUC within Brazil[9].

The purpose of models varies and influences the relative strengths and weaknesses. For example, some attempt to derive accurate numbers for iLUC impacts whereas others (such as E4Tech 2010) are intended to engaging stakeholders in discussions on this and help identify possible actions that could be taken to minimize the scale of the ILUC impacts.

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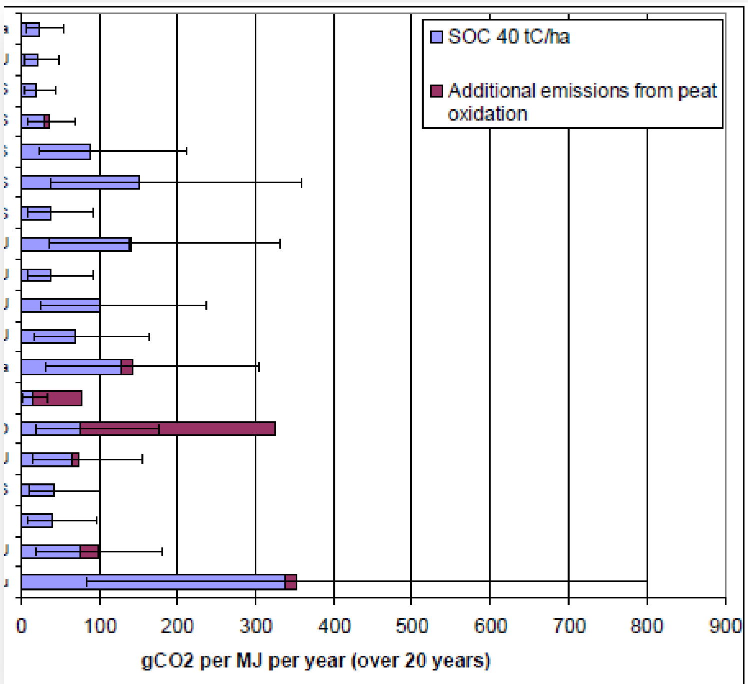
[4]http://www.fs.fed.us/pnw/pubs/pnw_rp495.pdf
[5]http://www.fapri.iastate.edu/models/
[6]https://www.gtap.agecon.purdue.edu/models/current.asp
[7]http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm
[8]http://www.dft.gov.uk/pgr/roads/environment/research/biofuels/pdf/report.pdf
[9]http://www.iconebrasil.org.br/arquivos/noticia/2107.pdf

A comparison of a number of models (including GTAP and FAPRI identified above) indicate iLUC GHG emission ranges (based on the projected area change due to biofuels) shown in **Figure 2**. The authors of the study stress the results are indicative – an average value of 40 tC/ha for soil C emissions was used (IPCC default values report 38 to 95 tC/ha following land cover conversion for EU and agricultural areas in North America). Error bars represent a maximum range using 95 tC/ha and minimum derived from an emission factor of 10 tC/ha (used in FAPRI-CARD calculations with GREEN-AGSIM) (Edwards et al, 2010). The results show values for iLUC ranging from less than 10 to around 800 $gCO2_{eq}$ per MJ biofuel.

Figure 2: Coarse Estimations of iLUC Associated with a Marginal Increase in Demand for Biofuels in Different Regions (EU, US and Brazil) in gCO2 Equivalent per MJ of Biofuel.



Source: Edwards et al (2010)

A different review of six scientific initiatives found values for iLUC ranged from 30 to 103 gCO2eq per MJ of biofuel produced (Cornelissen & Dehue, 2009). The results vary widely because of different assumptions. The validity of these assumptions is critical for assessing the validity of the model output.

iLUC emissions from a variety of studies with different assumptions are large (30 - 103 gCO2eq/MJ) when compared with fossil fuel reference values of 80 to 100 gCO2eq/MJ (Cornelissen & Dehue, 2009). They are still large when compared with GHG emissions from unconventional fossil fuels; recent data for Canadian tar sands in the EU suggests a range of 98.2-122.9 $gCO2/MJ_{LHV}$ (Brandt, 2011)[10]. Data in the US suggests GHG emissions from tar sands vary between 106-116gCO2eq/ MJ_{LHV} and those from oil shale vary between 137-159 gCO2eq/ MJ_{LHV} (Mui *et al,* 2010). This represents an increase over the US fossil diesel baseline in 2005 of 8%-73% (Mui *et al*, 2010). Accounting for indirect impacts in other industries is not yet standard practice but, as biofuels illustrate, the impacts could be significant. For example, methane leaks from natural gas pipelines and other indirect emissions are estimated to have increased contributions to GHG emissions in the US by

[10] Brandt, (2011) for the European Commission reviews a number of studies and concludes that lowest intensity oil sands process is less GHG intensive than the most intensive conventional fuel (as noted in recent reports by IHS-CERA, Jacobs Consultancy and others). Importantly, the most likely industry-average GHG emissions from oil sands are significantly higher than most likely industry-average emissions from conventional fuels. He finds the significant range between low and high estimates in both oil sands is primarily due to variation in modeled process parameters, not due to fundamental uncertainty about the technologies.

around 57% (production stage emissions were underestimated by around 120%) (EPA, 2010)[11]. Brazilian studies confirm high rates of leakage and suggest even these revisions in the US are underestimated[12].

The range of magnitude of iLUC impacts on the GHG balance of biofuels results from the use of different values for the following key modeling assumptions (adapted from Cornelissen & Dehue, 2009):

1. The choice of feedstock for the additional biofuel demand and location of demand increase.
2. Area and types of land use transitions.
    - The level of detail with which land cover and land use is identified.
3. The relationship between commodity demand, commodity prices and food demand.
    - Economic relationships are based on historical data and the validity is in doubt; many were estimated over a time period of low commodity prices. Current high commodity prices are expected to continue in the future and may be beyond the statistical range of previously estimated relationships.
4. Relations between agricultural intensification and commodity prices and/or demand (productivity increases).
5. Carbon stocks of different land use/land cover types.
6. Adoption of existing technology and likelihood for future technological change.
7. Accurate and explicit modeling of fertilizer demand and equilibrium prices.

The following paragraphs discuss some of these key assumptions in more detail. **Section 5** identifies ways in which they could be improved in future modeling approaches.

- **Assumption #1: Levels of Detail in Area and Types of Land Use Transitions**

The classification of land use changes considered in models are often inadequate in their level of detail, which influences the estimated magnitude of land use change as well as associated GHG emissions. In the Modeling International Relationships in Applied General Equilibrium (MIRAGE) model, for example, land use substitution takes place among ‘managed’ land categories (cropland, pasture, managed forest), and land use expansion takes place in ‘unmanaged’[13] lands categories (primary forest, savannah, grassland, shrubland, mountains) (Al-Riffai *et al*, 2010). However, not all cropland may be in use at a given time and therefore not all cropland is ‘managed’; some cropland may be idled and brought back into production as it becomes more economic to do so. This ‘buffer’ capacity of cropland would reduce the substitution within ‘managed’ land categories or expansion into other ‘unmanaged’ land categories[14]. Some cropland may also be double-cropped (i.e., two different

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[11]Obtained from technical information to support the rulemaking for reporting requirements for the petroleum and natural gas industry under 40 CFR Part 98, the regulatory framework for the Greenhouse Gas (GHG) Reporting Program. Table 2 in EPA (2010) illustrates that estimates increased from 201.8 to 317.4MMTCO2eq for 2006.
[12]http://pipelineandgasjournal.com/new-measurement-data-has-implications-quantifying-natural-gas-losses-cast-iron-distribution-mains?page=show
[13]Without an economic value.
[14]The IFPRI study discusses idle land in the context of the EU but it is not clear how this land is addressed in the rest of the world.

crops grown back-to-back in one season) rather than expanded or substituted. Babcock and Carriquiry (2010) state ‘In the Global Trade Analysis (GTAP) model, there is no possibility of idle land which could be drawn on if the demand for cropland increases’. This is a significant model limitation. They conclude that, in the US, the increase in crop acres in 2007 and 2008 could have been accommodated by the reduction in crop acres in 2004, 2005, and 2006. Furthermore, the 2009 reduction in crop acres has seemingly rebuilt up the stock of potentially idle land. These findings would significantly influence the magnitude of modeled land use changes.

