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Quantification of area and greenhouse gas impacts

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Executive Summary

Introduction

Biofuels are promoted as an option to reduce climate emissions from the transport sector. As most biofuels are currently produced from land based crops, there is a concern that the increased consumption of biofuels requires agricultural expansion at a global scale, leading to additional carbon emissions. This effect is called Indirect Land Use Change, or ILUC. The EU Renewable Energy Directive (2009/28/EC) directed the European Commission to develop a methodology to account for the ILUC effect.

The current study serves to provide new insights to the European Commission and other stakeholders about these indirect carbon and land impacts from biofuels consumed in the EU, with more details on production processes and representation of individual feedstocks than was done before. ILUC cannot be observed or measured in reality, because it is entangled with a large number of other changes in agricultural markets at both global and local levels. The effect can only be estimated through the use of models. The current study is part of a continuous effort to improve the understanding and representation of ILUC.

Background

Most biofuels today use feedstock grown on land that is suitable for food, feed or material production. An increase in biofuel consumption could therefore lead to cropland expansion in one of two ways:

- Directly, when new cropland is created for the production of biofuel feedstocks. This is called direct land use change, or DLUC;
- Indirectly, when existing cropland is used for biofuel feedstock production, forcing food, feed and materials to be produced on new cropland elsewhere. This expansion is called indirect land use change, or ILUC.

Direct and indirect land use change are intertwined in reality. They can lead to changes in carbon stocks on land, most notably through loss of above and below ground living biomass and soil organic carbon, which leads to an increase of greenhouse gases in the atmosphere. However, the uptake of carbon by crops and the effective use of co-products from biofuel production can partly compensate these emissions. The outcome of emission quantification studies present the net result.

This study aims to quantify emissions resulting from the existing EU biofuel policy up to 2020. The study therefore enables policy makers to assess the complete climate impacts associated with biofuel policies. Biofuel policies aim to mitigate climate change, but high emissions could compromise biofuels’ mitigation potential. Insights of this study can assist policy makers in designing future EU biofuel policy in such way that land use change impacts are effectively addressed.

ILUC modelling

Because ILUC occurs through global market mechanisms with many direct and indirect effects, it can only be modelled, not measured. Direct measurement will only provide partial accounting of the total effects. Previous studies have tried to quantify ILUC related emissions, to understand whether the use of biofuels really avoids greenhouse gas emissions on a global scale and by how much. The current study focuses on biofuels consumed in the EU. Note that it does not discuss whether biofuel producers should be held accountable for effects that are indirectly induced by their actions but which take place outside their control. Nor does it answer the question regarding how it can be ensured that biofuels actually reduce greenhouse gasses emissions compared to fossil fuels, within a certain timeframe. The aim of this study is only to model biofuel induced land use change and its greenhouse gas emission consequences, as consistently as possible, using a tailored version of the GLOBIOM model. Whilst this is not the first study that quantifies land use change impacts of EU biofuels – it follows a study published by the International Food Policy Research Institute (IFPRI) in 2011 (Laborde, 2011) – the current study quantifies for the first time land use change emissions from advanced biofuel feedstocks as well as several ‘alternative scenarios’, as further explained below. The study is relevant for the discussion on the 2030 EU policy framework for energy and climate change.

The study follows the general principles of ILUC modelling used in earlier studies, in which a “world with additional biofuels” (the policy scenario) is compared to the same world “as it would have developed without the additional biofuels” (the baseline). In this study, the policy scenarios are based on the European Union Renewable Energy Directive[1] (commonly known as ‘the RES directive’ or ‘the RED’). The computed ILUC impact of the additional biofuels follows from the difference between emissions in the policy scenarios and those of the baseline. This difference is then attributed to the additional biofuel demand in the policy scenarios.

The results of this study, commonly referred to as ‘ILUC values’ (or ‘factors’), are in fact the sum of direct and indirect emission effects. When comparing a policy scenario with a baseline, it is certain that the difference in quantity of land conversion and its greenhouse gas impact results from the difference between scenario and baseline: the additional biofuel demand. The modelling does not show to what extent the land conversion is caused directly or indirectly. For this reason, this study speaks about ‘LUC values’ rather than ‘ILUC values’ and about ‘land use change’ rather than ‘direct or indirect land use change’. Even the term ‘land use change emissions’ does not fully cover the different sources of emissions included in the final results, as some of the emissions are related directly to the change in crop or plantation type, which impacts carbon stock in biomass and soil. These emission savings are

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[1] Directive 2009/28/EC

deducted from the land use change related emissions, leading to the LUC values. For each modelled scenario we provide a precise breakdown of the result into various contributing factors.

This study includes various emission sources and sinks linked to related to biomass and soil carbon stocks. This includes direct soil carbon emissions resulting from the removal of forestry residues from forests[2]. Not included are emissions directly related to the biofuel production chain, including emissions related to feedstock cultivation and processing, biofuel production, transport and distribution. Box 1 gives an overview of emission sources included in this study.

Box 1: Overview of emissions included in this study and emissions not included

Emission sources included in this study

Peatland oxidation: emissions caused by peatland drainage due to oil palm plantation expansion.

Soil organic carbon: changes in carbon stored in soils.

Natural vegetation reversion (foregone sequestration): avoided emission savings due to reduced afforestation or reduced return of cropland to other natural land due to increased use of cropland. This effect takes place in particular in Europe where a trend exists of cropland abandonment.

Natural vegetation conversion emissions: release of carbon stored in forest biomass or natural biomass, at the moment the land use change occurs.

Agricultural biomass: changes in carbon stored in agricultural crops. These can either be biofuel feedstocks cultivated as a direct consequence of increased biofuel demand, or other crop cultivation, triggered indirectly by increased biofuel demand.

Some of these emission sources can be both positive and negative, even within the same scenario. Soil organic carbon emissions, for example, are positive emissions when carbon stored in soils is released, e.g. when forests or other natural biomass are converted and tilled for farming. The emissions are also positive when the build-up of soil organic carbon is avoided (relative to the baseline), e.g. when the collection of forest residues is increased. These emissions can result directly from increased cultivation of specific biofuel feedstocks, or result from the increased cultivation of other crops triggered by increased biofuel demand. At the same time, soil organic carbon emissions can be negative when carbon is stored in soils or crops, due to a switch of crop cultivation methods.

Emissions not included in this study

Agricultural production and chain emissions (direct and indirect): emissions resulting directly from the cultivation of crops (fertiliser production and use, machinery, etc.), conversion into biofuels, and product transport and distribution.

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[2] These could also be accounted for in the direct GHG emissions of biofuels, but that is not the case in the methology specified in the RES Directive.

Scenarios

Earlier studies have shown that the LUC impact differs per crop and supply chain. In the current study, 14 crop-specific scenarios for the main conventional and advanced biofuel crops are modelled, as well as separate scenarios for the cereal, starch and oilseed crop groups. Also, a central aggregated scenario is modelled for the EU 2020 biofuel mix, with 8.6% conventional biofuel consumption and 0.8% advanced biofuels[3] (in line with National Renewable Energy Action Plans).[4] In addition, an EU 2020 biofuel mix scenario with a maximum cap on the consumption of conventional biofuels of 7% is modelled, based on the same feedstocks, with 6,7% conventional biofuel consumption and 1,7% advanced biofuels (by volume). The division between conventional and advanced biofuels and the chosen feedstock mix have an important influence on the results of the aggregated scenarios. The division between conventional and advanced biofuels in the EU 2020 biofuel mix scenario is based on the National Renewable Energy Action Plans (NREAPs) submitted by Member States to the European Commission to allow comparibility with the previous LUC study (IFPRI 2011). The chosen feedstock mix only includes feedstocks which have been selected to be part of the study scope. Not all feedstocks that are part of the actual EU biofuels feedstock mix have been selected, most notably used cooking oil and animal fats are not included. The mix of conventional feedstocks is based on EU FAS Posts (USDA 2014), the mix of advanced feedstocks is determined by the model cost minimisation. While these choices are based on best available consistent information on the EU overall biofuel feedstock division, it is clear that the resulting feedstock mix does not necessarily reflect the actual situation by 2020. This means that the resulting LUC values for the aggregated scenarios should be treated with caution.

In addition to the EU 2020 biofuel mix scenario and the 7% cap scenario, several explorative scenarios are modelled to understand how the results would change, if more abandoned land in the EU was to be used for the biofuels feedstock production; if worldwide deforestation was to either increase or decrease; or if there were a global ban on peatland drainage. In total, 28 scenarios have been modelled (incl. four for straw), as presented in the figure below.

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[3] Before double counting.

[4] As submitted by Member States to the European Commission in 2010-11.

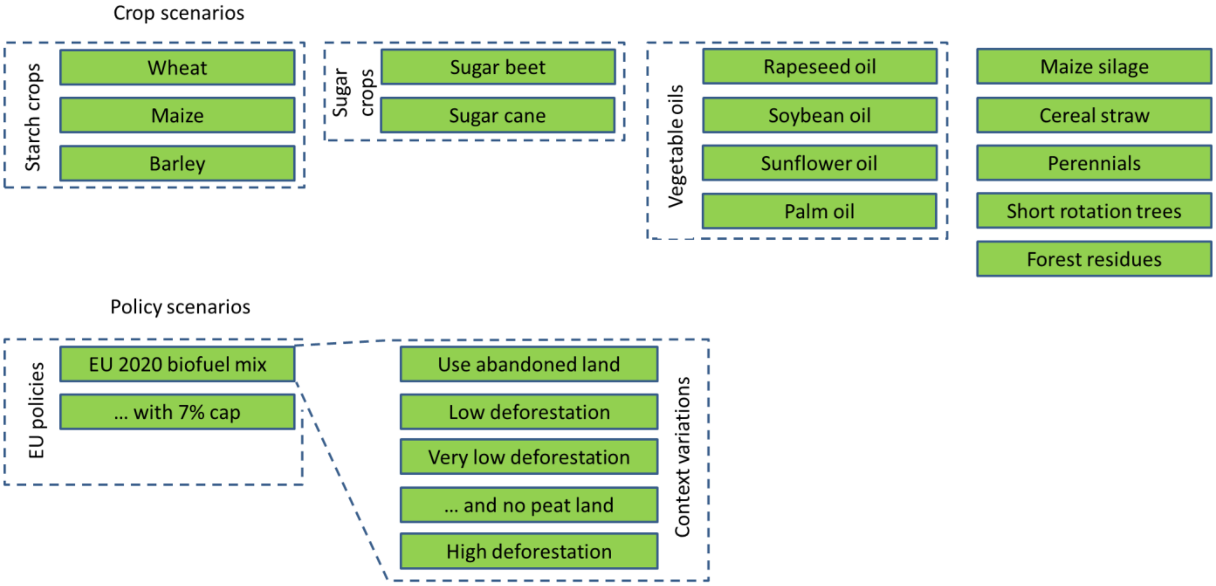

Figure 1: Overview of assessed crops, crop groups, policy scenarios, explorative scenarios and contextual variations

Both baseline and biofuel scenarios are modelled for the years 2020 and 2030. However, in the absence of a biofuel target for 2030, we assume that no further increase in biofuel consumption would occur after 2020, and that the feedstock composition would not change. For this reason, all our biofuel policy shocks are assessed for the year 2020.

Land use change emissions that result from the modelling are distributed over a 20-year period. For foregone sequestration emissions, avoided carbon stock accumulation is included for the first 20 years. Peatland emissions, which emit carbon dioxide every year, are also accounted over a 20 year period. A distribution of emissions over 20 years is common practice in land use change modelling, since most LUC emissions take place shortly after the conversion of previously non-agricultural land to agricultural land and it makes little sense to allocate all emissions to the first year after the conversion and to have zero LUC emissions in year two. The twenty-year period is in line with the period used for the allocation of direct land use change emissions in the greenhouse gas calculation methodology as laid down in the EU-RED. If a longer allocation period were chosen, for example 30 or 50 years, LUC emission values would be lower for some sources, since the total land use change emissions associated with a certain quantity of biofuels would be divided over larger number of years. However, annual flows from peatland and future foregone sequestration would not be reduced before 50 to 100 years (time for peat to be fully oxidised or forest to be fully regrown). Given the significant contribution from continued peatland oxidation, the LUC emissions from 50 year perspective is overall significant higher than from the 20 year perspective. Annual LUC emissions would however decrease, as shown under ‘main findings’ below.

Results

The total LUC emissions results are presented in Figure 2, expressed in grams of CO_2 equivalent per megajoule of biofuels (gCO_2eq/MJ). More detailed modelling results are provided in Chapter 4.

This study has two types of outcomes: quantities of land conversion caused by additional biofuel demand and, based on this land conversion, greenhouse gas emission impacts for each of the modelled scenarios. The total land use change caused by the EU 2020 biofuel mandate is 8.8 Mha (million hectares), of which 8 Mha is new cropland and the remaining 0.8Mha consists of short rotation plantations on existing cropland. From the 8.8 Mha, 2.9 Mha of conversion takes place in Europe by less land abandonment and 2.1 Mha of land is converted in Southeast Asia under pressure from oil palm plantation expansion, half of which occurs at the expense of tropical forest and peatland. The abovementioned 8.8 Mha is 0.6% of the total global crop area in 2012 of 1,395 Mha (FAO). This is around 4% of the total land area of Indonesia, or equal to the total land area of Austria.

