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Accounting for indirect land-use changes in GHG balances of biofuels

Review of current approaches

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1. Introduction

Increased demand for biofuels is expected to produce changes in the present land-use configuration. Furthermore there is a growing concern about the effect of land-use change on biodiversity, food supply, soil and water quality.

Biofuels production on current land and use of biomass in a given region can induce displacement of activities and land-use changes elsewhere. This effect is known as indirect land-use change (ILUC). Due to changes in the carbon stock of the soil and the biomass, indirect land-use change has consequences in the GHG balance of a biofuel.

A review of reference Life cycle assessments (LCA) of biofuels production (Gnansounou *et al.*, 2008) has shown that indirect land-use change has not been assessed till now and its effect on GHG emissions has not been included until present in this type of evaluation. The reason is that the degree of inaccuracy is still too high.

Due to the potential significance of ILUC emissions on the GHG balance of a biofuel pathway, different authors have stated the need for further research works (Cramer Commission 2007a, Cramer Commission 2007b, E4Tech 2006, Delucchi 2004, Turner *et al.* 2007, Reinhardt *et al.* 2007, Farrel and O'Hare 2008, Kloverpris *et al.* 2008, Hellman and Verburg, 2008, Searchinger *et al.* 2008). The USA and EU governments have also expressed the need for studying this effect. (EC 2007).

Current research is centered on four main questions:

How to quantify indirect land-use?

How to calculate GHG emissions from ILUC?

How to include them in a LCA?

How to account for them in Carbon reporting initiatives?

The present report reviews the current effort made worldwide to address this issue. A description of land-use concepts is first provided (Section 2) followed by a classification of ILUC sources (Section 3). Then, a discussion on the implications of including ILUC

emissions in the GHG balance of biofuel pathways (Section 4) and a review of methodologies being developed to quantify indirect land-use change (Section 5) are presented. Section 6 addresses the question of methodological choices in LCA to account for ILUC. The approaches to account for this effect in carbon reporting initiatives are discussed in Section 7. Finally, recommendations and further research work are described.

2. Land-use concepts

Direct land-use change

Land-use is defined as the type of activity being carried out on a unit of land. In the IPCC guidelines for Land-use, Land-use Change and Forestry (*GPG-LULUCF*) this term is used for the broad land-use categories. These land categories are a mixture of land cover (the type of vegetation covering the earth's surface) and land-use classes (IPCC, 2003a). Six top-level land categories for greenhouse gas (GHG) inventory reporting are specified. They include forest land, cropland, grassland, wetlands, settlements and other land.

Direct land-use change occurs when feedstock for biofuels purposes (e.g. soybean for biodiesel) displace a prior land-use (e.g. forest), thereby generating possible changes in the carbon stock of that land. This effect is well studied and default values of GHG emission factors are available. Nevertheless, GHG emissions from direct land-use change have just been included in LCAs of biofuels recently.

Indirect land-use change

Indirect land-use change occurs when pressure on agriculture due to the displacement of previous activity or use of the biomass induces land-use changes on other lands. The environmental effects of indirect land-use change are known as leakage i.e. the result of an action occurring in a system that induces effects, indirectly, outside the system boundaries but that can be attributed to the action occurring in the system. The displacement of current land-use to produce biofuels can generate more intense land-use elsewhere (Turner *et al.*, 2007).

In order to meet a given demand of biofuel a certain amount of feedstock is needed. These feedstock quantities can be obtained by: a) biomass use substitution, b) crop area expansion, c) yield increment in the same land, and d) shortening the rotation length. Apart from option c) all the other strategies may result in indirect land-use effects.

In the first case, this may result in indirect effects due to the decreasing of feedstock quantities for other purposes. This fact may have consequences on land-use dynamics in other producing countries of the impacted commodities. Option b) may result in direct land-use changes due to the replacement of existing activities in other land, and option d) will result in reducing the production of the alternative crops and consequently may imply a relocation of the associated activities. The magnitude of this impact will depend on how the displaced activities/uses are relocated.