Within the forestry dataset for GTAP, generalisations have also been made owing to a lack of data. For example, timber inventories have been developed for the different agro-ecological zones within a country, and for some regions (Europe, North America, and countries of the Former Soviet Union) hardwoods and softwoods within each ecosystem type can be considered separately because the inventories include this level of detail. For other regions, this is not possible and data are based on FAO data, which itself has limitations. Forest statistics have been compiled once every five to ten years for FAO’s Forest Resource Assessments since 1946 but countries do not necessarily report new and updated data at each time interval; data quality is notoriously variable across countries, and many countries report the same data as for past years, or apply projections and forecasts to data collected previously (up to several decades in the case of forestry statistics). Little to no quantitative accuracy information is available for FAO statistics. In a recent paper, Grainger (2008) highlighted various problems with tracking the long-term changes in tropical forest area using FAO statistics; his assessment revealed that constructing a reliable trend in forest area using these data is difficult, and evidence for forest decline over time is unclear when considering the limits of errors involved in making global estimates.Agro-ecological zones (AEZ) have been used to determine appropriate and likely locations of land change and subsequent GHG emissions but this approach itself has limitations. The AEZ approach (adopted in the modified version of GTAP) does not undertake a quantification of water availability within a watershed, and water is one of the most critical requirements for agricultural expansion. Without this check to see if the available water could support the proposed land use changes, the location and size of land changes are somewhat theoretical. Analyses that review Global Climate Change (GCC) models show that the impacts of climate change on most of the developing world will be significant reductions in agricultural productivity with increases in population growth and food demand (Cline, 2007) (see Natural Resources in Section 3).

- **Assumption #2: Relations Between Agricultural Intensification and Commodity Prices and/or Demand**

In most models of economic markets, the supply side is addressed in two equations. The first equation determines area and the second determines yield. These factors are discussed further. They are the relationships between crop price and yield, crop prices and land use change and finally, yields on ‘new’ acreage.

  - Assumption #2a: Crop Price and Yield Relationship

Box 3 illustrates the challenge in determining the crop price and yield relationship. As stated above, in most market modeling the supply side is handled with two equations. The first determines the area of land needed to produce a given crop supply. The second determines yield, i.e. the amount produced per unit land area. Economic theory suggests that farmers will adjust their input use (such as fertilizer and water) as prices change, thus resulting in different yields. The yield growth is estimated in different ways.

Box 3: Crop Prices and Yield

Are realized yields the result of prices or weather? Are the resultant prices for the following year that drive land use decisions the result of biofuel demand or yield shortfalls due to weather? Or plentiful stocks due to a good year?

- Some models e.g. FAPRI, FASOM assume an exogenous (independent) yield growth rate based on average historic yield growth rates (Lywood, 2009).
  - The results of EPA and Searchinger modeling approaches that use these models determine that the agricultural intensification associated with biofuel production is zero (Cornelissen & Dehue, 2009). This is inconsistent with the research from USDA (see Figure 3) (Fuglie, 2010).
- The model used by the California Air Resources Board (CARB) includes an elasticity factor[15] of 0.25 for yield changes with price changes. For example, a permanent increase of 10% in crop price, relative to variable input prices, would result in roughly a 2.5% rise in yields. This is based on a review by Keeney and Hertel (2009) whose literature review found evidence that yield response to price has been diminishing in recent years[16].
  - The results of CARB's modeling of biofuel demand do not enable an indication of the level of agricultural intensification that has resulted from biofuel use to be identified (Cornelissen & Dehue, 2009).

Yield improvements from technological change are not included in yield-price relationships but are an important factor. These include improvements such as development of varieties that make better use of nitrogen which will improve yields and also make them less price-dependent.

- Assumption #2b: The Relationship Between Crop Price and Land Use Change

Most models forecast the magnitude (and sometimes location) of land use change based on changes in crop prices. The model chooses which land, and how much land, to convert to crops based on a function called The Constant Elasticity of Transformation (CET). The CET depends, in part, on the share of revenue the landowner receives from different land use choices. In other words, if crop prices increase relative to the price of a commodity produced on a different land use (such as growing pasture grass), then the land will be allocated to crops[17]. The model then decides on the allocation of land between various crops, again based on relative returns in crop sectors (Lee *et al*, nd).

The choice of what type of land is converted to crops depends on elasticities of land transformation (contained within the CET). Large elasticities mean there is a large response to a change in a variable and small elasticities mean there is a small response to a change in a variable. This means that if pasture land is more responsive to crop prices (has a higher elasticity) than forest land, more pasture than forest would be converted, resulting in fewer calculated GHG emissions.

Using the CET function to model land use conversion has several limitations:

Non-market values are not accounted for: The skillset of farmers may be quite specific and therefore not subject to rapid change (unless land is sold). Land ownership also influences land use; tenant farmers may be limited in crop choice and land use by the demands of their landlords. In the US in 2007, more than 50% of farms were rented or leased in key agricultural areas such as the upper Midwest and along the Mississippi River Valley. Inertia also plays a role, for example with cattle producers, to maintain cows on pasture rather than crop the land. In the US, most cow herds are very small and are hobbies for individuals who have off-farm income. That land and any forest land they control is unlikely to be converted as it represents a lifestyle and has an aesthetic value that agricultural prices do not capture.

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[15] Elasticity is a measure of responsiveness to a change e.g. a change in yield in response to a change in price.
[16] https://www.gtap.agecon.purdue.edu/resources/download/4989.pdf
[17] Some modeling efforts have tied this with suitability of land through AgroEcological Zoning.

Projections are based on historical data and few data points: In GTAP, the CET parameters among the three land cover types and among crops are set according to the recommendations in Ahmed, Hertel and Lubowski (2008), based on 2002 econometric investigations by Lubowski (Lee *et al*, nd). CET parameters are based on only a few years of data from the USDA National Resources Inventory. Better data on the transition of **specific land parcels** and an analysis of that data to determine drivers of land transition will lead to more exact measures for large scale modeling and greater confidence in results from those models.

Land rents are modeled, not observed: In all current models, the most profitable use of the land can be calculated only if land is assigned an economic value. The value of land in models is represented by a rental value calculated for a given economic activity (for forested land see below). This is not based on direct observation of land rents by crop owing to lack of data so it has to be estimated. In GTAP for example, land value is estimated by aggregating the revenues of all the crops grown and 'sharing out' this value based on estimates of productivity (yields) across crops and AEZs[18]. This results in an average land rent that is applied worldwide for land that produces that crop in that zone. Land rents within the model also vary by crop, which is unrealistic, because they are based on economic returns rather than a rental payment to the landowner.

There are limitations in datasets for connected sectors: forestry: For forested land, rental represents estimates of the value of the land in the next best alternative to forestry (typically agriculture) for the region in question (Lee *et al,* nd). Land rental estimates based on returns may not sufficiently capture significant aspects of land use decisions. While annual net returns may suggest cropping is an economically attractive option to timber, the present value of a future timber harvest provides high returns on investment. Therefore modeling does not explicitly account for conversion costs or a large cash inflow of forest land, nor for the value of the stock of timber on virgin forest land that substitutes for current timber harvest on managed forest land (MIT, 2008[19]). These issues will influence decisions on land use but are not sufficiently well accounted for.

An alternative approach to explicitly modeling price as the direct driver for land use change has been undertaken by Bauen et al (2010). They analyse market responses (and subsequently land use change) through demand-based relationships for yields based on historic trends and through product properties and market analysis for product substitution. They have also used expert opinion to understand if extrapolations of historic trends are realistic based on their understanding of the particular markets studied and made relevant adjustments.