Figure 2 below shows the LUC emission values for each of the modelled scenarios and their break-down between various emission sources (see also Box 1 above). The part of each bar above zero on the y-axis represents positive emissions, while the part of the bar below zero represents negative emissions that are being deducted from the emissions. The resulting net LUC emission value is represented by the small triangle in each bar and by the number on top of each bar.

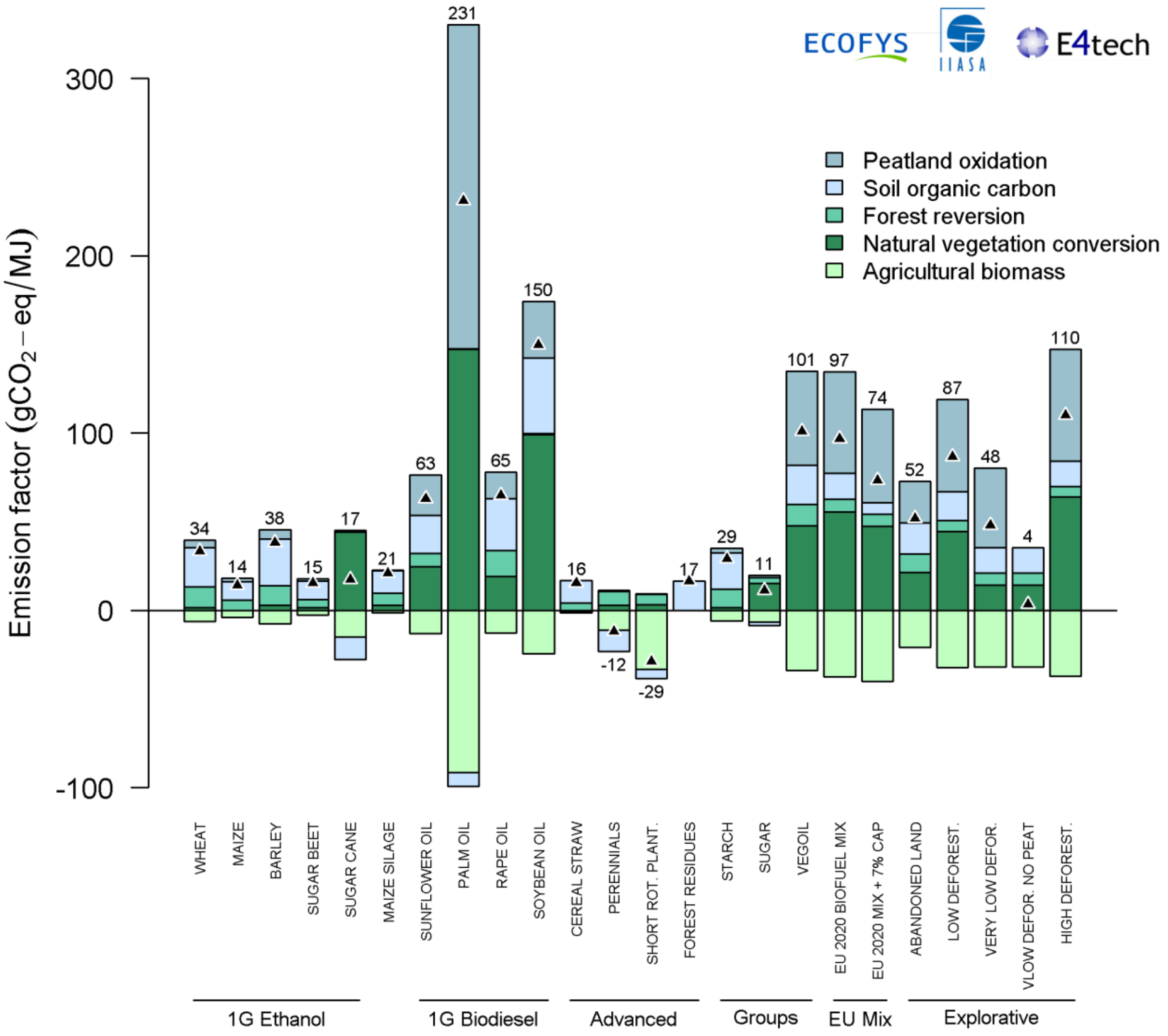

Figure 2: Overview of modelling results: LUC emissions per scenario. Source: GLOBIOM

Main findings

Feedstock-specific scenarios

1. Conventional biodiesel feedstocks have high LUC effects compared to the direct emissions resulting from the biofuel production process, with very high emissions for palm oil (231 grams of CO_2e per megajoule of biofuel consumed – gCO_2e/MJ), high emissions for soybean oil (150 gCO_2e/MJ) and 63 and 65 gCO_2e/MJ for sunflower and rapeseed respectively;
2. Drainage of peatlands in Indonesia and Malaysia plays a large role in LUC emissions for vegetable oils. This is especially the case for palm oil: 69% of gross LUC emissions for palm oil is caused by such peatland oxidation after land conversion;

3 The large and local emission source of peatland oxidation has an impact on the LUC values of other vegetable oils through the substitution effect, with vegetable oils interchangeable to a certain extent. Based on empirical data, we conjecture a relatively limited substitution effect, hence the large difference in LUC values for palm oil – the most cost competitive vegetable oil – and other more costly vegetable oils. Still, substitution plays a role and transfers some of the peatland emissions from palm oil to other vegetable oils;

4 The conventional ethanol feedstocks – sugar and starch – have much lower LUC emission impacts, at 14 and 34 gCO_2e/MJ biofuel consumedfor maize and wheat, 17 $gCO_2e/MJ$for sugarcane and 15 gCO_2e/MJ for sugarbeet. These feedstocks lead to a much lesser extent to peatland oxidation and deforestation compared to vegetable oils;

5 In general, crops with higher energy yield per hectare have lower indirect impacts on land use change and greenhouse gas emissions. A notable exception is palm oil, a high yielding crop whose performance is strongly impacted by emissions from deforestation and peatland conversion, as explained above;

6 Advanced biofuels have negative LUC emissions if produced from short rotation crops (-29 gCO_2e/MJ biofuel consumed) or perennials (-12 gCO_2e/MJ), mainly because of the increase in the carbon stock on the land that is converted to produce these higher carbon stock crops;

7 Advanced biodiesel (Fischer-Tropsch) from forestry residues leads to a significant LUC emission value of 17 gCO_2e/MJ biofuel consumed, despite the fact that no land use change takes place *per se* when harvesting forestry residues. The emissions result instead from a lower build-up of soil organic carbon. It is therefore more appropriate to speak about a 'soil organic carbon (SOC) emission value' for forestry residues, instead of a 'LUC emission value'. Note that, according to the Renewable Energy Directive, the emissions associated with collecting wood residues from the forest floor have to be included in the direct emissions (since it is the point of collection[5]). However, the impact on soil organic carbon associated with the same collection of residues is not included in the direct emissions, which is why it is accounted here;

8 Ethanol from cereal straw can lead to a LUC value of 16 gCO_2e/MJ biofuel consumed, caused by a slight reduction in yields of the main commodity (i.e. the cereal) in cases of overharvesting in areas where already high volumes of straw are harvested for purposes such as animal feed and bedding. This overharvesting leads to soil carbon depletion, and a small yield loss. If straw harvesting is limited to a sustainable removal rate of 33-50% (Ecofys 2013), no yield effect occurs and therefore no land use change effect is observed. Based on four different scenarios modelled for cereal straw, it can be concluded that the LUC value of 16 gCO_2e/MJ biofuel consumed would become 0 gCO_2e/MJ if a sustainable straw removal rate was introduced limiting the straw removal to once every two to three years or 33-50%.

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[5] Directive 2009/30/EC, Annex V, Part C, point 18.

Aggregated EU 2020 biofuel mix scenarios

9 The central 'EU 2020 biofuel mix' scenario gives a high LUC impact of 97 gCO_2e/MJ biofuel consumed. This high number is largely due to the fact that palm oil constitutes 16% of the feedstock of additional biofuels in 2020;

10 Applying a maximum percentage ('cap') on the consumption of conventional biofuels reduces the overall LUC emission effect from 97 gCO_2e/MJ biofuel consumed to 74 gCO_2e/MJ with a 7% cap on conventional biofuels, mainly because the share of advanced biofuels with low or negative emissions increases compared to a situation without a cap;

11 If total LUC emissions would be amortised over 50 years instead of 20 years, annual emissions would amount to 79 gCO_2e/MJ in the EU 2020 biofuel mix scenario.

Explorative scenarios

12 A scenario in which more abandoned land in the EU is used for biofuel production reduces LUC emissions of the EU 2020 biofuel mix from 97 gCO_2e/MJ biofuel consumedto 52 gCO_2e/MJ. Part of this reduction results directly from using abandoned land, while partly it results from a reduced share of palm oil in the total feedstock mix. Using abandoned land can be a good policy option, particularly if the land is degraded and soil carbon stocks are restored though use;

13 Global efforts to stop deforestation and peatland drainage could effectively reduce LUC emissions. The very low deforestation scenario shows that a substantial global incentive to leave forests intact, created in our modelling by charging a price of USD 50/t CO_2 emissions from deforestation, could reduce deforestation to a level that would result in overall LUC emissions for the EU 2020 biofuel mix of 48 gCO_2e/MJ, instead of the central scenario impact of 97 gCO_2e/MJ biofuel consumed. If such a low deforestation scenario were to be combined with an effective ban on peatland drainage, the overall LUC emission effect of EU biofuel policy would further decrease to just 4 gCO_2e/MJ. A more moderate incentive to reduce deforestation of USD 10/t CO_2 would have more modest results in reducing deforestation and would mean that the LUC emissions of EU biofuel policy would remain at a relatively high level of 87 gCO_2e/MJ biofuel consumed.

The very large LUC emissions resulting from increased palm oil use as a biofuel feedstock will likely lead to the question of how the existing EU sustainability criteria for biofuels are factored into this study. These criteria prohibit expansion into forests, expansion into areas with high biodiversity levels and peat land drainage. While these restrictions have a positive impact on the direct sustainability of biofuel production, unsustainable land conversion can still take place. The ban on 'unsustainable land conversion' causes biofuel feedstocks to be sourced mainly from existing farms and plantations, resulting indirectly in increased unsustainable land conversion to meet demand for food, feed and materials, or to supply other markets than the European Union. Only if sustainability criteria that offer a similar level of protection are extended to the food, feed and materials sectors and if these are applied and effectively enforced globally, then these unsustainable practices may be effectively tackled.

Whereas a global approach could be effective to tackle unsustainable land use change, this study shows that one of the major contributors to LUC emissions, peat land drainage, is a relatively local problem. If peatland drainage in Indonesia and Malaysia were stopped, the negative greenhouse gas impact of land use change would reduce dramatically. This requires an effort either from the Indonesian and Malaysian governments, all palm oil using sectors (food, personal care products, biofuel) or, best of all, a combination of both. Whether by global action to stop unsustainable land conversion, or by local action to stop peatland drainage, our study shows that LUC values can be reduced by effective policies.

A modest (for most feedstocks) but interesting emission source is foregone sequestration, which is the effect that, without demand for biofuels, cropland area might decrease and partly revert into grassland or forest. Using more cropland to produce biofuel feedstocks in Europe slows down this process of land abandonment. This has a negative carbon impact, because it implies that carbon accumulation through natural vegetation and young forest regrowth does not take place. If such "foregone sequestration" is indeed considered a business-as-usual development included in the baseline, it will have an impact on LUC emissions. In this study, most foregone sequestration takes place in the EU and more intensive cropland usage in Europe prevents reversion from taking place. We acknowledge that this topic can be debated, as the extent to which the effect occurs in reality is not well documented. Cropland which is abandoned due to agricultural market dynamics does not always automatically revert to forest, due to, for example, annual mowing by farmers in order to receive CAP money, occasional mowing by local smallholders, or extensive grazing. Foregone sequestration was largely left out of the IFPRI study: forest regrowth on abandoned land was not included although some afforestation was included in the IFPRI baseline. Because of the uncertainty concerning foregone sequestration and in order be able to better compare the results of the present study with the results of the IFPRI study, we present Figure 3 below with LUC values both with and without foregone sequestration. In the scenario result sheets in Section 4.2, results are also presented both with and without foregone sequestration. Excluding foregone sequestration has a large impact on ethanol feedstocks; the LUC value for wheat for example drops from 34 to 22 gCO_2e/MJ biofuel consumed and for maize from 14 to 9 gCO_2e/MJ. The EU 2020 biofuel mix scenario result drops from 97 gCO_2e/MJ to 90 gCO_2e/MJ without foregone sequestration.

In addition to the values with and without foregone sequestration, Figure 3 also shows the estimated ranges of uncertainty for each scenario for which a Monte Carlo sensitivity analysis has been performed. Important uncertainties remain, as will always be the case in modelling exercises. They are related to variability around biophysical values that cannot be reduced and uncertainty around causalities assumed by the modelling approach. However, a significant number of uncertainties can be explored within the modelling framework. The most important ones analysed in this study are varying levels of market and producer responses (related to demand, trade, vegetable oil substitution, intensification and land expansion), and some biophysical characteristics (water availability, co-product protein content, the soil carbon and yield impact of straw removal, and the peat land emission factor). The sensitivity analysis shows that, in some cases, LUC emissions of conventional biofuels could be negative; it could however also lead to much higher results per scenario. It is important to keep in mind that the uncertainties are large and often considerable ranges of modelling results exist.