Increased crop prices will create incentives for more land use in crop exporting nations (e.g. USA, China, India, Brazil, Argentina) and importing nations (e.g. China, Egypt, Japan, Germany, Spain, Mexico, Brazil). Consequently, the use of feedstock for biofuels production can generate the conversion of uncultivated land (e.g. set-aside, fallow, forests), the shift of previous uses of the biomass (e.g. material, animal feed, food) and the shift of previous activity in a territory (e.g. cattle, forestry, food crops). These displaced activities and uses of the biomass will increase the pressure on land in the countries where there is a shortfall of agricultural land. While in the EU energy crops are expected to be produced in idle land, in developing countries the biofuel feedstock supply is expected to be achieved by expanding crop area.

Moreover, biofuels production will also increase the supply of co-products e.g. straw from wheat for ethanol production, soybean/rape meal from soybean/rape oil production for biodiesel, Distiller's Dried Grains with Solubles (DDGS) from bioethanol production, sugarcane bagasse from sugar cane for bioethanol production. Using co-products for energy production can increase agricultural pressure for animal feedstock production. An increased availability of soybean meal can induce corn producers for animal feedstock to shift to other production activities. Even though the land-use change is generated by the co-product it can be considered as an indirect effect of the biofuel pathway.

3. Classification of ILUC sources

ILUC can be typified by its geographical and temporal scope. This classification is based on concepts given by Turner *et al.* (2007). However, we have fixed the system boundaries at the country level.

Spatial ILUC: Displacement of prior production to other location



Spatial ILUC occurs when the production of crops for biofuels in a land pushes the previous activity to other location. The use of the new location to place the previous activity generates a land-use change attributable to the implantation of the biofuel crop on that land. (i.e. replacing pastureland for energy crops may induce deforestation elsewhere to place pastureland). The black box depicts the energy crop.

Temporal ILUC: Shifting land-use in the same location



Temporal ILUC is defined as the land cleared for another purpose but that is later used for biofuels' crop production (i.e. land deforested for pastureland can be later used for energy crops).

If a forest land is deforested for pasture-land and then this surface is used for other purpose it is not rational to assign all the impact to the first land-use. The impact should be distributed over a certain time horizon and allocated between the subsequent land-uses. The impact of rendering available a certain land for agricultural purposes should not be attributed only to the

first crop planted in that land as the subsequent crops also benefit from that land-use substitution.

Use ILUC: Shifting biomass use in the same location



Use ILUC occurs when the land-use in a location remains the same but the production is used for another purpose pushing the production for the previous purpose to other land.

The introduction of a new demand for the same feedstock has caused the expansion of plantations. This expansion is considered as an indirect effect of shifting the biomass use.

Direct land-use changes from crops expansion for biofuels production can be overlapped with indirect land-use changes from shifting biomass use. Using present sugarcane plantations to produce ethanol may shift sugarcane plantations for sugar to other land. However, if the biomass use remains the same (indirect land use is avoided), new plantations will be used to produce ethanol. Consequently, avoiding changes in biomass-use will result in direct land-use changes for sugarcane production.

Displaced activity/use ILUC: Avoiding national land-use change by shifting previous activity to other country



Displaced activity ILUC refers to direct land-use changes occurring in another country due to the shifting of the displaced activity.

The displaced activity can be substituted by imports from other producing country. i.e. meat import from Argentina due to reduction in Brazilian cattle production. An increase demand for meat in Argentina may generate land-use changes in that country (e.g. set-aside to pasture-

land for cattle). This direct land-use change in other country can be attributed to the Brazilian biofuel production as an indirect land use change induced by this biofuel pathway.

The same applies when the biomass use is substituted. Changing corn cultivation from animal feed to ethanol production and using soybean for food production may induce production increments in other soybean and corn producing countries. Direct land-use changes due to corn and soybean expansion area and their effects can be linked to the displaced use of the biomass in the studied country.

The situation where crops rotation in a land is substituted by a monoculture also applies here (i.e. shifting corn-soybean rotation to only corn may displace soybean production to other soybean producing places).