- Assumption #2c: Yields on "New" Acreage

Another critical assumption is the difference in yields between newly converted lands and established areas of the same crop (Babcock & Carriquiry, 2010). The CARB GTAP model defines an elasticity factor of 0.5 for yields on 'new' acreage, i.e. the average yield on new land will be half of that on existing cropland (Lywood, 2009). The choice of elasticity is significant; ***a range of the elasticity factor from 0.25 to 0.75 results in a 77% change in GHG emissions*** (Lywood, 2009). The choice of a 0.5 elasticity factor for yields on new acreage suggests that cropping at those yield levels would be profitable only if prices more than doubled, because that land is not now cropped at current prices with yields that are twice as high.

Edwards et al (2010) state that using assumptions of yields on "new" acreage based on a specific crop (e.g. corn) are incorrect. They suggest yields should be based on the marginal or incremental

[18] https://www.gtap.agecon.purdue.edu/resources/download/3596.pdf
[19] http://dspace.mit.edu/bitstream/handle/1721.1/41521/MITJPSPGC_Rpt155.pdf?sequence=1

land that is brought into production, not simply the expanding crop of interest. In the EU for example, they suggest that the “yield drag” from increasing wheat production is not a result of the yield of wheat on new acreage. Wheat would be produced on the most productive land and would not likely result in yield reductions. Instead, the marginal (or incremental) land is used for marginal crops, in the case of the EU, rye. In the United States, if more soybeans are grown on ‘new’ acreage, yields won’t drop but cotton or small grain yields that are planted on the new acreage could be lower if they are planted on marginal ground (Babcock & Carriquiry, 2010). Marginal yield on land devoted to crops likely varies dramatically across crops (Babcock & Carriquiry, 2010) making a single factor for crop yield on new acreage too simplistic. The theory relies on prices among competing crops to be far enough out of equilibrium to start assigning land to different crops based on quality. Bauen et al (2010) also conclude that is it too difficult to develop marginal data that would incorporate changes to several parameters at one time. They state that marginal analysis is well suited when small changes are analyzed that do not lead to a systemic change (e.g. the type of varieties grown or management practices) because marginal data only incorporates changes to one parameter.

In Brazil large land expansion for soybeans alone has provided a clearer test of the assumption of yields on “new” acreage. Babock & Carriquiry (2010) illustrate that there is no reduction of yields on new acreage here.

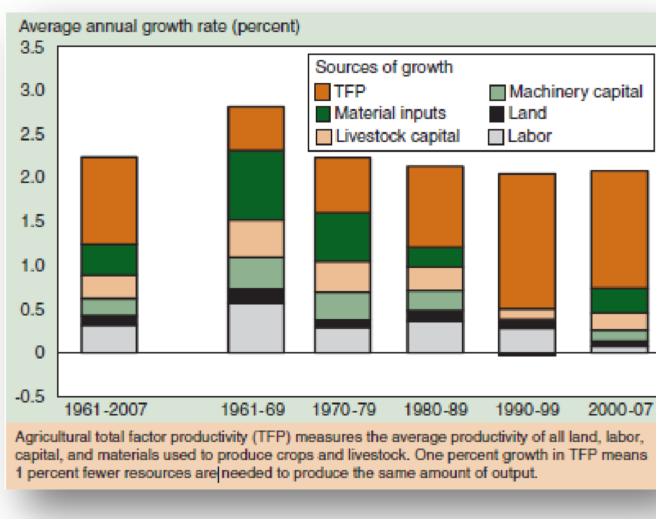
In the GTAP model, the broad crop categories (oilseeds, coarse grains, other grains, and other crops) makes it difficult to differentiate between marginal crops and non-marginal crops because each category contains both (Babcock & Carriquiry, 2010).

Evidence for these so-called “yield drags” is available but complex. It is crop mix changes that are key to understanding how crop yields will change in response to new land being cultivated (Babcock & Carriquiry, 2010). Monitoring these changes that could be used to produce improved data for models requires a careful accounting for substantial changes in crop mix (Babcock & Carriquiry, 2010).

An alternative approach to assessing relations between agricultural intensification and commodity prices and/or demand.

Using data from 1961 to the present, Lywood (2009) established direct relationships between historic changes in yield and land area for different crop-region combinations. These relationships were then used to determine the relative contribution of yield and area changes to output growth. A regression analysis that shows that 75% of incremental output growth for EU cereals is explained by yield growth and 25% by land area growth (Lywood et al, 2009). A different picture arises for the case of South American soy, where 100% of incremental output growth is from land area growth alone with no attribution to yield increases. However, this approach encounters limitations. Bauen *et al* (2010) cite the work of

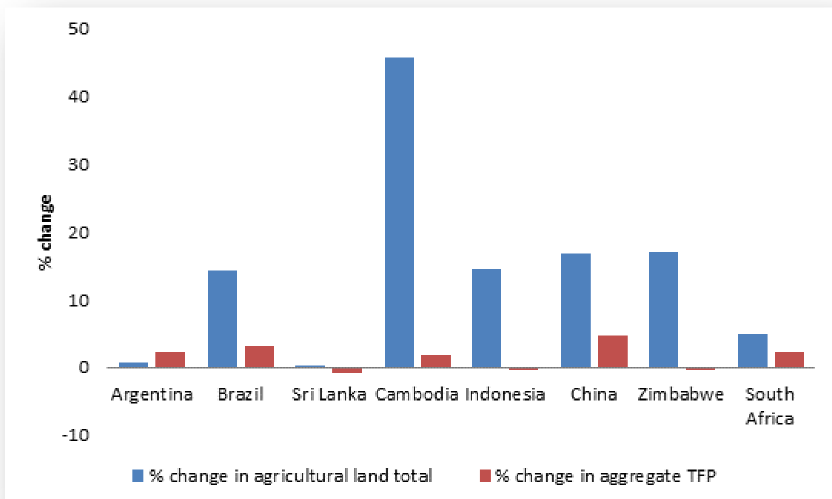
Figure 3: Total Factor Productivity Accounts for a Rising Share of Agricultural Growth over Time.



Source: Fuglie (2010)

Lywood et al (2009) which found the predictive power of the yield/area modeling was not as strong for SE Asia oil palm as it was for EU cereals[20] potentially owing to a comparably smaller (shorter time) dataset available on which to predict future changes. Furthermore, indicators such as crop yields are only partial measures of productivity. Assessing yields and land areas for specific crops may miss the wider picture of resource shifting or saving in certain sectors to improve total productivity in others[21]. Total Factor Productivity (TFP) is a concept introduced to address the limitations of partial measures. It measures efficiency in overall input and captures the impact of adoption new technology or farming practices. USDA's Economic Research Service has published analysis (**Figure 3**) showing that the growth in global agriculture is overwhelmingly due to increases in productivity due to technological change and allocative efficiency and not the use of additional inputs or resources (Fuglie, 2010).

Figure 4: Comparison of Changes in Agricultural Land Area and Total Factor Productivity (TFP) Changes 1981-2001.



Source: http://www.earthinstitute.columbia.edu/cgsd/events/documents/evenson.pdf for TFP and FAOStats for changes in agricultural land area.

The results of **Figure 4** illustrate TFP estimates compared to crop specific yield estimates from 1981 to 2001 for several countries. Argentina and Brazil are interesting to compare based on their geographic location and large expansion into agricultural markets such as soybeans. While Brazil has a slightly higher TFP change (3.22% compared to 2.35%) its total agricultural land use area has increased by over 14% compared to only 0.75% for Argentina.