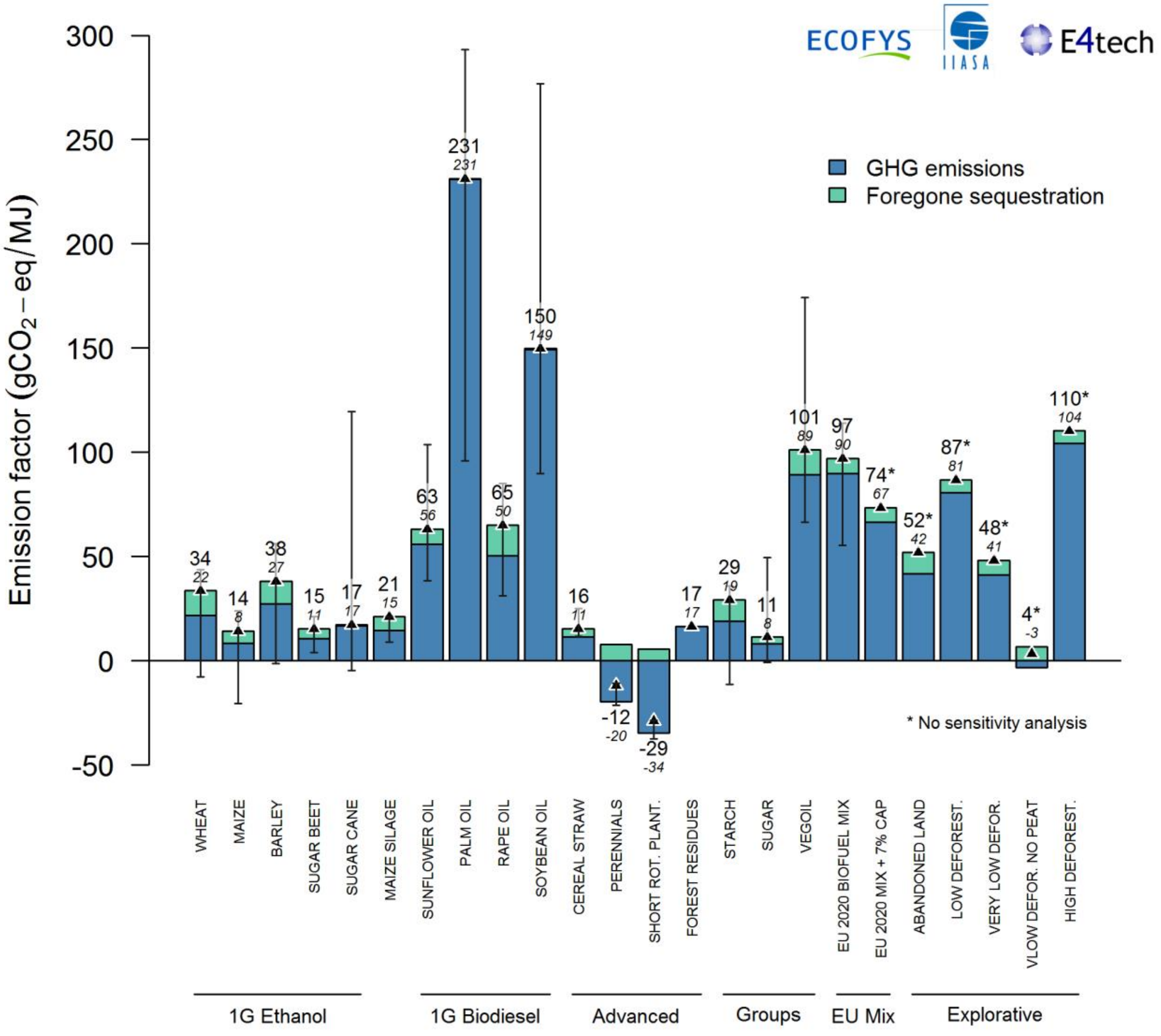

Figure 3: Overview of modelling results: LUC emissions per scenario with and without foregone sequestration and with uncertainty ranges (bars indicate the range within the first and the last decile). Source: GLOBIOM

Some important parallels exist between this study and the previous LUC quantification study focusing on EU biofuels that was published by the International Food Policy Research Institute IFPRI in 2011. Both studies show that sugar and cereal feedstocks perform better than vegetable oils. Both studies show the large influence co-product use and yield increase have on lowering LUC effects. Both studies also show that peat land drainage for oil palm plantation expansion plays a large role in LUC emission values for palm oil and other vegetable oils. An important difference with the IFPRI study is the very high LUC impact for palm oil and soybean oil in the current study, arising from the high share of new oil palm plantations that are being developed on peatland and the higher peatland emission factor assumed, based on the latest available literature. Another important difference is the resulting total land use change measured in hectares. As described above, the aggregated ‘EU 2020 biofuel mix’ scenario in the present study leads to 8.8 Mha of LUC.

In the IFPRI study (Laborde, 2011), however, the total EU biofuel demand shock results in 1.7 Mha of LUC, four times less than the area result in the present study. In line with this large difference in LUC area, the total estimated LUC emissions of the present study are also considerably higher than those estimated by IFPRI: 1,495 $MtCO_2e$ in our central ‘EU 2020 biofuel mix’ scenario, compared to 495–516 $MtCO_2e$ in IFPRI depending on the chosen central scenario. Whereas we estimate the area effect to be more than four times larger than IFPRI, the emission effect is only three times larger. Looking, however, to individual crop-specific scenario results, LUC emission values in the present study are approximately similar to those in the IFPRI study, although palm oil and soybean oil are striking exceptions.

There has been an important debate on whether or not LUC emission factors should be used in biofuel policy. Our results show that LUC emissions are likely to be substantial, but some inherent uncertainty cannot be avoided in the estimation of such emissions and many parameters and assumptions influence the results. From this perspective, only a few feedstocks can be designated as having high or low LUC emissions with a high degree of confidence, with advanced feedstocks having low LUC emissions, or soil organic carbon but no LUC emissions, while palm oil and soybean oil clearly have substantial LUC emissions. However, our work also identifies some clear chains of effects and highlights impact patterns that can vary significantly between feedstocks. If, for example, deforestation and peatland drainage in Indonesia and Malaysia could be avoided by introducing appropriate environmental safeguard systems, LUC emissions for palm oil, soybean oil and other vegetable oils would strongly decrease. These effects should be kept in mind when discussing the emission impacts of current biofuel policy.

For this work, our consortium gathered the best available datasets and built upon the most recent literature published up to early 2014. Stakeholders have been consulted in 2013/14 to obtain inputs and feedback, as further described in the Introduction (Section 0). Following suggestions from stakeholders, the GLOBIOM model was also improved substantially for a number of topics during the course of 2014, followed by the actual LUC modelling. A Scientific Advisory Committee provided valuable comments on our approach that we took into account to the largest possible extent. Notwithstanding these efforts, many particular aspects will still require future research and LUC quantification will always remain the reflection of our understanding of agricultural market behaviour. While modelling can be improved with better datasets and better understanding of certain dynamics and interlinkages, uncertainties cannot be avoided. The main uncertainties are described and tested in Annex V.

Table of contents

1 Introduction

1.1 Study context and aim

In order to fulfil its commitment to mitigate greenhouse gas emissions, the European Union (EU) engaged in an ambitious programme to develop renewable energy sources by 2020. The 2009 Renewable Energy Sources (RES) Directive (2009/28/EC), or 'RED', includes a target of 10% renewable energy in transport. The majority of this renewable energy comes, and is expected to come, from biofuels. The EU introduced mandatory sustainability criteria for biofuels in the RED. These criteria ensure that feedstock production does not cause unsustainable land conversion, i.e. conversion of land with high biodiversity values or carbon stocks. However, when feedstock is (sustainably) sourced from existing farms or plantations, this could still lead to expansion of agricultural land elsewhere, causing indirect land use change, refered to as ILUC. The carbon impact of ILUC can temporally reduce or undo the carbon benefits of biofuels. ILUC is a sensitive topic, with widely varying opinions on whether the effect can be quantified in a robust way and how ILUC modelling results should, or should not, be used in EU biofuel policy. In October 2012, the European Commission published a legislative proposal[6] to introduce measures aimed at addressing ILUC. The European Council and Parliament reached agreement on an amended version of this proposal in 2015, which means that measures to address ILUC will be included in the Renewable Energy Directive[7].

This study aims to quantify land use change emissions resulting from the existing EU biofuel policy up to 2020 and assesses also the land use change impacts of this policy in 2030. The study enables policy makers to assess the complete climate impacts from biofuels policies. Biofuel policies have been designed to mitigate climate change, and high land use change emissions can compromise biofuels' mitigation potential. More insights into land use change emissions resulting from biofuel production can help policy makers to find the best way to design the future EU biofuel policy in such way that land use change is effectively addressed.

1.2 ILUC: a brief background

When demand for biofuels increases and food and feed crops are starting to be used for biofuels, the shortage in food production may be compensated by new food production on previously non-agricultural areas elsewhere, such as forests or grasslands. Alternatively, land remains in agricultural production that would otherwise be abandoned. This has a climate impact, because conversion of forest or grassland to agricultural land can lead to significant releases of CO_2 to the atmosphere. ILUC takes place outside the biofuel production and supply chain, but can be linked to biofuel production due to the international nature of agricultural commodity markets. The effect cannot be measured, only modelled with large and complex economic models.

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[6] COM(2012)595

[7] As well as in the Fuel Quality Directive (FQD – 2009/30/EC).

How does the ILUC effect work in practice? At present, biofuels are mainly produced from agricultural crops that are also used for food, such as rapeseed, maize or palm oil. If more biofuels are produced to fulfil renewable energy targets, demand for these crops rises as well. Following the basic law of supply and demand, increased demand compared to supply leads to a price increase of the crop. The market can respond to this price increase in several ways:

- Reduce consumption;
- Increase supply by creating additional cropland (somewhere);
- Improved agricultural productivity.

Firstly, increased crop prices will cause some decline in food consumption, both because people will eat less and because food waste in the supply chain will be reduced. Secondly, farmers will invest in increasing their yield by improving their agricultural methods, because they can get a better price for their crops. Thirdly, to a certain extent, previously non-agricultural land will be converted to agricultural land to compensate for the crop that was taken from the market. Because of the open and global nature of agricultural commodity markets, this conversion of land can take place anywhere in the world. This effect can be even more indirect, since an increase in demand for crop x can cause this crop to expand at the expense of crop y, which in turn can drive the conversion of forest or grassland elsewhere. This makes ILUC a cross-border effect, acting internationally and also across crops. Agricultural commodities are partly interchangeable, depending on their function, location and price levels. For example, palm oil can be used by the food sector to compensate for an increased use of other vegetable oils, such as rapeseed by the biofuels sector. This means that if palm oil is cheaper than rapeseed oil, increased consumption of rapeseed for biofuels in Germany at the expense of rapeseed previously used in the food sector may lead to an increased interest in palm oil and hence to deforestation in Indonesia. Note that the EU RED does not allow deforestation and expansion into peatland for biofuel feedstock. It should also be noted that Indirect Land Use Change (ILUC) is not exclusively related to biofuel production, but that other land using sectors cause land use change. This study focuses on LUC effects from biofuels, since it is relevant for policy makers to assess how to ensure a policy that is designed to mitigate climate change can indeed serve its purpose.

The results of this study, commonly referred to as ‘ILUC values’, are in fact a mix of direct and indirect emission effects. When comparing a policy scenario with a baseline, it is certain that the differences in quantity of land conversion and its greenhouse gas (GHG) impact results from the difference between scenario and baseline: the additional biofuel demand. The modelling does not show to what extent the land conversion is caused directly or indirectly. For this reason, this study speaks about ‘LUC values’ rather than ‘ILUC values’ and about land use change rather than direct or indirect land use change.

1.3 Modelling approach

This study follows the method of LUC modelling used in most studies, in which the world with an increase in biofuels, called “the policy scenario”, is compared to exactly the same situation but now without the biofuels mandate, “the modelling baseline”. In the current study, we focus on the impact of the EU RED. Therefore, we compare a world with increasing EU biofuels consumption to a world in which this consumption is fixed at 2008 levels and does not further increase. The computed LUC impact is the difference between the baseline and the policy scenarios. Differences in LUC emissions between the two scenarios will provide emissions that are attributable to the increase in biofuel demand between the baseline and applied policy scenarios.

According to the methodology for calculating DLUC emissions laid out in the EU RED, and also used in the October 2012 LUC proposal Impact Assessment by the European Commission, the LUC factor is obtained by dividing CO_2 emissions from land use change by an amortisation period of 20 years to provide a final estimate in grams of CO_2-equivalent per megajoule (gCO_2e/MJ). More details on the model and modelling approach are provided in the sections below.

1.4 Using GLOBIOM to model LUC

For the purpose of this study we use the GLOBIOM (Global Biosphere Management Model)[8], developed by IIASA (see Havlik et al. 2011, 2014). The model effectively represents the world’s agricultural and forestry sectors and most relevant economic and demographic indicators and trade relations. GLOBIOM is an equilibrium model, meaning that the supply and demand sides of the agricultural and forestry sectors are represented, with supply and demand being equal at a certain price level. During the modelling, a biofuel demand ‘shock’ is applied and compared to the ‘baseline’ situation. This means that a certain quantity of biomass demand increase is assumed, leading to an increase in prices. The model calculates the supply side changes and feedback-loops that this shock causes. This iteration or adjustment stops when a new equilibrium between supply and demand sides is found at a new price level.