4. Impact of ILUC on GHG balance of biofuels

Preliminary studies

Land-use changes (LUC) may have consequences in the GHG emission balance as it may generate carbon balance variations in soils and in the biomass produced on that land. However, these changes do not imply necessarily a negative effect. Conversion of forest, wetlands, and grasslands to cropland usually results in a net emission of carbon from biomass and soils to the atmosphere. However, cropland established on previously sparsely vegetated, highly disturbed lands and some grasslands can result in a net gain in both biomass and soil carbon. Moving from a long-term (20 years) cultivated system to a shifting cultivation can reduce the loss of carbon. Shifting cultivation means that the land is set-aside for a certain period, allowing the soil to partially recover from intense agricultural use. However, changes in the carbon stock can also take place even if the land-use does not change. That is the case of cropland remaining cropland, where the activity is the same but the land cover has changed (IPCC, 2003c). Good management practices in a field, such as reduced tillage, leaving crop residues at place and increasing external input of organic matter, contributes to carbon stock improvement.

Agronomic research is being conducted in this sense to propose mixed production systems that allow to stock carbon in soil and to reduce indirect land use effects. For example, Cerri and Cerri (2007) proposed to replace degraded pastures in Brazil by co-producing sugarcane and improved pastures on the same land. This allows avoiding the displacement of pastureland into forest, increasing land productivity. They compare both scenarios to determine the GHG emissions from soil carbon stock change using the GEFSOC (Global Environment Facility Soil Organic Carbon) model (Easter *et al.*, 2007).

GHG emissions from indirect land-use change are claimed to be even more important than emissions from direct land-use change. Despite the high inaccuracy, some authors have produced a range of values to show the magnitude of this effect.

Farrel and O'Hare (2008) have made rough estimations of ILUC GHG emissions driven by biofuels demand in the USA, concluding that if temperate grasslands and tropical forests are converted to croplands, the GHG emissions of most biofuels pathways are higher than those of the fossil reference e.g. shifting corn-soybean to produce only corn for ethanol may induce soybean expansion into forest in other soybean producing regions. This would result in GHG emissions 6 times higher than those of gasoline.

Searchinger *et al.* (2008) have studied the impact of including direct and indirect land-use GHG emissions in the LCA of corn-based ethanol in the USA. They have constructed scenarios to estimate the effect of increasing US ethanol production to 56 billion liters by 2016¹. They conclude that 10.8 Mha will need to be converted to cropland elsewhere to substitute corn for other uses and to compensate the decrease of soybean production due to avoiding soybean-corn rotation. Part of the US corn is produced as animal feedstock and using it for ethanol production will induce corn production to feed animals elsewhere. Moreover, part of US corn is produced in rotation with soybean and so if a corn mono-cropping system is placed on that land, the soybean production will be shifted to other soybean producing countries. Consequently, USA corn production for ethanol will generate GHG emission for a period of 167 years until emissions from land-use change can be balanced with the benefit from substituting fossil fuel..

EU governments recommend using idle land for biofuels production in order to avoid indirect effects. Management strategies such as that proposed in Cerri *et al.* (2007) can avoid indirect

¹ Ethanol production in USA was 16.2 billion liters in 2005 (Worldwatch Institute, 2006)

GHG emissions and even turn the balance more favorably. At present however, no studies are available concerning this issue.

Indirect land-use changes shifted to other countries

Determining direct land-use changes in other countries due to biofuel production in a given country is not straightforward and is recommended to be analyzed and expressed as avoided land-use changes in the producing country. For example, determining how the Proalcool program has induced deforestation for sugarcane plantations in India for sugar production, or how reduction in Brazilian cattle production by soybean plantations have caused pasture-land expansion in Argentina due to increased Brazilian cattle products import, seems not possible at the present stage of knowledge. First, because no model exists to determine which land-uses in other countries have changes due to the relocation of displacements and, secondly, because it is still doubtful whether we should penalize biofuels production in a country with effects that are occurring elsewhere and as a consequence of political and economical decisions in those countries in order to profit from a market opportunity (e.g. expansion of soybean production in China due to reduced exports from Brazil as a consequence of using soybean to supply the domestic biodiesel demand).

Some global economic models, especially general equilibrium models, attempt to solve this problem by evaluating the impact of increased land demand for biofuels production in the global land distribution for agricultural purposes. However, as stated, at this stage it seems that even if these effects should be known and a causal relationship should be established, the consequences (GHG emissions) are particularly difficult to be accurately attributed to the expansion of biofuels production in a given country and consequently it would be delicate to include them in the GHG emission balance at a country level.