- **Assumption #3: Carbon Stock Assumptions and Resulting GHG Emissions**

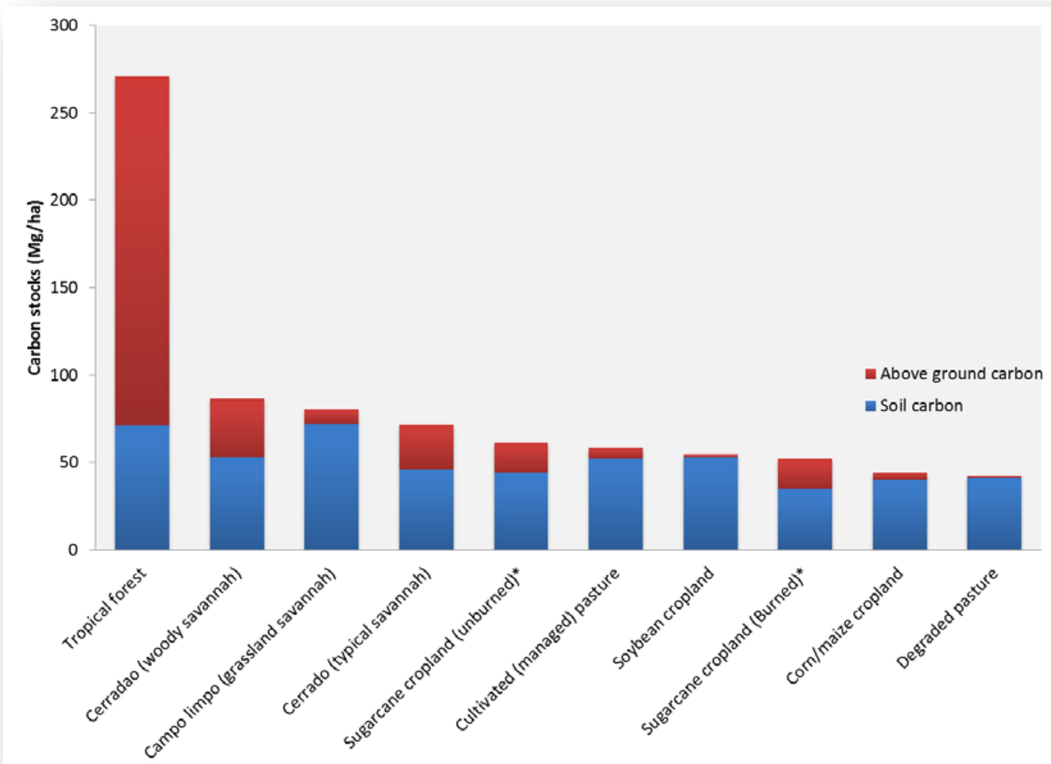
GHG emissions from land use changes are based primarily on the difference between the carbon stocks present on the land prior to land use conversion and the time-averaged carbon stocks of the land after the change has occurred. This differencing method estimates CO2 emissions associated with changes in biomass, but CO2 emissions also occur from soil when land is tilled and converted to

[20]Root Mean Square Error (RMSE) of 1.36% for palm compared with 0.66% for EU cereals (Bauen *et al* 2010).
[21]http://www.ers.usda.gov/AmberWaves/September10/PDF/GlobalAgriculture.pdf

annual cropland. Non-CO2 emissions (methane and nitrous oxide) are also produced when land is burned and/or converted to rice cultivation.

Carbon stocks vary considerably among different land cover types and different geographic regions. This is particularly true of land cover types that contain woody biomass such as forests, shrublands and savannas; trees can be short or tall, sparsely distributed across the landscape or packed into dense forest stands, and the relationship between tree diameter and carbon stock is exponential. All of these factors impact the magnitude of the carbon stocks present on a given area of land. **Figure 5** illustrates the substantial variation in carbon stock estimates for different land types in Brazil.

Figure 5: A Comparison of Published Average Carbon Stocks for Land Categories within Brazil.



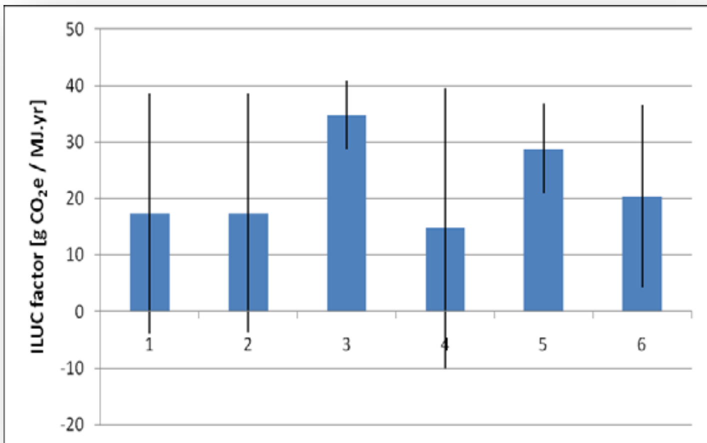
Notes: Experimental data obtained from more than 80 reports within 8 years to 2008 to yield comparable results for soil types, soil depth (0-20cm), methodology and cultural practices. Below-ground biomass is not specifically identified.
Source: Amaral (2008)

For most analyses, carbon stocks are based on IPCC Tier 1 estimates that vary by continent and ecological zone, but estimates can vary considerably. Comparisons between IPCC Tier 1 estimates and experimental data in Brazil are illustrated in Macedo (2008) and show that IPCC approaches can overestimate and underestimate actual carbon stocks.

The uncertainty associated with using high level data for estimating carbon stocks results in challenges for iLUC quantification.

Figure 6 represents possible magnitudes of iLUC associated with different scenarios for oilseed rape biodiesel demand. The uncertainty bars included in Figure represent only the uncertainty associated with carbon stock values. **The uncertainties associated with carbon stock are large – some bigger than the iLUC factor itself.** This is true of other analyses within the same report and not only associated with oilseed rape. There is a significant need for improved estimations of carbon stocks before any quantitative conclusions can be drawn on indirect land use change impacts (E4Tech, 2010).

Figure 6: Indirect Land Use Change Impacts ($gCO_2e/MJ_{biofuel}$ per year) for Six Different Scenarios Modeled for Oilseed Rape Biodiesel.



Notes: Error bars represent only uncertainties with carbon stock. Assumptions leading to high ILUC factors include a low utilization of rapeseed meal as animal fodder (scenario 3), a low displacement rate of soybean meal by rapeseed meal but a higher displacement rate of feed wheat (scenario 5) and a low production of oilseed rape in Europe with higher productions in Ukraine and Canada (scenario 6). Other assumptions lead to lower ILUC factors, such as for example good (i.e. effective) anti-deforestation policies in Malaysia and Indonesia (scenario 4) and high European oilseed rape production (scenario 1 and 2).
Source: E4Tech, 2010

Emissions from the oxidation of tropical peat caused by drainage for planting oil palms are not often included in current economic models for iLUC (Edwards *et al*, 2010). An estimate of emissions from peat oxidation at 19 tCO2/y-ha of oil palm is equivalent to a drainage depth of only around 20 cm. If included, all GHG results for biodiesel show significant extra emissions (Edwards et al, 2010). This is likely an optimistic scenario as most estimates put oil palm drainage in the region of 80-95 cm which leads to emissions of about 73 t CO2/ha/yr.

Most models have focused on GHG emissions from land use change in assessing the impacts of biofuels and not accounted for cultivation and management practices that can produce or reduce emissions. For example, increasing fertilizer application to deliver yield increases is may increase the magnitude of indirect GHG emissions but preliminary calculations show that, although not negligible, this effect is unlikely to be so large as to change the overall conclusions about the magnitude of the iLUC impacts (E4Tech, 2010). US research suggests that combining better management practices with biomass-fueled energy processes can substantially improve the emission profile compared to a reference case. Kim, Kim and Dale (2009) calculate that conversion of grassland to corn for biofuels in the US has an average payback time of 11 years and but that winter cover cropping and no-till could reduce this to 2 years[22].