GLOBIOM is a global recursive dynamic partial equilibrium model with a bottom-up representation of agricultural, forestry and bioenergy sectors. The model is global because it covers 57 countries and regions worldwide (EU28 plus 27 countries and regions in rest of world). GLOBIOM is recursive dynamic instead of static, and is thus able to model changes over periods of time. The model is a partial equilibrium, as opposed to general equilibrium, because it covers the most relevant sectors (agriculture and forestry) in great detail while information from other sectors is kept external to the model. Finally, GLOBIOM is bottom up, because the supply side of the model is built up from bottom (land cover, land use, management systems) to top (production/markets). GLOBIOM is developed since 2007 and a EU dedicated version has been set-up over the past four years (Frank et al., 2013).

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[8] www.globiom.org

The model computes the global agricultural and forest market equilibrium by choosing land use and processing activities to maximise the sum of producer and consumer surplus, subject to resource, technological and policy constraints. The level of production in a given area is determined by the agricultural or forestry profitability in that area (dependant on suitability and management), market prices (reflecting the level of demand) and the conditions and costs associating with conversion of the land, expansion of production and, where relevant, to international market access. Trade is modelled following the spatial equilibrium approach, which means that the trade flows are balanced out between different specific geographical regions. This allows tracing of bilateral trade flows between individual regions.

By including the bioenergy sector, forestry, cropland and grassland management, and livestock management, the model allows for a full account of all agriculture and forestry GHG sources. GLOBIOM accounts for ten sources of GHG emissions, including crop cultivation N_2O emissions from fertiliser use, CH_4 from rice cultivation, livestock CH_4 emissions, CH_4 and N_2O emissions from manure management, N_2O from manure applied on grassland, above and below ground biomass CO_2 emissions from biomass removal after converting forest and natural land to cropland, and CO_2 emissions from soil carbon, including cultivated organic soil (drained peat land, at country level). These emissions inventories are consistent with IPCC accounting guidelines.

A more detailed description of the GLOBIOM model and how the model is used to quantify LUC is provided in Annex I.

1.5 Modelling baseline, scenarios, feedstocks and sensitivity analyses

This study models a number of scenarios by comparing them with a modelling baseline. This baseline describes the evolution of relevant sectors between the base-year 2010 – the year which the EU RED entered into force – and the year 2020 – for which the ‘biofuels shock’ is modelled.

The baseline includes biofuel consumption outside the EU plus the level of EU biofuel consumption (3.2%), as also used in the IFPRI study. The baseline excludes the implementation of the Renewable Energy and Fuel Quality directives, assuming that EU biofuels will remain at 3.2% in the baseline up to 2020. The baseline assumptions are presented in Chapter 2.

Several policy scenarios are compared with the baseline. Selected scenarios are listed in Table 3. First, feedstock-specific scenarios are modelled, looking at the effect of increasing the incorporation level of one biofuel feedstock only (the list of feedstocks is presented in Table 7 in Chapter 3). Scenarios on the total EU biofuel mix in 2020 were also modelled. In addition, alternative scenarios are developed that assess the impact of using abandoned farmland for biofuel crop production in the EU and lower or higher deforestation. There is large recognition of the sensitivity of LUC impacts to behavioural parameters in economic models. For that reason, sensitivity analyses are performed to explore uncertainty ranges around the results of these scenarios. These highlight different developments of the model variables from the same baseline. For instance, changing the elasticity of endogenous yield response can lead, for the same future food consumption patterns, to different land use changes.

The sensitivity analysis is performed through Monte-Carlo simulations, i.e. the GLOBIOM model ran a large number of times, drawing random values for parameters in a plausible distribution, to produce an estimate of the results distribution. The Monte Carlo simulations, modelling parameters used in the simulations and outcomes of the simulations are further described in Section 3.5 and Annex IV, while summary graphs are included in the modelling result sheets presented in Section 3.2.

The table below provides an overview of scenarios modelled in this study. A more in-depth description of each of the scenarios is provided in Chapter 3.

Table 1: List of scenarios in this study

#	Baseline and scenarios	Nr.	Sensitivity analysis
	Baseline		
A0	Baseline: global trends between 2000 and 2030		YES
	Feedstock scenarios		
A	**"Marginal feedstock":** A0 +1% biofuel consumption per feedstock	13	YES
A1	**"Marginal feedstock for cereal straw"**: A0 + 1% shock of straw ethanol for EU and for three selected Member States	4	YES
A2	**"Marginal feedstock groups"**: as A, but with crop groups (ILUC proposal)	3	YES
	Policy scenarios		
B	**"EU biofuel mix in 2020":** A0 + biofuel consumption forecasts from MS NREAPs	1	YES
B1	**"EU biofuel mix in 2020 with 7% cap":** B + maximum of **7%** conventional biofuels	1	NO
	Explorative scenarios		
C	**"Biofuels + increased use of abandoned land in EU"**: incentivised land expansion into EU abandoned land in the baseline + Scenario B	1	NO
C1	**"Biofuels + low deforestation ":** assumed lower deforestation (two levels) worldwide and halting of peatland conversion in the baseline compared to recent trends + Scenario B	3	NO
C2	**"Biofuels + high deforestation":** assumed higher deforestation worldwide in the baseline compared to recent trends + Scenario B	1	NO
	TOTAL NUMBER OF SCENARIOS	**27**	

1.6 Interactive project approach leading to transparent results

Stakeholder involvement is essential in improving the understanding of LUC impacts and to create maximum transparency in the modelling exercise. The following actions have been taken for this purpose:

- We have provided a detailed description of the modelling approach and differences in comparison to the previous IFPRI study;
- We invested in stakeholder outreach;
- We established a scientific advisory committee;
- In this report, inputs are discussed in detail;
- Modeling results are decomposed to increase the understanding of various 'LUC dampening effects' such as yield increase and demand reduction, and the role of various sources of emissions as part of the total results.

Stakeholders received ample opportunities to provide input to the study. Two stakeholder consultations were organised, ongoing exchange with stakeholders took place via the project mailbox (ILUC@ecofys.com) and an Advisory Committee was formed with nine international experts on ILUC quantification and agriculture. The first stakeholder consultation took place in November-December 2013 and aimed to make stakeholders familiar with the GLOBIOM model and identify possibilities to improve the model during the course of the study project. To this end, separate stakeholder meetings with conventional ethanol supply chain, conventional biodiesel supply chain, advanced biofuel producers and non-government organisations (NGOs) were organised in Brussels. Prior to these meetings, the consortium circulated a brief description of GLOBIOM, plus a more detailed description of the GLOBIOM and comparison with MIRAGE-BioF model (IFPRI) to around 200 stakeholders in the ILUC debate, with the invitation to provide comments, suggestions or questions to the project mailbox. This consultation resulted in a long-list of 47 possible improvements to GLOBIOM and suggestions for feedstocks and scenarios to be modelled. This long-list was discussed with the Advisory Committee and the European Commission's steering committee

The second consultation took place in February-March 2014, this time to discuss proposals for a number of improvements to be made to the GLOBIOM model, proposals for a modelling baseline, scenarios and feedstock choice, and to outline the planned sensitivity and uncertainty analysis. The consortium circulated relevant documentation to around 200 stakeholders and published the consultation documents on the project website.[9] Four stakeholder meetings with the above-mentioned stakeholder groups were organised and stakeholders were invited to submit comments via the project mailbox. Comments and suggestions obtained in this second consultation were assessed by the consortium and discussed with the European Commission's steering committee. This resulted in a final selection of changes to be made to the GLOBIOM model, a set-up for the modelling baseline and scenarios, and the feedstocks to be modelled.

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[9] www.globiom-iluc.eu

Following the second consultation, the consortium started to implement the selected changes to GLOBIOM (see Chapter 3 for a more detailed description). In parallel, the consortium prepared a document with modelling parameters, mainly focusing on biofuel production pathways, which were shared for comments with selected biofuel industry associations and subsequently published on the project website.

Some stakeholders requested our consortium to obtain access to the model. It was not possible to fulfil this wish within the scope of our study, as the model in itself is not 'open source' and is proprietary owned by IIASA who invested significantly in developing and fine-tuning the model and datasets used. It is clear that the model, like any equilibrium model, is a highly complex tool, as it represents the entire global agricultural and forestry sectors and the most important global economic drivers and trade relations, with thousands of lines of modelling code. This means it can only be effectively operated by modelling experts. IIASA works with other research groups in several joint research projects, during which those research groups are being trained to use the model and subsequently have access to the model. IIASA is open to collaborate with research group(s) who would like to perform a research project, which could take the form of a peer review of the current study.

The study consortium had several meetings with the scientific advisory committee, whose role was to critically assess our proposed modelling approach, suggest improvements to the GLOBIOM model and assess draft modelling results. The committee was not involved in the actual modelling but was able to obtain a good overview of the way in which IIASA performed the modelling.

1.7 How the current study follows previous land use change studies

Land use change quantification started in the United States. In 2008, Searchinger and colleagues were the first to publish estimates of indirect land use change impacts associated with US biofuel consumption, by means of a modelling framework. They looked at different alternative feedstocks used to produce ethanol using the FAPRI-CARD model. They calculated that greenhouse gas emissions from indirect land use change would represent 104 gCO_2e/MJ for corn ethanol alone if amortised on a 30 years period. They calculated that, in order to achieve 20% emission savings from corn ethanol relative to fossil fuel, the corn ethanol would need to be produced from the same land for over 167 years to repay the ILUC emissions. Looking at some other feedstocks, the authors were pessimistic: growing miscanthus instead of corn in fertile areas would still generate 111 gCO_2e/MJ in impacts and need 52 years to repay (thanks to a better LCA direct saving coefficient) and Brazilian sugar cane ethanol would need four years to repay if expansion occured into grassland, but 45 years if tropical forest was converted.

US researchers Keeney and Hertel (2009) strongly criticised Searchinger's paper, arguing that the role of endogenous yield response to price change had not been adequately addressed in the analysis. They argued that endogenous yield response could be higher than in Searchinger's alternative scenario, in which 20% of additional demand could be met by increased corn yields. They presented simulations with a variant of the GTAP model where a third of the additional demand could be met through crop yield increases. Their model was further used to provide more comprehensive analysis of US biofuel mandates. They found a 30-year LUC value (LUC emissions per unit of biofuel averaged on a 30-year period) of 27 gCO_2e/MJ. Although this value is a quarter of the value initially calculated by Searchinger, this result is still too high to allow climate change mitigation benefits from using corn ethanol.

The GTAP model has also been used in a wider set of LUC impact estimations led by the California Air Resource Board (CARB) in the context of the Low Carbon Fuel Standards regulation. LUC impacts used by CARB are 30 gCO_2e/MJ for corn ethanol, 46 gCO_2e/MJ for sugarcane ethanol, and 62 gCO_2e/MJ for soybean biodiesel (CARB, 2009).

In parallel, a more comprehensive assessment of impacts of different US biofuel feedstock is the Regulatory Impact Analysis performed by US EPA and released in 2010. Using a wide set of models (FAPRI, GREET, FASOM), the exercise computed ILUC factors for many existing and advanced biofuels. The ILUC factor for corn ethanol from EPA is identical to the CARB estimate, at 30 gCO_2e/MJ, but it is lower for soybean biodiesel, at 40 gCO_2e/MJ for 30 years (EPA, 2010). Sugar cane ethanol has the lowest ILUC factor at 4 gCO_2e/MJ, whereas switchgrass ethanol is attributed 14 gCO_2e/MJ.

In 2010, the first large LUC quantification for EU biofuels was published. Al Riffai and colleagues estimated a 20-year LUC factor of 18-20 gCO_2/MJ for EU biofuel policy, with scenarios relying significantly on sugar cane imports (with the range reflecting different trade assumptions), using the MIRAGE-BioF model. The model was also used to look at the respective impact of each feedstock by testing the effect of some marginal shocks. They found that biodiesel feedstocks typically result in higher LUC impacts per unit of energy than bioethanol ones. This IFPRI study by Laborde (2011), assessing the impact of the NREAPs with the same model, has been used by the European Commission as the scientific basis for its Impact Assessment[10] that accompanied the 'ILUC proposal' referred to in Section 1.1 above. Other computable general equilibrium (CGE) models have found similar results: Britz and Hertel (2011) used the GTAP model to explore rapeseed related LUC impacts in Europe and estimated a LUC value of 42 gCO_2/MJ, confirming the higher LUC emissions from biodiesel feedstock are mostly due to lower yields and the typical replacement by palm oil causing expansion in high carbon stock land.

Most modelling exercises that have been performed so far were based either on general equilibrium approaches (models such as GTAP, EPPA or MIRAGE), or economic model linkages (EPA design). Both techniques suffer from notable limitations:

- CGEs have a clear lack of sectorial detail, robust supply side description and lack of tractability of the biophysical variables. These models are mainly based on social accounting matrixes and rarely incorporate a precise account of input-output physical constraints and process technologies;
- Model linkages incorporate greater detail thanks to refined national models but can suffer from inconsistencies. For example, the 2010 EPA model could not reproduce similar production and export levels for some commodities as the two FASOM and FAPRI models.