5. Quantifying ILUC due to biofuels production

Indirect land-use change is characterized as:

- Market driven

Relocation of displacements will depend on the demand for the displaced products and the availability to supply feedstock to achieve the given demand. These factors are dependent mainly on market prices of displaced commodities.

- Global effect

Displaced products will be relocated between producing countries of the same commodity worldwide.

- Spatial dependent

Spatial distribution of raw materials to produce displaced products will be determined by location factors. These factors are bio-physical characteristics within each producing country (and even agro-ecological zones) that do not depend on global markets. They account for meteorological conditions, soil characteristics, topography, landscape fragmentation, population density and distances to roads and markets.

- Time dependent (chronological sequence of land-uses, rotation period)

Land-use in a given location is a dynamic process. The land-use can change based on rotation period of the cropland or grassland and finally, over time, a chronological sequence of successive land-uses is obtained.

A global economic approach is needed to account for the market driven process and the global effects. Down-scaling these effects require space-time modeling to account for geographical and temporal dependence of land-use changes.

Current methodologies

General scientific consensus exists about using an economic approach to address indirect land-use changes. All the available studies at the moment use general/partial equilibrium models. The only confirmed hypothesis is that indirect land-use changes occur. However, at present, only rough estimations based on hypothetical cases are available. These estimations give a range of values that shows the magnitude of the effect, and focusing primarily on negative impacts (i.e. deforestation). No model have been developed or used to down-scale indirect effects lower than the national level and neither to predict the spatial relocation of displaced activities.

Quantification of ILUC is characterized at present by:

- Economic modeling of demand for land in a general/partial equilibrium approach
- Modeling of global ILUC by relocation of activities on a worldwide scale
- Worst case assumptions
- Subjective choice of land where to allocate displaced activities
- Restricted to cropland relocation
- Restricted to land-use due to biomass-use substitution and avoided crop rotation
- ILUC is modeled as decreased supply in producing country/increased production in other producing country of the same commodity
- Displaced land-use is not currently modeled

In Searchinger *et al.* (2008), the FAPRI international model² is used to allocate displaced corn production for other purposes and soybean displaced from rotation in the same land. However, because a partial equilibrium model of agricultural commodities is used, interaction with other economic sectors is not accounted for. The approach does not account for other ILUC sources. Converted land is assigned based on the proportion of lands that have been transformed into cropland in the past and no specific modeling of the spatial allocation of

² <http://www.fapri.iastate.edu/models/>

indirect effects was done. Cropland conversion in other countries due to US ethanol production is quantified and CO₂ emissions for each region are calculated and expressed per liter of ethanol. This data is used as input for the GREET³ model to calculate the GHG balance of US corn-based bioethanol.

The GTAP⁴ model was used by Kloverpris *et al.* (2008) to evaluate land-use changes due to crops consumption. Indirect-land use for a given crop is modeled as expansion and intensification processes, assuming crop displacement as an intermediate state to a new general equilibrium. They proposed some adjustments of the GTAP model to account for long-term scenarios, agricultural expansion (based on the introduction of supply curves), dynamic technological improvements, conversion of outputs in physical units, separate modeling of inputs to agricultural production and model down-scaling to country-specific results. Main focus is in modeling of the intensification process. An application of the approach to wheat consumption in Brazil, China, Denmark and USA is being developed (Kloverpris *et al.*, under preparation).

A first attempt to account for the spatial distribution of biofuel crops was developed by Hellmann and Verburg (submitted), linking the LEITAP⁵ (a modified version of GTAP), the IMPAGE⁶ and the Dyna-CLUE⁷ models. The CLUE (Land-use Change and its Effects) model is a georeferenced model for the analysis of LUC (Veldkamp and Fresco, 1996). The integrated model allows making a spatially explicit, multi-scale, quantitative description of land-use changes through the determination and quantification of location factors of land-uses based on the actual land-use structure. The approach allows to determine explicitly the location of crops expansion and consequently, the direct land-use effects of biofuels. The model was applied to biodiesel and bioethanol production in the European context. ILUC are assumed to occur, but no treatment of this issue is proposed. However, an extension of this methodology to account for displacements may be feasible.