[22]Forty counties from nine corn producing states (Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, Ohio, South Dakota, and Wisconsin) as sites for the analysis. DAYCENT – an agroecosystem model – was used to model the impacts on soil organic carbon along with carbon in above and below-ground biomass and nitrous oxide emissions from soil. These states represent a wide variety of soil, climate and crop production practices. The model predicts that the average grassland carbon density is 4.0 ± 1.1 Mg of carbon per hectare. This value is similar to the average carbon density of temperate grassland (4.3 ~ 4.7 Mg of carbon per hectare) (Kim, Kim

Drawing on substantial work in this area Bruce Dale concludes that "it is not possible to draw broad conclusions across a large geographic region about the effects of a particular land use change on the resulting greenhouse gas emissions. Very different greenhouse gas emissions are caused by differences in local soil types (organic matter content, sand, etc.), local climate (temperature, rainfall, etc.), and especially by different tillage and fertilization practices".[23]

5. POTENTIAL IMPROVEMENTS TO iLUC ASSESSMENT AND QUANTIFICATION

This paper has identified a number of challenges to assessment and quantification of iLUC. This section identifies potential improvements of that could be used to:

a. Improve modeling estimates for improved quantification of iLUC
b. Improve knowledge of the relative contribution of biofuels to iLUC amongst other drivers

a. Improving Modeling Estimates

The modeling of all cropland decisions in all local markets worldwide requires data that do not exist and quantifying underlying behavioral relationships not addressed by models. Even if they were, the statistical error in those estimates would be significant due to measurement error and data acquisition problems. This paper has identified some ways in which modeling efforts could be improved but acknowledges their inherent limitations.

i. Retrospective model runs to assess accuracy

Some models attempt to identify impacts on land use change and therefore GHG emissions in the future. The confidence levels in the types and magnitudes of land area changes resulting from the scenario approaches could be determined by a retrospective scenario run. The models would be set to determine the land use change impact of current or recent biofuel production levels from a past baseline level. The land use change impacts that the model predicts for, say, last year, could be tested against satellite imagery that is now available which would assess the extent to which the magnitude and type of actual land use changes have been reasonably predicted by the models (but this would not address the challenge of attributing that land use change solely to biofuels). The GTAP website says by definition the models can never be tested, this is likely because they are solutions for the future under specific assumptions about the future that will never be realized exactly as they were modeled.

ii. Improved land cover data for model parameterization

One major approach for more accurate representation of agricultural land in Computerized General Equilibrium models (such as GTAP) is to introduce additional heterogeneity in available land cover types, which would require improved data beyond the coarse-scale, global land cover maps that are currently used. Because iLUC is a global phenomenon, current analyses have been limited by the land cover products that are available at the global scale. These products have global coverage, but are coarse in spatial resolution and land cover categories are defined too broadly. For iLUC analyses, it is essential to be able to distinguish the "cropland" category into different crop types, identify shifting

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& Dale. The reference case assumes a dry milling process with corn stover as boiler fuel and that ethanol replaces gasoline in an E85 fuel system (Kim, Kim & Dale, 2009).

[23] http://biofuelsandclimate.wordpress.com/2008/03/17/indirect-land-use-thoughts/

cultivation systems that rotate between active and fallow periods, distinguish agricultural systems that alternate between crops (corn/soy) within rotation system from those that do not, and identify pasture systems that are managed for hay vs. managed for cattle for example.

Remote sensing imagery is available to do these types of analyses, but committed resources are necessary to produce consistent, annual land cover datasets at a resolution that is appropriate and with a classification system that is useful for answering the questions of interest. Current iLUC models have been necessarily limited by the data that are available. New sources of remote sensing data, such as imagery collected from lidar and radar sensors, have emerged in recent years that can be used to produce detailed land cover maps. For example, lidar data can be used to derive forest height, which would give an indication of forest condition (intact vs. degraded) when used in combination with other data. Radar sensors are able to penetrate clouds, which makes it useful to derive land cover in perpetually cloudy areas that are widespread across the tropics. However, as with optical satellite data (e.g., Landsat), processing all of these imagery types into land cover maps with global coverage is a huge undertaking that would require significant time and resources. Most recently, new efforts are underway by Google.org to use its cloud computing infrastructure to process vast amounts of Landsat imagery from the past 40 years. This processing will result in scientists' ability to produce land cover maps with customized classification schemes at a spatial scale of 30-m resolution. Google announced this "Earth Engine" initiative in December 2010 at Forest Day 4, associated with the climate negotiations in Cancun, Mexico.

iii. Include limitations of water availability

Addressing water availability is critical. Recent modeling improvements such as using the AEZ approach for climate suitability based on suitability for rainfed agriculture is a step forward but this does not account for existing water requirements and potential hydrological changes caused by land use changes.

iv. Update elasticities

Economic relationships are based on historical data and the validity is in doubt; many were estimated over a time frame of low commodity prices and we are now in a period of high commodity prices which is expected to continue for some time into the future. There have also been significant technological advances over the past that will also affect yield responses and producer behavior (e.g., GMOs). Elasticities should be updated based on more recent information.

v. Yields on new acreage

Observations on 'new' areas of production can be derived from remotely sensed data. Coupled with statistical information on yields, it should be possible to derive better estimates of yield on new area. It is unlikely that a single factor (as defined in models to date) is applicable for all regions.

b. Improve Knowledge of the Relative Contribution of Biofuels to iLUC (Causality)

Direct land use change can be monitored, including where the change occurred, what changes took place, and what the magnitudes of these changes were. Remote sensing tools, such as aerial photography and satellite imagery, can identify some types of land cover. When these tools are used in the same location over time, land cover changes can be assessed. However, indirect land use change is a global, market-driven phenomenon that is, by definition, not directly observable or measureable. Much of the work to date has focused on economic models to predict land use changes around the world as a result of biofuel policies. An early section of this paper discussed a number of other significant and non-economic drivers of land use change.

In order to understand how much land use change can be attributed to biofuels, it is important to identify the relative importance of different drivers. Some drivers could be linked to a biofuel impact with higher or lower degrees of confidence and others will not be related to biofuel expansion per se but, say, to agricultural policy and land concession locations. In order to do this a spatial model should be estimated at some manageable level to determine whether economic models accurately capture land use change. Modeling land use change spatially and then back-checking through a variety of methods will give more confidence to any extrapolation of the model to larger areas. Repeating the analysis in different locations will determine how widely applicable the set of determinants is to other geographic areas.

Actual land use change must be modeled against variables hypothesized to affect decisions to make such changes. Economic variables such as input and output prices are currently coupled with biophysical variables such as crop yields to determine profitability. Other economic variables must also be considered. They include proximity to developed land, proximity to transportation networks, distance to markets and transportation costs, local infrastructure, expectations of future profitability, and tax structures.

Additionally, there are non-economic variables to consider in land use decisions for which data are difficult to obtain. Farmer age, the existence of a succeeding generation willing to farm, capital reserves, neighboring land use, business support systems, cultural mores, legal restrictions, water rights and availability, and attitudes toward environmental stewardship all play a role in land use decisions.

6. POTENTIAL MITIGATION OPTIONS

Several approaches to identify iLUC mitigation measures have been developed at a project scale (Ecofys & Winrock International, 2010). This is based largely on the concept of risk i.e. if biofuels or feedstocks meet specific criteria they could be classified as low/medium/high risk of (causing) iLUC.

One approach to identifying and promoting biofuels that are 'low risk' with respect to iLUC is identified by Ecofys & Winrock International, (2010) – the concept that biofuel productivity is increased (above a business as usual scenario). This means the production of sufficient volumes of feedstock to meet biofuel demands without compromising existing demands. In this way it is thought that biofuels will not create pressures on land use and therefore will not transfer land use change pressures (and subsequent GHG emissions) elsewhere. Some relevant approaches are identified in **Table 2** are presented along with their limitations and challenges. The options in Table 2 are not intended as an exhaustive list[24].

Offsets, developed as GHG mitigation measures under the Kyoto Protocol, have not been the subject of discussions on mitigation option for iLUC. Offsets could, for example, enable a company to purchase high carbon stock land (such as forests or wetlands) intended for agricultural use, conserve these lands and claim the avoided GHG emissions. While global GHGs can be offset, there are risks associated with locally important biodiversity and establishing whether biodiversity in one area can be

[24] A wider selection of opportunities across the whole supply chain are identified in http://cmsdata.iucn.org/downloads/shell_iucn_iluc_workshop_report___sept_2010.pdf

'swapped' and compensated by another. This area requires further discussion among stakeholders to ascertain its feasibility and acceptability as a mitigation option.