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[10] SWD(2012)343

While these models have been improved, questions on the uncertainty around LUC impacts have been raised more often and more strongly in recent years.

In 2010, Plevin and colleagues assessed the uncertainty in LUC models through a simplified model. They showed that the 95% confidence interval on carbon stock, model behaviour, or amortization period would result in range of LUC impacts from 21 to 142 gCO_2e/MJ/y. More strikingly, they found an upper bound of 340 gCO_2/MJ, much higher than all previous estimates, whereas their lower estimate would be only about 10 gCO_2e/MJ.

In order to support the scientific foundation for its legislative proposal on ILUC, the European Commission commissioned IFPRI to improve and refine their MIRAGE-Biof model and estimate LUC values for EU biofuels. In October 2011, the IFPRI report "Assessing the Land Use Change Consequences of European Biofuel Policies" was published, which to date is the most referred to source of quantitative information on LUC GHG effects of EU biofuel consumption.

It can be concluded that a wealth of analysis has been undertaken on LUC impacts, but significant uncertainties remain in part due to shortcomings in the modelling approaches. From the previous studies, the IFPRI-MIRAGE study in particular is relevant, as it focuses on EU biofuels like this study. For this reason we compare GLOBIOM with IFPRI-MIRAGE in our detailed description of GLOBIOM in Annex II.

2 Description of the modelling baseline

In this study, the LUC impacts of the European biofuel policy are assessed by comparing different biofuel demand scenarios with a baseline scenario (see Figure 11 in Chapter 3). Basically, we compare a world without the EU RED and FQD directives to a world with the European biofuel incentives under various scenarios. The baseline represents the way the world develops between the model base year, 2000, and 2030, without European biofuel incentives. The model is calibrated in the year 2000 because some important spatially explicit datasets are not available every year and 2000 is the most commonly studied reference point.[11] However, because more recent statistics are available on market data, some more recent parameters, such as evolution of GDP, population, fossil fuel prices, exchange rates, average yield and consumption patterns, have been used to better model recent developments, permitting comparison with the modelled results for the period 2000-2010, as illustrated by this section.

The baseline uses the level of biofuel consumption in the EU in 2008 just before the RED and FQD Directives were passed by EU legislators. This EU demand equals 9.8 Mtoe of conventional biofuels (equivalent to 3.2% of the total liquid fuel demand) and is kept constant throughout the modelled time span. However, biofuel policies that have been, or will be, introduced between 2008 and 2030 in other regions of the world are included in the baseline.

Aside from biofuel demand, there are many variables that influence demand for land-based products and thereby land use. Examples include population growth, GDP and dietary patterns. Equally, there are variables on the supply side that influence the acreage needed to meet demand for land-based products, such as crop yield and livestock productivity. Furthermore, the development of the energy demand in the European transport sector will play a role in determining the amount of biofuel that is needed to meet the 10% EU RED target and hence influences the total LUC impacts from the EU biofuel policy.

In the establishment of the modelling baseline, assumptions have been taken regarding the development of the variables mentioned above. Data and sources for the most important exogenous parameters used in the baseline are presented in Section 2.1. The results for the most important endogenous parameters are presented in Section 2.2. Further information on the input data used in this modelling study is provided in Annex V.

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[11] The JRC global land cover dataset (GLC 2000) has been released for the year 2000 only. For the EU, the Corine Land Cover dataset is available for the years 2000, 2006 and 2009. The crop allocation model from IFPRI (SPAM) provides data for two years, 2000 and 2005. The Gridded Livestock of the World (GLW) dataset on livestock distribution is available for the years 2000 and 2005 only. The global biomass carbon map from Ruesch and Gibbs (2008) relies on land cover for the year 2000 and has not been yet updated to later years.

2.1 Baseline assumptions

This section presents the most important assumptions that are used in the baseline scenario.

2.1.1 Macroeconomics

Driver	Assumption	Data source
Population growth	"Middle of the Road" pathway (SSP2 scenario) in which the world population reaches 7.6 and 8.3 billion in 2020 and 2030 respectively.	SSP Database: (IIASA,2015)

The Shared Socio-economic Pathways (SSPs) are consistent and harmonised prospective scenarios developed and widely used by the scientific community in the framework of research on climate change. The "Middle of the Road" pathway (SSP2) used in the baseline assumes the continuation of currently observed trends in population growth with 7.6 billion people globally in 2020 and 8.3 billion by 2030.

Driver	Assumption	Data source
GDP growth	"Middle of the Road" pathway (SSP2 scenario) in which the global per capita GDP increases from USD 6,700 in 2005 to USD 8,800 and USD 10,900 in 2020 and 2030 respectively.	SSP Database: IIASA (2015)

Data from the same (Middle of the Road) Socio-economic Pathway is used to ensure consistency of GDP projections with population assumptions. In SSP2, the trend of fast growth in emerging regions continues. Per capita GDP is projected to increase by 125% for China and 170% for India between 2010 and 2030.

2.1.2 Energy

Driver	Assumption	Data source
Fuel demand in EU transport	Total liquid fuel demand in the EU-28 transport sector decreases from 12,947 PJ in 2010 to 12,294 and 11,955 PJ in 2020 and 2030 respectively.	EU Energy, Transport and GHG emissions Trends to 2050 (European Commission, 2013)

Fuel consumption in the transportation sector has been declining in Europe since the peak of oil prices in 2007-2008. We follow the Reference 2013 scenario of DG Energy for our projections of future fossil fuel demand in the transportation sector, which anticipates continuation of this trend. Under this scenario, total EU demand for transportation fuel is expected to decrease further by about 8% between 2010 and 2030, also as a consequence of accelerating energy efficiency improvements. The share of diesel in total diesel and gasoline consumption increases from 68% in 2010 to 82% in 2030 in total transport fuel demand and from 42% to 61% in passenger car fuel demand.

Driver	Assumption	Data source
Biofuel demand in EU	Kept constant at 2008 levels: 1G: 3.2% (408 PJ) of total EU transport fuel demand 2G: 0%	Laborde (2011)

The EU biofuel demand in the baseline is kept constant at 2008 levels, the year before the 10% renewable energy target for the transport sector was enforced in the EU RED and the emissions reduction target was revised to 6% in the FQD. This equates to 408 PJ, equivalent to 3.2% of the total fuel demand in the EU transport sector. Of this 408 PJ biofuel demand in 2008, 83% is biodiesel and 17% is ethanol (consistent with the assumption used in the IFPRI 2011 study), all produced from 'first generation' (1G) feedstocks. Hence zero 'second generation' (2G) biofuel demand is assumed in the baseline. The EU biofuel demand is kept constant until 2030 at 2008 levels to assess the LUC impact of the EU mandate. At the same time this assumption allows for comparison with the 2020 LUC values reported by IFPRI (2010), in which the same approach is taken.

Driver	Assumption	Data source
Biofuel demand in rest of the world	Main biofuel mandates incorporated, summing up to: 1G: 338 PJ (2000), 1,717 PJ (2010), 2,406 PJ (2020) and 2,828 PJ (2030) 2G: 0 (2000 – 2010), 16 PJ (2020) and 21 PJ (2030)	Values based on Lotze-Campen *et* al. (2014) adapted for lower biofuel demand in US and Brazil

1G biofuel demand in the rest of the world is based on the US Information Energy Administration for USA and on AgMIP 1G scenario (Lotze-Campen et al., 2014) for the rest of the world.
This latter set of projections has been developed by a consortium of modellers working on global agricultural scenarios. The demand for biofuel outside the EU comes mainly (but not exclusively) from the following countries as a consequence of national biofuel commitments:

USA: Partial implementation of the 2,871 PJ (36 billion gallon) Renewable Fuel Standards mandate by 2022; 1,166 PJ (14.5 billion gallon) from maize ethanol in 2020 and 259 PJ (3.6 billion gallon) from advanced non-cellulosic biofuels (70% biodiesel and 30% sugar cane based). Cellulosic ethanol development remains marginal with only 16 PJ deployed by 2020 (0.2 billion gallon).
Brazil: Stable ethanol incorporation and assumption of prolongued transportation fuel demand over the next decades in line with the 2000-2010 increase, rising from 467 PJ in 2010 to 731 PJ and 994 PJ in 2020 and 2030, respectively. Biodiesel incorporation triples during the period, from 64 PJ in 2010 to 219 PJ in 2030.
Argentina: Incorporation of 10% biodiesel in diesel fuel by 2020 at 64 PJ.
China: Stable ethanol incorporation rate, but increases of 8% per year in fuel transport demand, to reach 27 PJ by 2030.
Canada: Incorporation of 5% ethanol in gasoline by 2020 (27 PJ); no biodiesel demand considered.

Indonesia: Consumption of 0.9 Mt of palm oil biodiesel in 2013 (USDA). Indonesia has introduced a biodiesel mandate that sets strong targets in coming years, up to 20% in 2020. However, biodiesel consumption in reality lagged far behind the mandate quantity, so it remains unsure what the expected biodiesel consumption will be in 2020. For this reason, we chose to include double the quantity of the real biodiesel quantity consumed in 2013 in our study baseline.

Biofuel produced in the regions above is not all freely traded. Indeed, some restrictions are currently in force, such as EU anti-dumping duties on biodiesel imports from Argentina, US and Indonesia and US corn ethanol. In our modelling, we therefore consider that soybean biodiesel exports from Argentina to the EU, and corn ethanol exports from the US to the EU, are impossible. However, we do not put restriction on palm based biofuels from Indonesia, due to the potential to produce hydrogenated vegetable oil from palm and to export it to the EU market. Duties on biodiesel are relatively inefficient for limiting the flow of palm oil use from these different regions, due to the possibility to directly ship the raw feedstock to another country or to the EU directly to produce the biodiesel.

Biofuel feedstocks are transformed into various types of liquid fuels through different transformation processes, whose conversion efficiencies are provided in Appendix IV.5. It should be kept in mind that no specific assumption is made in the baseline about variation in conversion efficiencies over time.

Driver	Assumption	Data source
Solid biomass demand for energy	Global solid biomass demand continues to grow from its 2010 level (43,800 PJ) until 2030, but at a decreasing pace, reaching 47,200 PJ in 2020 and 48,500 PJ in 2030 (final energy).	World Energy Outlook, 2010 (IEA, 2010); "Current policies" scenario.

The model assumptions on solid biomass demand levels are fitted to historical data from 2000 (38,500 PJ) and 2010 (43,800 PJ) using data from International Energy Agency. Electricity generation from woody biomass is assumed to strongly increase from 4,000 PJ/y in 2010 to 10,200 PJ/y in 2030 at a global level. Traditional use of biomass remains significant in developing countries and increases by 4.5% up until 2030 before decreasing. In particular, demand growth remains high in Sub-Saharan Africa (+18% 2010–2030) whereas it stabilises in India (+3%) and decreases in China (-30%). This use still represents 76% of the total solid biomass consumption by 2030.

Driver	Assumption	Data source
Fossil fuel prices	Crude oil price is considered stable at a high level over the 2010-2030 and is assumed at USD 121 for 2020–2030 (in real terms).	World Energy Outlook 2013 (IEA, 2013) [12]

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[12] The consortium used the most up-to-date price assumptions from the World Energy Outlook at the time of the modelling (IEA 2013), but relied on some older edition for the long term solid biomass projections, as all the detailed datasets from that year were already available to the consortium. Energy consumption projections, that depend heavily on past investments, are subject to more ineria than energy price projections, that are more influenced by conjonctural developments.

The model captures the increased price of fossil fuel since 2000 with a four-fold increase in the price of crude oil from USD 25-30 per barrel in 2000 to USD 109 in 2012. This shock is implemented in the model for the year 2010 and impacts the price of fertilisers, and therefore farm gate prices, in large producers of agricultural products (see crop prices in Section 2.2.9).

2.1.3 Food and agriculture

Driver	Assumption	Data source
Diet patterns	In the 30 year modelling period, per capita food consumption increases across the world by 11.6% from an average of 2,729 kcal/capita/day in 2000 to 3,045 kcal/capita/day in 2030 (see Figure 4).	GLOBIOM with SSP2 macroeconomic assumptions and diet preference changes from Alexandratos and Bruinsma (2012)

Food demand in GLOBIOM depends on two main factors: i) an exogenous component, depending on evolution of income per capita and food pattern changes as anticipated by FAO; ii) an endogenous response, depending on change in price level in the model. Projections for food demand in the model baseline are illustrated in Figure 4. Total level of consumption increases in our baseline scenario from 2729 kcal/capita/day to 3,045.[13] These projections are in line with those from FAO (Alexandratos and Bruisma, 2012), which project 2960 kcal/capita/day by 2030, but are slightly larger due to higher GDP growth.[14] For the year 2010, however, our projections are lower by 3.5% compared to FAOSTAT data, due to the response in the model of consumers from developing countries to price increases in the period 2000-2010.[15] Per capita meat consumption increases in developing regions by 34%, from 27 kg/person/year in 2000, to 36 kg/person/year in 2030. In the same period, the meat consumption per capita increase in the developed regions is smaller (12%), mainly due to the decrease of consumption of ruminant meat. Compared to developing countries, however, the absolute per capita meat consumption in 2030 (97 kg/person/year) is still three times higher. The global average per capita meat consumption increases by 21%, from 37 kg/person/year to 45 kg/person/year. In developed regions, a small substitution occurs from bovine meat to pig and poultry meat consumption. Similar patterns are reported for milk and other dairy consumption.