Clean Development Mechanism (CDM) and Joint Implementation (JI) methodologies from the UNFCCC (United Nations Framework Convention on Climate Change) aims to consider indirect emissions (so called “leakage emissions”) in their project-specific methodological

³ <http://www.transportation.anl.gov/software/GREET/>

⁴ <https://www.gtap.agecon.purdue.edu/models/current.asp>

⁵ <https://www.gtap.agecon.purdue.edu/resources/download/3258.pdf>

⁶ <http://www.mnp.nl/en/themasites/image/index.html>

⁷ <http://www.cluemodel.nl/index.htm>

approach. However, no specific methodologies for biofuels production from crops or residues under CDM/JI mechanisms have been approved yet. Notwithstanding, some methodologies have been proposed⁸ for specific projects. GHG from indirect deforestation are considered in bioethanol production from sugar cane (UNFCCC, 2007a). A fixed radius area around the project site will be annually monitored in order to assess the impact of sugar cane plantation on the displacement of forest for crops or grassland. The conservative assumption is that an increase in sugar cane area due to the project activity will result in an equivalent area to be deforested for other purpose. Other methodologies include indirect deforestation based on the same approach (UNFCCC, 2007b & 2007c). In biodiesel production from non-edible oil, the problem is avoided claiming that the methodology is restricted to oil crops planted on severely degraded land, waste land, and marginal land (UNFCCC, 2007d). Even though these cases can be found in reality it seems less probable that this will be the general case.

Other partial and general equilibrium models have been developed to determine land-use changes due to biofuels (and even bioenergy) production, but they are limited to direct changes (Tokgoz et al., 2007, Ignaciuk et al., 2006a & 2006b). But, extension of these models may be feasible to account for ILUC.

6. System modeling of ILUC

Conventional LCA vs. System wide approach

Essential elements for determining the emission factor of ILUC include the system boundaries, the reference system used and the management of time. While time management is a common aspect with direct land-use change accounting, the definition of the system boundaries and the reference system are critical in the indirect land-use issue.

Different choices of the modeling approach will lead to different results, especially considering the land-use issue (Lesage *et al.*, 2006). The most appropriate and widely-applied methodology to determine the GHG balance of a biofuel pathway is the Life Cycle

⁸ Proposed methodologies in CDM are those baseline and monitoring methodologies currently under consideration by the CDM Executive Board.

Assessment (LCA). This tool evaluates the environmental impact of a product through the quantification of input and output flows of the production system based on average data and fixing the system boundaries to those flows physically connected to the product under study. However, indirect land-use issue occurs outside the input output flows considered in the so called “Attributional LCA”. This approach is static, and in consequence dynamic processes are not considered. Static modeling do not account for price variations, changes in demand or technological improvements.

Due to the nature of ILUC, a more sophisticated system approach should be applied to fully account for this effect. Several authors have applied the so called “Consequential LCA” (CLCA) to evaluate the changes produced in a system as a consequence of a decision. The CLCA is based on a system-wide approach where system boundaries are expanded to consider the impact on the affected activities, and is therefore appropriate to study ILUC.

At present CLCA was the adopted methodology to assess ILUC in biofuels production. It has been applied to study indirect land-use changes of corn production for ethanol in the USA (Feng *et al.*, 2008) and proposed by Kloverpris *et al.* (2008) to estimate ILUC due to crops consumption.

7. Accounting for ILUC in biofuels Carbon reporting initiatives

At present, carbon reporting initiatives do not account for indirect land-use.

The Dutch government has delayed the inclusion of this issue to the year 2011, until a robust methodology to account for this has been developed. They suggest evaluating GHG emissions and biodiversity losses together (Cramer Commission, 2007b) addressing the problem at the governmental level, as they state that ILUC is a global impact that cannot be linked to a single producer. However, they have proposed a general methodology to estimate this impact at the Dutch and EU level (box 1).