Table 7: Opportunities, limitations and practical challenges associated with a limited number of iLUC mitigation options.

Current Opportunities	Limitations to Addressing iLUC	Practical Challenges
Use underutilized land, sometimes referred to as degraded, abandoned, or marginal land.[1]	Increasing productivity requires increased water. Within one watershed changes in hydrology could deliver water availability problems for other users and trigger land use change elsewhere as a result. On social side, the "unused" or marginal land could be in use for example as land for foraging and firewood. Displacing this activity elsewhere is an iLUC impact.	Developing universally applicable definitions and criteria for 'underutilized' land. Defining appropriate baselines and business as usual projections to determine productivity increases.
Improve productivity of biofuel feedstocks on lands where they are currently grown to increase yields through improved fertilization and irrigation techniques, crop rotations, double-cropping, etc.[1]		Defining appropriate baselines and business as usual projections to determine productivity increases
Improve productivity through crop-livestock and other integrated bioenergy systems, such as integrating sugarcane or soy with cattle and biofuel crops with other crops. Biofuel crops are essentially "new" in such a system and do not reduce productivity of the existing crop.[1]	As above.	As above for determining baselines. Determining procedures for allocating increased productivity to non-biofuel outputs (cattle and soymeal) and biofuel outputs (soy oil).
Use wastes and residues as a feedstock.	Largely expected not to encounter limitations but in some cases could have negative impacts if the waste has existing uses.[2]	
Increased efficiency through reducing supply chain losses.	Largely expected not to encounter limitations.	Complex supply chains create tracking and measurement problems.
Increased efficiency through integrated processing systems such as co-location of ethanol production and cattle lots.	Largely expected not to encounter limitations.	Defining appropriate baselines and business as usual projections to determine efficiency increases.
Carbon offsets.	Biodiversity in one area less likely to be 'swapped' and compensated by another.	Stakeholder buy-in to offset concepts.

[1] Ecofys & Winrock International, 2010
[2] http://www.renewablefuelsagency.gov.uk/reportsandpublications/indirecteffectsofwastes

The operation of such approaches as credible verification and monitoring programs has not been considered in detail and is a considerable gap in moving towards an action-based solution for iLUC. The following section addresses these and other issues in moving towards a framework for addressing iLUC.

7. TOWARDS A MONITORING AND VERIFICATION FRAMEWORK

<u>The goal of a monitoring and verification framework is to assure the development of sustainable biofuels by strengthening approaches to iLUC assessment, mitigation and monitoring</u>.

This paper concludes that the potential for iLUC from biofuels does exist but that more detailed context, missing from modeling approaches, is critical in understanding the potential risks and magnitude of iLUC.

It appears that modeling approaches are not the most appropriate basis for establishing risks associated with iLUC from biofuels. A more credible approach is to assess the local/regional context in order to develop effective mitigation. The local/ regional context better defines:

- The risk that biofuel production in the region will transmit land use pressures (driving iLUC).
- The risk that GHG emissions resulting from receiving LUC pressures (locally or internationally) will be high.

A framework for addressing iLUC should:

a. Enable the relative risks of iLUC to be assessed
b. Provide guidance on appropriate mitigation options
c. Provide guidance on robust and credible monitoring and verification approaches

Figure 7 provides an illustration of a monitoring and verification framework. The framework should be based on a number of principles that provide confidence in it as a robust and appropriate approach:

- Transparency. *All assumptions, data and references should be disclosed.*
- Credibility. *The system should not be able to be 'gamed'.*
- Accuracy. *Uncertainties and bias should be reduced as far as practical*.
- Cost-effectiveness.

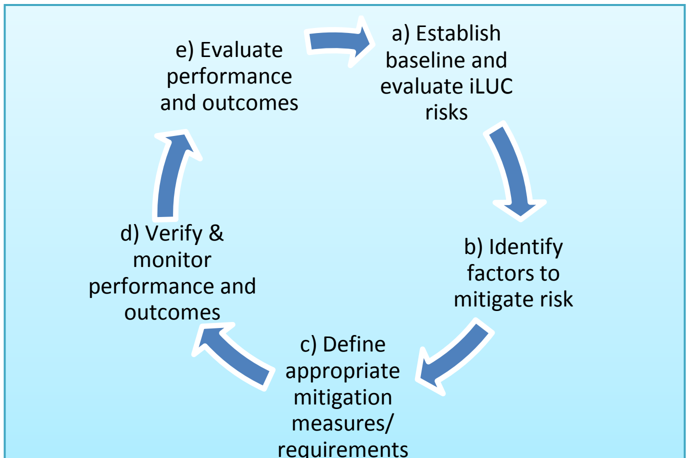


Figure 2: A Framework for Addressing iLUC.

This section does not define specific details of a framework but the following sections identify key issues and further work required to support the development of credible verification approaches, regardless of the ultimate application. Winrock International is exploring aspects of the development of such a framework and will develop a draft framework.

The scope and application of such a framework could be influenced by policy decisions. For example, the EPA and CARB have included iLUC factors (penalties) within GHG calculations for biofuels. The European Commission is exploring the use of an iLUC factor. In such cases a framework would likely be seen as an opportunity to provide the process through which further detail and ‘proof’ could reduce or remove the iLUC penalty.

a. Enable Relative Risks of iLUC to be Assessed

This paper concludes that the following parameters should be considered as critical drivers of iLUC and associated GHG emissions and should therefore form part of any framework for iLUC mitigation and monitoring:

- Land use planning
- Governance
- Productivity
- Trade
- Natural resources - water
    - Current discussions on mitigation options miss other issues that may influence iLUC e.g. productivity increases such as yield increase require increased water consumption which reduces water availability and influences the type and location of LUC.
- Demographics

Table 3 is based on an approach for classifying risk suggested by Ecometrica (forthcoming). It illustrates a potential approach to identifying areas in which biofuel production may be classed as ‘low risk’ using the critical factors identified above and identifies practical challenges.

- Low risks of transferring land use pressures (causing iLUC)
- Low risks of negative impacts on carbon stocks
    - There is a difference between high risk of land use change and high risk of GHG emissions; land that is converted may not be a high contributor to GHGs.

Further work is required in the following areas.

- **The criteria and thresholds for defining risk categories need to be further developed in order to move towards operationalizing an iLUC framework.**
- **Thresholds and requirements for moving between risk categories also need to be explored and evaluated.**

Table 8: Potential factors for developing a low iLUC risk category at national and sub-national scales. Note: This approach draws on historical trends, existing situations and potential or planned activities to develop a risk-based approach. It does not attempt to define causality / attribution of iLUC to biofuels alone.

Factor (See notes below)	Potential Indicators/ Approach	Rationale
Land use planning:		
Agricultural development areas not located in areas of high C stock **Potentially suitable land not located in areas of high C stock**	Use GIS to overlay carbon stock maps[1] and agricultural development areas (**see Box 2**)	High emissions from iLUC are associated with agricultural expansion in general on high carbon stock land
Governance:		
Good environmental protection and enforcement of	Qualitative assessments based on institutional capacity and outcomes of	Good governance is key to ensure legislation is enforced. Historical