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[13] Our definition for food consumption following the one from FAO, this variable accounts here for food effectively ingested and for household waste. Therefore the values reported excess by far recommended daily intakes from usual dietary guidelines.

[14] See Valin et al. (2014) for more details on how SSP2 macroeconomic growth rate changes FAO projections compared to FAO assumed growth rate.

[15] It is important to note that FAOSTAT data on food consumption – or literally "food supply quantity per capita" – correspond to calculated data by difference between production, trade and other uses and is not reported data. Comparison with such statistics should therefore been done with care.

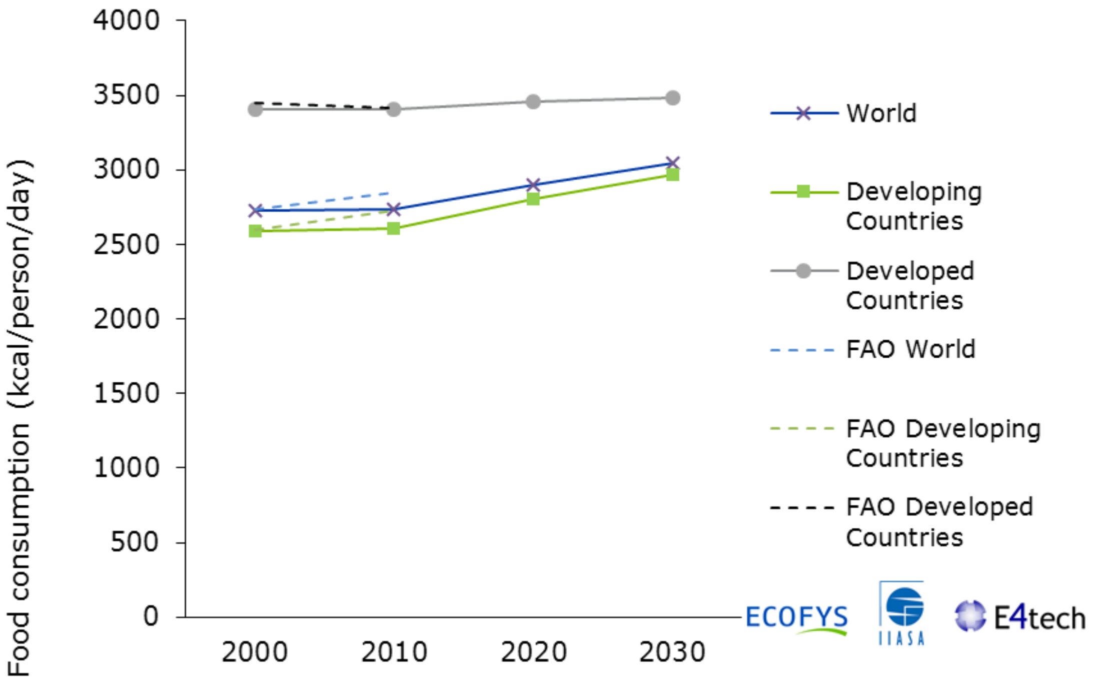

Figure 4: Per capita food consumption projections in the baseline. Source: GLOBIOM and FAOSTAT

Driver	Assumption	Data source
Common agricultural policies	- Direct payments under CAP stay constant - No subsidy on energy crops - No further impact of Ecological Focus Area policy on level of set-aside land in EU agricultural production	Eurostat (2014)

The level of direct payments (financial support directly granted to farmers to ensure a stable income in volatile market) is assumed to stay constant throughout the modelling timeframe and energy crops are not financially incentivised. The Ecological Focus Area (EFA) policy, which obliges farmers to appoint 5% of their land as an EFA (which covers a range of land types including fallow land, hedges and areas with nitrogen fixing crops) – a value that might go up after review in 2017 – is not assumed to have any further impact on the EU agricultural production and the level of set-aside land is considered here constant. Recent policy developments on the EU Common Agricultural Policy, such as the sugar reform, is not taken into account.

Driver	Assumption	Data source
Trade policies	- Status quo of trade policies accounted for, with the exception of the WTO accession of China and Russia (in 2001 and 2012 respectively) - Free Trade Area of the Americas (FTAA), currently under negotiation, is not accounted for	World Trade Organization www.wto.org MacMap-HS6 tariffs database www.cepii.fr

Tariff information in GLOBIOM is based on MAcMap-HS6 2001, which provides details on the applied bilateral protection at the level of product tariff lines. This tariff information is used to calibrate the model in the year 2000 and tariff changes are then applied in the baseline where relevant. China's accession to WTO in 2001 is considered to have had a major impact on the imports of soybeans from Latin America, and in the case of Russia, accession to WTO in 2012 prevents any form of price regulation by import or exports tariff adjustments. With respect to trade of biofuels, we assume that imports to the EU of corn ethanol from US and biodiesel from Latin America and Southeast Asia are restricted by anti-dumping measures. The corresponding feedstocks, however, can be traded.

2.1.4 Biomass demand in other sectors

Driver	Assumption	Data source
Other biomass demand	Uses other than food and feed are assumed to follow the pattern of food demand, except for some particular commodities for which outstanding trends have emerged over the past decade. In particular, we took into account the expansion of palm oil use in Asia and in North America, and the expansion of cotton in South Asia. At the EU level, biomaterial (biopolymers, bitumen) and biochemical (surfactants, solvents, lubricants) have been increasingly used over the past decade, but scenarios on their prospects diverge. As a defaut assumption, we do not consider here any further increase in the incorporated share of biomaterials.	FAOSTAT

Biomass demand grows in all sectors throughout the modelling timeframe and total annual biomass demand increases to 4.5 Gt in 2030 (a 70% increase compared to 2000). Of the total additional biomass demand in 2030 (compared to 2000), the feed sector takes the largest share (35%), followed by the food sector (28%), other sectors (23%) and the biofuel sector outside the EU (14%).

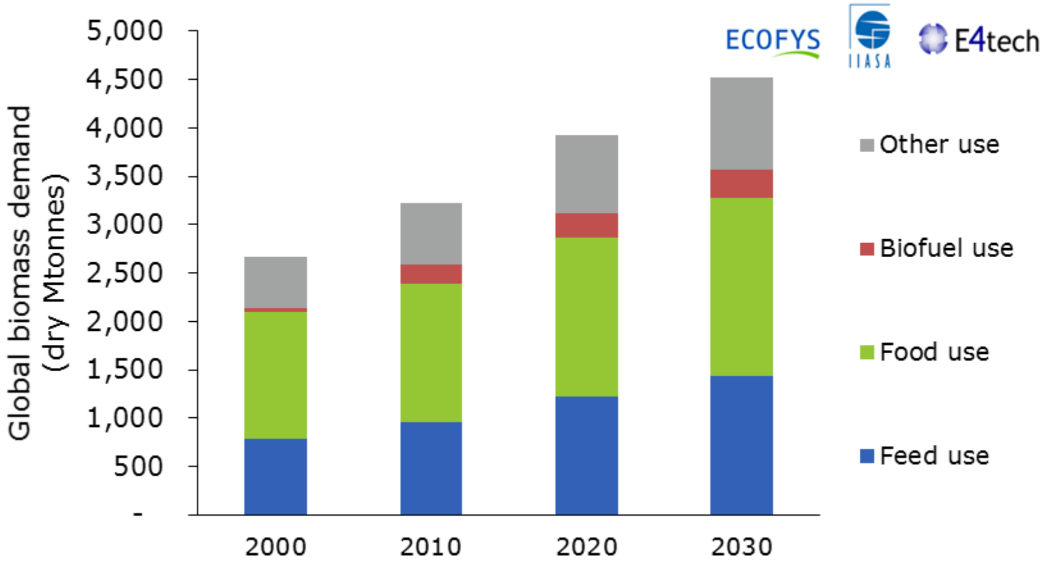

Figure 5: Global biomass projected demand by sector in the baseline. Source: GLOBIOM

2.1.5 Land use

Driver	Assumption	Data source
Land protection	Protected areas based on WDPA	World database on protected areas: IUCN and UNEP (2014)

The World Database on Protected Areas (WDPA) is the most comprehensive global dataset on terrestrial and marine protected areas and is maintained at the UNEP World Conservation Monitoring Centre (UNEP-WCMC). This dataset is introduced in the model here to define 'no expansion' areas corresponding to protected areas into IUCN categories Ia (Nature Reserve), Ib (Wilderness area) and II (National Park). Land conversion is excluded from these areas in the model and no agricultural or forestry activities are allowed.

Driver	Assumption	Data source
Deforestation policy	No particular deviation from deforestation trend observed in the period 2006–2012	Global Forest Resource Assessment 2010: FAO (2010) and Hansen et al. (2015)

The reference period for deforestation is 2005–2012. This means that the effects of policies put in place between 2000 and 2010 are only considered to the extent that their effects have been visible by 2012, the most recent date available for land cover change data at the time of the start of the modelling. Evidence for the effectiveness of policies to avoid deforestation includes, for example, Brazil, where deforestation decreases from an average 3.4 Mha forest losses/y in the period 2001–2005, to 2.4 Mha in the period 2006–2009, and 2.3 Mha in the period 2010–2012, following substantial efforts for a greater enforcement of protection and monitoring policies.
In contrast, in spite of several initiatives to better control pressures on forests, clearings in Indonesia has increased over time from 0.9 Mha in 2001–2005, to 1.6 Mha in the period 2006–2012. The year 2012 has been marked by the highest deforestation rate registered to date, with more than 2 Mha of forest cleared. Therefore, no inflexion in deforestation trend is considered in that region in the model baseline.[16] The effects of climate change on the forest cover and the carbon uptake rate are not modelled.

Deforestation as modelled in GLOBIOM only captures a part of the historic deforestation, because the model only represents expansion of land for agricultural activitiesand not illegal logging and forest degradation for fuel wood or other purposes. In Brazil, for the period 2010–2020, the model

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[16] At the time of redaction of this report, newly released statistics for the year 2013 by Global Forest Watch indicate for that year a much lower deforestation rate in Indonesia than on the previous years, at 1 Mha. This information could not be used by the consortium, but would have remained anyway too isolated to conclude that the trend has been reversed in this region. In order to explore potential implications that such favourable development would have on the results of this study, we refer the reader to the low deforestation scenarios presented in the next section.

calculates 0.6 Mha of forest clearing per year.[17] In Southeast Asia, deforestation is projected at 0.5 Mha per year, and in Sub-saharan Africa, at 1 Mha per year.[18]

2.2 Baseline results

2.2.1 Biofuel production and feedstock quantities used

Biofuel production increased from 25 PJ to 350 PJ between 2000 and 2008 in Europe (with an additional contribution of silage corn, whose production amounted to 155 PJ, both for biofuels, heat and power combined). This can be observed in Table 2, which shows biofuel production levels from the model between 2000 and 2030. Both 2000 and 2010 data are sourced from GLOBIOM but calibrated on external statistics from EurObserv'ER and estimates by EU FAS posts (USDA Foreign Agriculture Service) for the EU and based on US Energy Information Administration for global statistics. During the same period, the production of biofuel in the rest of the world increases from 338 PJ in 2000 to 2,873 PJ in 2030, following our assumptions. The strongest growth between 2000 and 2010 corresponds to the development of corn ethanol in the US, whose volume has been multiplied by eight as a result of the Renewable Fuel Standards program. After 2010, we consider that this development stalls and the highest growth (5.8% per year) is observed in ethanol from sugar cane, stimulated by Brazilian demand (incorporation policy is assumed unchanged) and exports to North America (Table 2).

Wheat straw, short rotation coppice, forestry residues and grassy crops are not reported in this table, because no demand for these biofuels is assumed in the baseline. Silage corn, however, is reported in this table, because it is used in the baseline for both cogeneration and combustion in transport (the two different uses could however not be distinguished).

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[17] Note that this version differs from the regional version of GLOBIOM dedicated to the study of deforestation in Brazil, and that represents all the deforestation drivers in that region (see www.redd-pac.org).

[18] This version differs from the regional version of GLOBIOM applied to deforestation in the Congo Basin (Mosnier et al., 2012).

Table 2: Biofuel production per feedstock

Feedstock	Biofuel and biogas production from crops (PJ/year)							
	2000		2010		2020		2030	
	EU	RoW	EU	RoW	EU	RoW	EU	RoW
Corn ethanol		130	10	1,055	9	1,166	9	1,183
Palm oil biodiesel	2			29		95		94
Rapeseed oil biodiesel	20		212		202		198	
Soybean oil biodiesel	3	0	93	166	88	388	86	509
Sugar beet ethanol			19		18		17	
Sugar cane ethanol		204		488		826		1,093
Sunflower oil biodiesel	0		5		4		4	
Wheat ethanol		4	12	28	11	44	11	61
Silage maize[a]			155		155		155	

[a] Both uses in transportation and in heat and electricity sector are accounted here.