The UK Renewable Transport Fuel Obligation (RTFO) initiative does not account for ILUC in the carbon reporting. They will monitor ILUC externally through government but the

approach they will adopt to do this is not clear (E4Tech, 2006). Their criteria for carbon conservation is based on the “carbon pay back time” (CPBT) that is defined as the number of years that a biofuel crop has to be grown in that land in order to compensate the carbon losses resulting from the land-use change and to render available that land for energy crops production. The CPBT is the ratio between the carbon stock loss and the annual carbon abatement of the biofuel pathway. Carbon stock loss varies from one site to another depending on the initial C stock in the land and the sequence of subsequent land-uses placed in that land. Carbon abatement depends on crop yield and GHG emissions reduction of the biofuel compared to the fossil reference. Eligible biofuels are those whose carbon pay back time do not exceed the period of 10 years. For example, if Brazilian sugarcane is planted in pastureland and no indirect effects are derived from this expansion the CPBT is 4 years. However, if pastureland is shifted to forest land, the sugarcane CPBT can rise to 46 years (Searchinger, 2008). At present CPBT applies only to direct land-use change. A similar mechanism could however be implemented to account for indirect conversion.

Box 1. Dutch proposed methodology for estimating GHG emissions from ILUC

1. Determine the relevant markets/areas delivering biofuels to the country/EU.
2. Determine the expansion of each of these markets due to biofuels, due to food/feed and in total.
3. Determine how the additional demand is being met.
4. Determine the GHG emissions of expansion of these markets.
5. Distribute the impacts of market expansion over biofuels and food/feed.
6. Divide these effects by the amount of biofuels per market.

Source: Cramer Commission, 2007a.

Much discussion is being done in the USA concerning the inclusion of ILUC in the Low Carbon Fuel Standard (LCFS) of California. Many research groups (Annex 2) are tackling this issue but no decision has been taken yet. ILUC needs further research to solve

methodological problems before including the related GHG emission source in carbon reporting initiatives.

8. Conclusion

Recommendations

We recommend fixing the system boundaries at the world-wide level (commodity-trading countries) for economic modeling of ILUC and fixing the system boundaries at the national level to downscale relocation of displaced activities/uses using a spatial explicit model.

We recommend a system-wide approach to model indirect land-use change in biofuels production.

Collaborative works is needed at international level in order to develop a common and appropriate methodology to account for ILUC.

Further research works

Further research should focus on:

- Down-scale global effect to regional level
- Predict the relocation of displaced activities using a spatial interface
- Study other ILUC sources (temporal, displaced activities)
- Develop emission factors based on soil type and management practices
- Adjust economic model to account for ILUC in biofuels production

The Laboratory of energy systems of the Swiss Federal Institute of Technology - Lausanne (LASEN) is studying ILUC in biofuels production and a PhD thesis is currently ongoing in this subject, applied to the Brazilian case of sugarcane-based ethanol and soybean-based biodiesel.

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Annex 1 Research groups in ILUC

The Transportation Sustainability Research Center, University of California (A. Farrel), USA.

Calculation on potential ILUC to comply this the LCFS in California

<http://www.its.berkeley.edu/sustainabilitycenter/>

Dept. of Chemical Engineering & Materials Science, Michigan State University (B. Dale), USA.

<http://www.chems.msu.edu/>

Food and Agricultural Policy Research Institute (FAPRI) - Center for Agriculture and Rural Development (CARD), Iowa State University (A. Elobeid, A. Babcock), USA.

Indirect land use changes due to corn production for ethanol in the US

<http://www.card.iastate.edu/>

Institute for Energy and Environmental Research - IFEU (G. Reinhardt), Germany.

<http://www.ifeu.org/english/index.php?bereich=lan&seite=bioenergie>

Laboratory of Energy Systems, Ecole Polytechnique Fédérale de Lausanne (E. Gnansounou), Switzerland.

Indirect land-use change of soybean-based biodiesel and sugarcane-based ethanol production in Brazil

<http://lasen.epfl.ch/>

Dept. of Manufacturing Engineering and Management, Technical University of Denmark (H. Wenzel), Denmark.

Modelization of land use due to crops consumption in GTAP

<http://www.man.dtu.dk/English.aspx>

Centro de Energia Nuclear na Agricultura (CENA), University of Sao Paulo (C.E. Cerri), Brazil.

Modeling carbon footprint of sugarcane management practices (crop expansion vs. intensification)

<http://www.cena.usp.br/>