Factor (See notes below)	Potential Indicators/ Approach	Rationale
- High C stock areas[2] **- Protected areas** **- Water rights** **- Land tenure**	legal disputes for example Use GIS to overlay historical land cover maps, protected areas and agricultural development areas to determine extent to which protected areas have been protected	evidence can be gained from remotely sensed data and statistical information
Natural resources:		
High available water supply	Undertake watershed scale assessment. Risk assessment could be based on an indicator of water stress that accounts for environmental flows (see notes below)	Watershed scale assessment is essential for understanding sustainability of water use. Water is a key driver of land use decisions
Cropland area not substantially increasing	Use remote sensing data (or national statistical data) to determine acres/hectares of total cropland area	Coupled with information on productivity can indicate efficiency gains to deliver outputs rather than land expansion
Productivity:		
Total productivity is increasing	Total factor productivity (**See Annex 1**) or total agricultural outputs (tonnes/year)	Indicators such as crop yields are only partial measures of productivity. Falling yields for certain crops may miss the wider picture of resource shifting or saving in certain sectors to improve total productivity in others
Co-products from feedstock or biofuel production substitute land based products	Cause-effect (consequential) approaches that determine impacts of co-products have illustrated ranges of 'credits' associated with avoided LUC[3]	Producing additional co-products from bioenergy production could reduce land planted in crops displaced by co-products
Trade:		
Agricultural export levels maintained and/or **Import levels of agricultural products maintained or reduced**	Rolling (5-year for example) average of key agricultural exports	Maintaining exports in regions on increasing bioenergy levels suggests a supply 'gap' has not been created that has generated iLUC. This does not account for stocks and surpluses and their influence on iLUC
Demographics		
Population is stable or decreasing	Population trend from national census data	Increasing populations put pressure on resources that may lead to resource scarcity for biofuel production

[1]Note that the level of uncertainty associated with carbon stock maps depends on the approach to mapping. For an overview of approaches see Gibbs *et al,* 2007.
[2]There is a difference between high risk of land use change and high risk of GHG emissions; land that is converted first may not be the highest contributor to GHGs. A process for assessing the relative risk of GHG impacts of LUC is set out in **Table 5.**
[3]See E4Tech (2010) and Nassar *et al* (2010).

Notes on factors identified in Table 3

- *Land use planning*
  In areas where areas of agricultural development are zoned this approach may be relatively straightforward. In other areas, spatial analysis of land use suitability combined with other factors such as distance to roads,

other farmland etc would be required to develop a ‘threat map’ that could be used to assess the likelihood that future agricultural development would take place on high carbon stock land.

- *Governance*
  Good governance is key to ensure legislation is enforced. The extent to which protected areas, carbon stocks and other criteria have been protected can be monitored through appropriate scales of remote sensing imagery. Freely available imagery from LANDSAT is available at 30m resolution but is likely to require interpretation and processing. Smaller areas will require finer resolution sensors such as IKONOS and Quickbird (See Winrock, forthcoming). Qualitative information on levels of enforcement can be gained from interviews and surveys with key stakeholder groups in regions. Section 5 of this paper noted that new efforts are underway by Google.org to use its cloud computing infrastructure to process vast amounts of Landsat imagery from the past 40 years. This processing will result in scientists’ ability to produce land cover maps with customized classification schemes at a spatial scale of 30-m resolution within very short periods of time.

- *Natural resources*
  Indicators of water scarcity such as Water Resources per Capita or Water Stress Index are beneficial because they can provide clearly defined thresholds for water stress and water scarcity. Some account for important issues such as the non-linearity of stress effects but have significant limitations as they do not account for volumes of water required to maintain ecosystem health. The International Water Management Institute (IWMI) has developed a water stress indicator which incorporates environmental water requirements (GWSP Digital Water Atlas, 2008) and shows where the proportion of the utilizable water in world river basins currently withdrawn for direct human use is in conflict with environmental water requirements but does not account for the non-linearity of stress effects. An indicator that addresses the important components of each and could classify risks would be beneficial.

- *Cropland area is not substantially increased*
  Agricultural land area will not remain static and so defining an ‘acceptable’ level of change that defines a low risk for iLUC impacts will be challenging. Furthermore, datasets related to monitoring cropland appear limited. Some cropland may be classed as grassland because it is ‘idled’ cropland or part of a rotation system that includes longer fallow periods. This capacity may be a substantial buffer as crops expand and would not necessarily indicate land use pressure transfer. The identification of short-term idled cropland would be relevant to monitoring efforts (see Winrock, forthcoming) and could indicate lower levels of carbon stock changes than if native or long-term idle/fallow land was cultivated.

  Determining the extent to which productivity increases alone have met biofuel demand would depend on the boundaries of the analysis and the extent to which volumes of feedstocks used for biofuels can actually be identified. On the demand side, defining biofuel demand could take place at different scales (regional, national or international) and would influence the extent to which productivity increases are judged to have met biofuel demand.

- *Productivity*
  Indicators such as crop yields are only partial measures of productivity. Falling yields for certain crops may miss the wider picture of resource shifting or saving in certain sectors to improve total productivity in others. The indicator could be Total Factor Productivity (**see Annex 1**) but is potentially difficult to measure and not reported in a regular timeframe, if at all. Total agricultural output as an indicator would be an alternative. It can be determined using FAO statistics and valued as the annual production of 185 crop and livestock commodities since 1961 at a fixed set of average global prices expressed in constant 2000 U.S. dollars. Using a consistent set of prices to value production regardless of where the production occurs ensures that increased output in one location has the same effect on global production as an increase in another location (Fuglie, 2010). Reliance on FAO statistics is however not ideal (see section (d) below on availability and accuracy of data). There is a need for exploration of better tools that more directly measure production levels of key commodities.

Co-products from feedstock or biofuel production may substitute land based products and could be associated with 'avoiding' land use change or with reversion of current cropland producing crops being displaced by co-products. DDGS from ethanol production associated with corn and wheat can replace soymeal and, in theory, reduce its demand and reduce rates of expansion. However, the reduced soymeal in some cases could lead to 'lost' soyoil which could be made up by palm oil which may increase in area (E4Tech, 2010). Identifying trade and substitution patterns would be required to assess the extent to which credits for avoided land use change were warranted and their magnitude.

- *Trade*
  iLUC theory suggests that if export levels are reduced there is a potential that the 'gap' in supply has to be filled elsewhere and causes LUC. This is too simplistic an approach. The local market context and role of stocks and surpluses plays a role in determining whether supply gaps need to be filled by land conversion. The Philippine biofuel program was based on the fact that 10 percent of sugar was surplus to domestic requirements and therefore 'world market' sugar. The price for this surplus sugar was lower than domestic prices; an ethanol alternative provided higher prices and drivers for investment to deliver substantial yield improvements. In this case, exports of sugar would be reduced but sugarcane yields increased. The extent to which the net effect was a low or high risk to iLUC is uncertain. Determining what is an 'acceptable' level of change in trade that represents low iLUC risk is a challenge that will require further study.

- *Demographics*
  Increasing populations put pressure on resources through water consumption, land for food, land for development/urbanization. A trendline is more likely to be appropriate rather than a specific quantitative indicator and thresholds to define low, medium and high risks of pressure on resources would have to be defined.

b. Explore Options for Identifying Mitigation Factors

The extent to which the levels of risk identified at a regional level could be used to identify quantitative or qualitative mitigation factors and the extent to which these are likely to be effective requires further study. The use for the framework would determine how the factors are used, for example, the mitigation factors could be the basis of developing eligibility requirements and/or performance requirements for an assurance scheme. Qualitative mitigation factors would be based on identifying practices to move from high risk to medium or low risk categories. Quantitative factors would define metrics intended to represent effective mitigation against a specific risk. **Table 4** provides an illustration of mitigation factors based on specific risks.

Table 9: Illustration of how mitigation factors may be set against specific risks.

	Agricultural Development Taking Place On High Carbon Stock Land	Water Scarcity
High	Avoiding X tonnes of CO_2eq emissions over Y years[1]	Using no more than Y m^3 of water per hectare through water scarce months of A and B[2]
Low	As above (with lower figure)	Demonstrating best practice and commitment to continuous improvement
Data / approach for establishing risk	*Historic 10 year data on land cover and change. Combine with statistical info to determine land use. Assess changes using remote sensing imagery to estimate carbon stocks and changes*[3]	*Water scarcity metrics are available (e.g. Pfister, Smahktin - IWMI) and should be adjusted for temporal variations in flow as well as environmental flow requirements where these are not considered*

	Agricultural Development Taking Place On High Carbon Stock Land	Water Scarcity
Data / approach for monitoring compliance	*Procedures for establishing credits for CO_2eq emission avoidance are required*	*A remote sensing algorithm has been developed that measures consumptive water use with high confidence levels*[4]

[1]The factor could be used to establish requirements on a regional basis e.g. through quantification of CO_2eq emissions from land use change to cropland. Credits for avoided emissions could be generated through offsets, yield increases, use of nitrogen inhibitors.