2.2.2 Livestock productivity

Driver	Assumption	Data source
Livestock feed conversion efficiency	Livestock feed conversion efficiencies increase in developing regions by up to 30-50% by 2030 for SSP2 but grow only slowly in Europe (below 5% increase).	Animal Change: IIASA 2011

Livestock feed efficiency is increasing in all parts of the world and is driven in GLOBIOM by technological change (exogenous trend from the Animal Change project; see IIASA, 2011) and livestock system transitions, with the model explicitly representing different livestock management systems. In the EU, livestock productivity for meat measured per unit of land increases by 8% for ruminants between 2000 and 2030. If we measure this productivity in terms of feed conversion efficiency, the increase is even lower, at 7%. For pigs and poultry, however, feed conversion efficiency is considered close to its maximum and no significant change is observed in the period.
It is in the rest of the world that productivity gains are the most impressive in the period 2000-2030. It increases by 63% for ruminant meat on per ha basis, and 33% for feed conversion efficiency. On the pigs and poultry side, productivity is also increasing with the transition from smallholders to more industrial systems, but in terms of resulting conversion efficiency, this results in a decrease in the model, because smallholders systems rely heavily on scavenging, which progressively disappears with livestock sector industrialisation.

Table 3: Meat productivity in the EU and the rest of the world		**kg protein/ha grassland**				**kg protein/t dm feed**			
		2000	2010	2020	2030	2000	2010	2020	2030
EU28	Bovine meat	64.4	66	67.6	67.9	9.9	10.3	10.7	11
	Sheep and goat meat	27.2	28.6	29.7	30.9	5.5	5.7	6	6.3
	Pig meat					16.7	16.8	16.8	16.8
	Poultry meat					32.9	32.8	32.2	32.1
Rest of the world	Bovine meat	6.8	8.2	9.7	11.1	3.5	4.1	4.6	5.2
	Sheep and goat meat	5.1	6.2	7.4	8.7	3.1	3.4	3.7	3.9
	Pig meat					18.2	17.4	16	15.7
	Poultry meat					26.3	25.7	24.7	24.5

2.2.3 Crop yield

Driver	Assumption	Data source
Crop yield	AgLINK-COSIMO baseline 2010-2030 for the EU28 and extrapolation of yield change on period 1998-2012 for the rest of the world	FAOSTAT

Between 2010 and 2030, the global crop productivity of biofuel crops increases on average 1.0%/year (0.6%/year in the EU28 and 1.1%/year in the rest of the world). Strongest productivity growth is expected in wheat production between 2010 and 2020, with a strong catching up of yield in Latin America – still at two third of EU average yield in 2010, but steadily increasing. Maize productivity is assumed to continue with a significant yield increase globally, whereas sugar crops follow a more moderate yield increase. In particular, the strong increase in yield productivity observed historically for sugar beet in the period 2000-2010, and related to the sector restructuring, is no longer reflected in the model projections for 2010-2030, following the AgLINK-COSIMO assumptions.

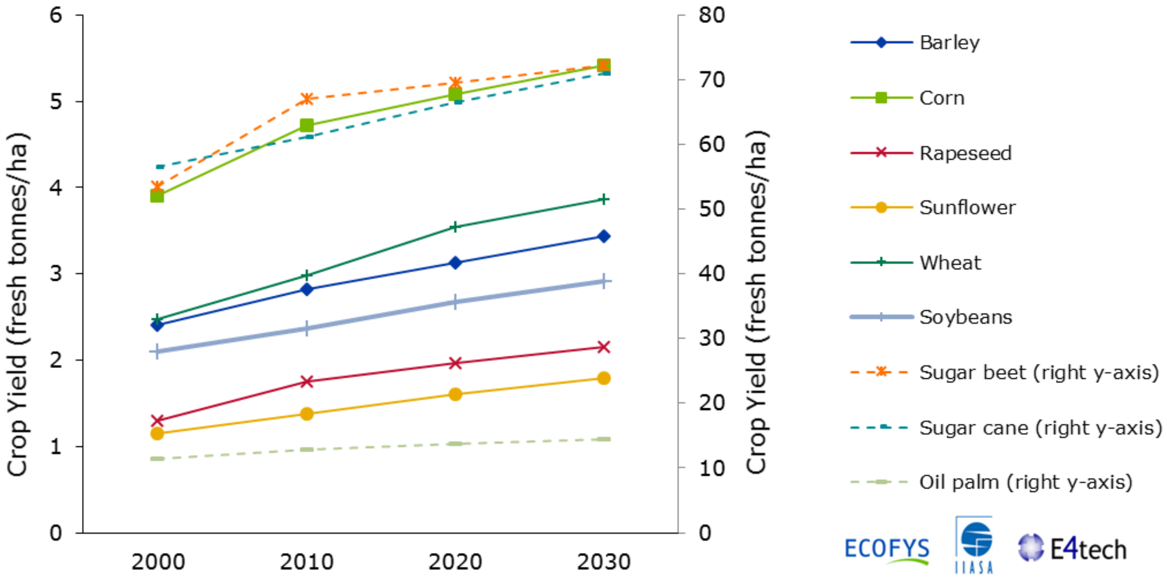

Figure 6: Crop yield projections in the baseline for some biofuel feedstocks. Source: GLOBIOM

Note that the yields from FAO have been further adjusted in GLOBIOM to better reflect the effect of multi-cropping, the practice of harvesting two or more crops successively from the same cropland in one year. Country specific shifts in cropping intensities are obtained from the literature as exogenous variables, although it should be kept in mind that no specific endogenous response is associated with this feature (see Annex II.8 for more details on the multi-crop modelling assumptions taken in GLOBIOM).

2.2.4 Total crop production

In the baseline, in response to food demand, feed needs for livestock, biofuel and fibre demand, total crop production increases by 70% from 2.60 Gt/year in 2000, to 4.52 Gt/year in 2030. The crop production increase between 2000 and 2030 is only 5% in Europe, which is consistent with current observations, as cereal production has been observed to grow by only 3.5% in Europe between 2000 and 2010, and oilseeds expansion (+40%) has been historically associated to the biofuel demand, which is maintained stable in our modelling after 2008. In contrast, production is projected to increase by 82% in the rest of the world. This can be compared with a 22% increase in cereal production between 2000 and 2010, and 56% increase for oilseeds (accounted in primary equivalent).

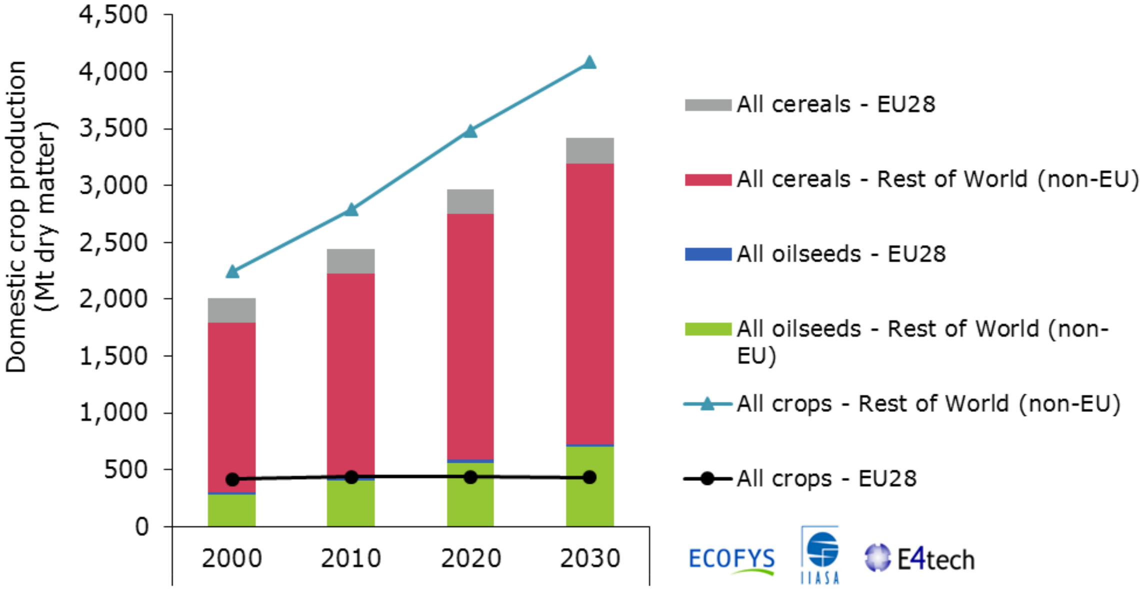

Figure 7: EU and rest of the world crop production in the baseline. Source: GLOBIOM. Line for 'all crops' includes non-cereal and non-oilseed crops

2.2.5 Cultivated area

The global cultivated area for crops included in GLOBIOM (about 70% of total cultivated areas) increases by 11.1% between 2000 (954 Mha) and 2030 (1,060 Mha), after a modest growth of 0.6% between 2000 and 2010 (960 Mha) and a much more rapid increase by 2020 (1,013 Mha). Cultivated area corresponds to areas used for crops, and differs from harvested areas that add to this number all the multi-cropped areas. According to FAOSTAT, arable land would have increased by 20 Mha between 2000 and 2010, therefore extrapolating this trend linearly would lead to 60 Mha of expansion by 2030. The increase in cultivated areas between 2000 and 2010 is more limited in the model due to the assumption about multi-cropping development, in particular in India and China, and also due to the slightly decreased demand in the model from the response to food price changes over the period 2000-2010 (see food demand assumptions). These areas however increase in the period 2010-2030 when prices are more stable and demand is increasing more steadily with the increasing population and economic growth. Throughout the modelling timeframe, the strongest growth is expected in Sub-Saharan Africa (53% in absolute terms), also, followed by Central & South America (42%), North Africa (30%) and Southeast Asia (18%). Total cultivated area declines in Oceania (-20%), Eastern Asia & Pacific (-12%), the EU (-13%) and South Asia (-4%).

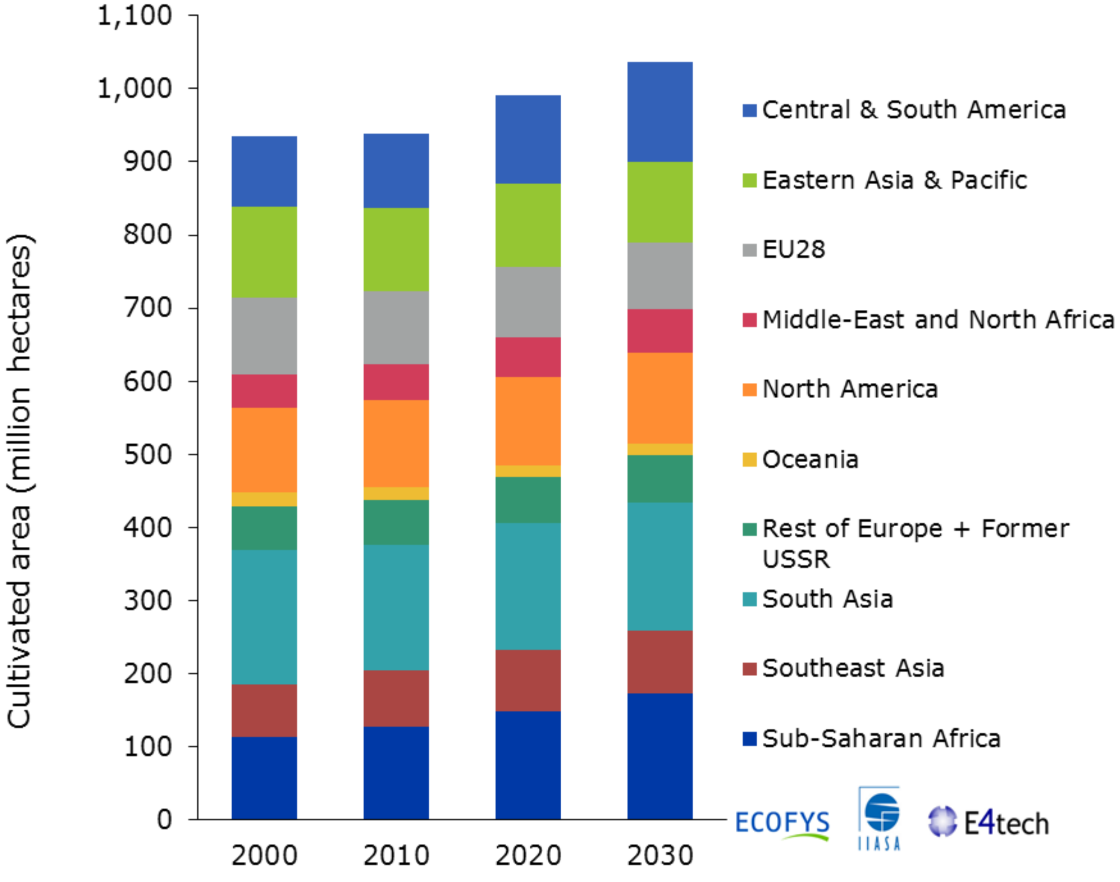

Figure 8: Total cultivated area per region in the baseline projections. Source GLOBIOM

2.2.6 Absolute crop area change

Global harvested areas have significantly increased over the past years, with an additional 100 Mha harvested between the years 2000 and 2010, of which the GLOBIOM crops account for around 80 Mha. The absolute area change per crop projected between 2010 and 2030 amounts in GLOBIOM to 159 Mha, which corresponds to the same rate of expansion per decade as 2000–2010. Expansion patterns across crops differ significantly between regions (see Figure 9). Changes in the EU are relatively small and, in the absence of any biofuel policy and following the slowing down of meat demand, total crop area declines, mainly through wheat harvested area (-2.5 Mha) and maize (-1.2 Mha). Changes are more pronounced in the Americas, Eastern Asia & Pacific and the Africa with the largest absolute crop area increase in the Americas and Africa. Significant changes at a crop level include maize area expansion at the expense of wheat, soybean area expansion in Central & South America (20 Mha) and oil palm area expansion in Southeast Asia (6 Mha) and Sub-Saharan Africa (2.5 Mha).