[2]At a regional level investment in water storage to ensure sufficient aquifer recharge could be a mitigation factor so long as there are no negative impacts within the rest of the watershed of such action.

[3]All historical trends are not equal. Time, location and duration of "trends" matter.

[4]SEBAL - http://www.waterwatch.nl/fileadmin/bestanden/Publications/Poster_SEBAL_Tool_project0075.pdf

The feasibility of establishing quantitative mitigation requirements should be explored further and should include:

i) The availability of readily available and cost effective measurement and monitoring approaches.
ii) The effectiveness of establishing quantitative performance measures in addressing iLUC versus qualitative (moving from high risk to low risk).
iii) The allocation of requirements e.g. applying requirements to all biofuel suppliers/producers; on those who source any feedstock from the region of risk; according to the proportions of feedstock sourced from regions of risk.

c. Provide Guidance on Appropriate Mitigation Options

A start has been made on identifying iLUC mitigation measures and indicators of risk (Ecofys & Winrock International, 2009; Ecometrica, forthcoming, E4Tech, 2010). However, local context has not yet been addressed and proposing general iLUC mitigation options such as increasing yields or cultivating degraded areas (**see Section 6**) may not be appropriate or free of further risk e.g. in water constrained areas. **Appropriate mitigation options can only be formulated once the risks within a region have been identified**.

Appropriate and effective mitigation options could be undertaken at a site scale for an individual operator or within a broader scale such as a landscape or region. **Table 5** illustrates potential mitigation options for an operator that sources or produces biofuels within a region characterized by specified risks.

A process for defining appropriate mitigation options and associated procedures for verification of compliance is required. A well-defined process will be more effective in addressing iLUC than prescribing general actions that do not benefit from relevant geographic context.

Table 10: An example of potential mitigation options for operators associated with risks if iLUC impacts at a regional level and the requirements to facilitate the verification and monitoring of compliance. Mitigation options could also be delivered at a regional level, e.g., by administrative bodies within the region.

Regional Risk	Potential Mitigation Options for Operators	Requirements to Operationalize
The region is developing high carbon stock areas for agricultural purposes in general	• Purchase high carbon stock land and use as offsets • Select 'degraded' areas to deliver maximum carbon stock increase • Utilize residues as feedstock	• Procedure for establishing offset equivalents • Process for selecting suitable lands[1] • Guidance on sustainable residue removals[2]
Relatively high water scarcity within the watershed	• Demonstrate water use is within acceptable limits • Demonstrate water use from recycled sources • Invest in water storage or aquifer recharge systems • Improve water utilization efficiency of other water users • Investment in multiple use water systems • Specific actions within river basin management committees/groups	• Define procedures for establishing water availability
Cropland area is increasing	• Demonstrate crop yield increases • Demonstrate co-products are substituting land-based alternatives • Demonstrate cropland area increases do not compromise carbon stocks	• Procedures for using yield data with data on stock levels and exports to measure contributions of crop yield increases to avoided LUC (**see Trade notes, page 26**) • Procedures to define and quantify credits for co-products
Total factor productivity is static or decreasing. ***The region is using inputs less efficiently***	• Demonstrate yield increases • Demonstrate optimal levels of fertilizer application • Demonstrate reductions in losses through supply chain	• Procedures for using yield data with data on stock levels and exports to measure contributions of crop yield increases to avoided LUC (**see Trade notes, page 26**)

[1]See Responsible Cultivation Areas; Ecofys, WWF and Conservation International (2011).
[2]'Sustainable harvests' for forestry residues over 20 or 40 or 60 year cycles can still use more biomass than is regrown and can have greatly elevated greenhouse gas emissions relative to business as usual. Therefore, monitoring harvest relative to annual sequestration would be critical to ensure GHG accounting credibility.

d. Evaluate the Availability of Accurate and Relevant Data

Obtaining accurate, relevant, and standardized data is key to making fair and reasonable assumptions about iLUC risks and performance. A good example of a potential trade-off between data availability and accuracy is the use of FAO statistics to determine land use or determine Total Factor Productivity (see Notes on **Table 3**). The FAO Statistical Database is a repository for more than a million time-series records from over 210 countries and territories. The dataset is often used because it is available for many relevant parameters for every country in the world. Little or no quantitative accuracy information is available for FAO statistics. Data quality is notoriously variable across countries, and many countries report the same data as for past years, or apply projections and forecasts to data collected previously (up to several decades in the case of forestry statistics). Grainger (2008) highlighted various problems with tracking the long-term changes in tropical forest area using FAO statistics; his assessment revealed that constructing a reliable trend in forest area using these data is difficult, and evidence for forest decline over time is unclear when considering the limits of errors involved in making global estimates.

Identification of relevant data, along with an assessment of strengths and limitations, would be necessary in the development of a framework.

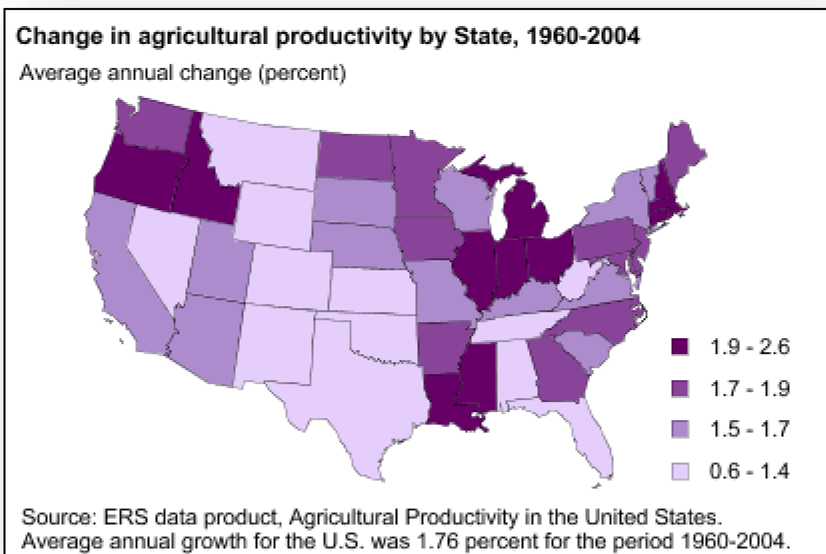
This paper has outlined some of the further efforts that are required to develop the details associated with an operational framework for iLUC. An effective monitoring and verification framework will provide a stronger assessment of iLUC risks and a process through which these can be mitigated (if possible and necessary) and monitored. The development and operation of a framework requires cross-disciplinary working in order to draw on the best available data and techniques and to point the direction toward future developments and potential for improvements in measurement and monitoring.

ANNEX 1 – TOTAL FACTOR PRODUCTIVITY

Total Factor Productivity

Productivity is a key component of iLUC discussions and measurements are required in any monitoring approach. Indicators such as crop yields are only partial measures of productivity. Falling yields for certain crops may miss the wider picture of resource shifting or saving in certain sectors to improve total productivity in others. Total Factor Productivity (TFP) is a concept introduced to address the limitations of partial measures and measures the extent to which productivity increases are occurring more comprehensively than looking at crop yields alone. It measures efficiency in overall input and captures the impact of adoption new technology or farming practices. TFP growth is measured as the difference between the growth rate of overall agricultural output and input quantities. For example, if output grows by 2% per year while input use increases by only 1.5% per year, then TFP grows by the difference, or 0.5% per year (Fuglie, 2010). A model has been developed by the USDA ERS model to provide a measure of the growth in agricultural TFP over time for each country, global region, and the world. Data is drawn from FAO and illustrates the data and approach used. Other studies have used such an approach to assess TFP at country levels (Avila & Evenson, 2010).

Figure B: USDA ERS calculations of the average annual change in US Agriculture Total Factor Productivity, 1960-2005 (%).



Source: http://www.ers.usda.gov/Data/AgProductivity/

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