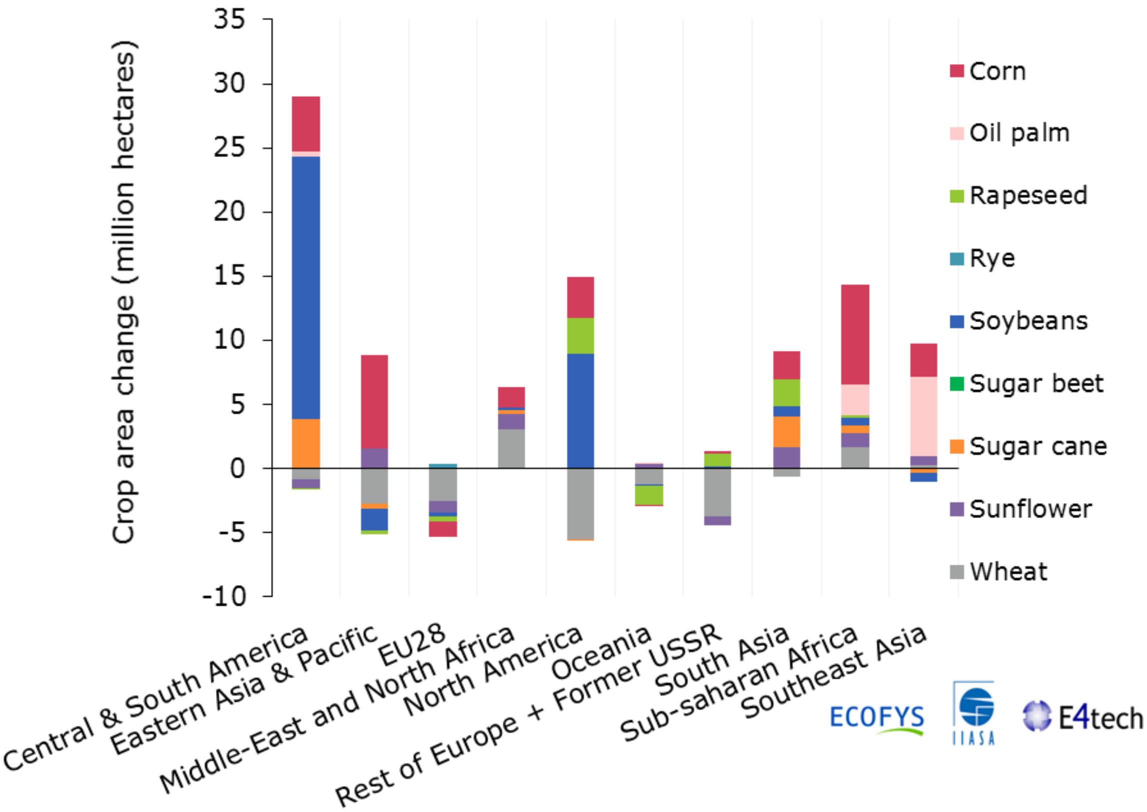

Figure 9: Crop area change in the baseline between 2010 and 2030. Source: GLOBIOM

2.2.7 Land use change

Absolute LUC by land use type between 2010 and 2030 shows a similar pattern across regions: forest and other natural vegetation land is lost to grassland and cropland. Cropland expands in particular in Central & South America and Sub-Saharan Africa at the expense of forest and other natural vegetation, which is well in line with historic observations (see Section 2.2.5 on cultivated area).[19] The EU is an exception and sees an increase in forest and abandoned land. Without biofuel policies, traditional cropland decreases between 2010 and 2030 by 9 Mha, to the benefit of energy plantations for solid biomass (5 Mha) and afforestation (7 Mha), which also expand into other natural vegetation. Around 4 Mha are additionally abandoned over the period in regions where cropland reduction is not followed by any other uses. Abandoned land can also occur in some regions other than the EU, but does not expand between 2010 and 2030. On the contrary, past abandoned land is observed to decrease in Eastern Asia and in South Asia due to the demand increase for agricultural products.

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[19] It should be noted that outside of Europe, no afforestation policies are implemented in these scenarios. Therefore, some regions, like Eastern Asia, which is notoriously characterised by a trend of reforestation, do not show this pattern in our projections.

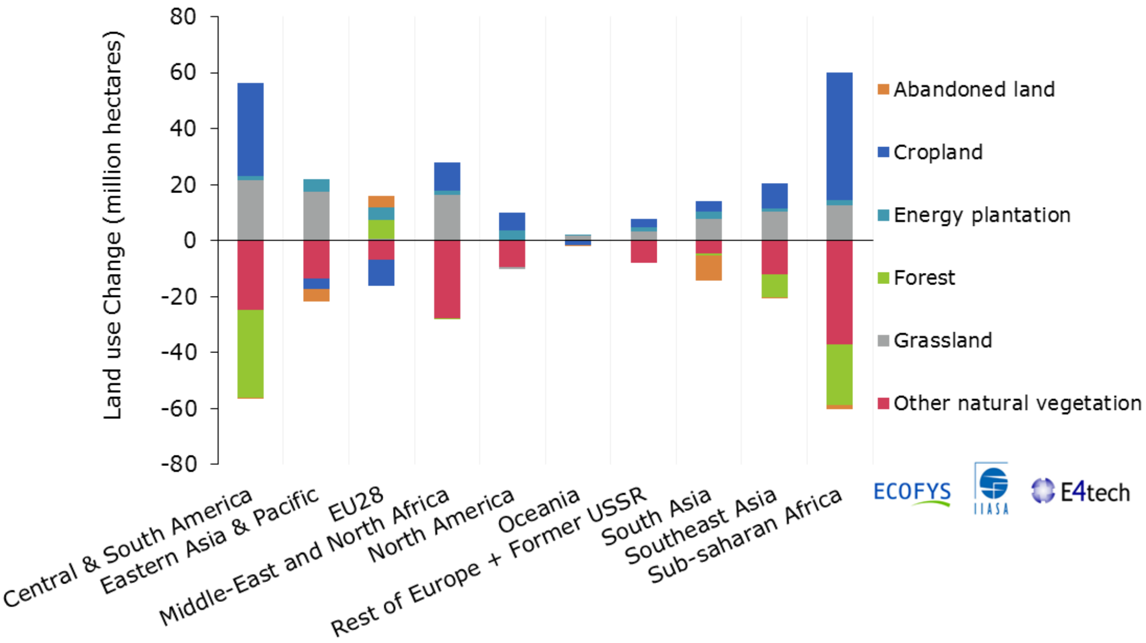

Figure 10: Land use change baseline projections between 2010 and 2030. Source: GLOBIOM

2.2.8 Greenhouse gas emissions from agriculture and forestry

Greenhouse gas emissions from different sources in agricultural and forestry sectors (including crop cultivation and livestock) increase continuously along the baseline. Agricultural emissions in GLOBIOM increase from 3,710 $MtCO_2$ to 4,440 $MtCO_2$ between 2010 and 2030, due to the increase in livestock population, the increased use of fertiliser and the expansion of rice cultivation.[20] This corresponds to an increase of 20% over the 20 year period, to be compared with the historical growth rate from FAO of 13% between 2000 and 2010. Absolute levels for the year 2010 differ between FAO and GLOBIOM due to differences in the GHG sources accounted for and the emission factors used,[21] as well as different production levels related to the food prices impact (see Section 2.1.3).

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[20] Note that there are uncertainties on emission factors for each sources and different approaches are found in the literature. FAO accounted for the same sources and production levels as GLOBIOM 1,170 $MtCO_2$-eq in 2000 versus 1,110 $MtCO_2$-eq.

[21] See Herrero et al. (2013) for differences in accounting on the livestock sector and Valin et al. (2013) for the crop sector.

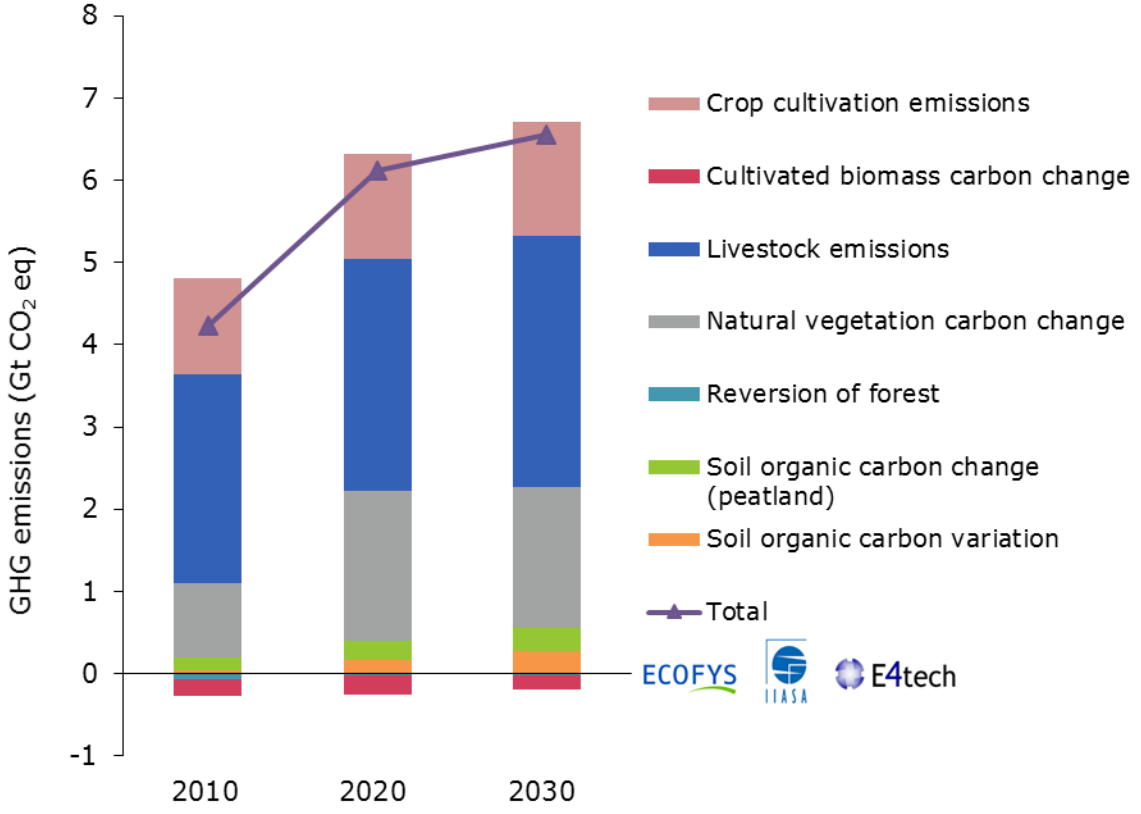

Figure 11: Greenhouse gas emissions from agriculture and forestry in the baseline. Source: GLOBIOM

2.2.9 Crop price

Prices in GLOBIOM develop in the baseline under the pressure of change in exchange rates, increases in oil prices, and changes in demand for food, feed and biofuels. Due to changes in these drivers in the period 2000-2010, initial prices in GLOBIOM, calibrated to average historical values of these drivers in 2000, are shifted up when projecting towards 2030. Table 4 shows how GLOBIOM projected prices compare to recently observed ones. Crop prices all reproduce an increase between 2000 and 2010 in line with recent trends for cereals, sugar cane and oilseeds. In the case of corn, the model projection is higher than in historical record because the US biofuel shock is fully applied in the baseline in the year 2010 (decadal time step). Sugar beet prices are higher in the model than in the historical record, because some sources of production costs decrease, steaming from change in farm structure, are not captured in the model. After 2010, because oil prices and exchange rates are considered to stabilise, all prices follow a slight downward trend until 2030, supported by productivity increases.

Table 4: Main crop prices in the baseline. Source: GLOBIOM

World prices	Hist. average	GLOBIOM			
	2009-2011	Calibration 2000	2010	2020	2030
(€/wet tonne)					
Maize (EU)	164	155	232	211	197
Wheat (EU)	160	103	152	141	133
Barley (EU)	143	93	150	126	109
Sugar beet (EU)	32	40	54	56	55
Sugar cane (Brazil)	18	10	14	14	13
Rapeseed (EU)	363	176	398	270	240
Soybeans (Brazil)	281	181	247	233	224
Sunflower (EU)	371	211	295	277	259

Note: Historical producer prices in current EUR (source FAOSTAT, reference France). GLOBIOM prices correspond to average producer prices in the EU or Brazil, expressed in real terms. Exchange rate fluctuations between EUR and USD since 2000 are accounted for.

2.2.10 Livestock prices

Livestock prices are primarily influenced by the price of feed and, for internationally traded products, by exchange rate. These determinants are represented in our model and fluctuations of livestock product prices reflects the variation in crop prices. For ruminant products, the increase in the price of grain and oilseeds is only partially reflected in product prices, due to the presence of other costs for feeding and animal management. For monogastric products however, the link to crop prices is more direct (main cost source) and the model reproduces the upward trend in prices observed in the historical period between the calibration prices from 2000, and the calculated price from 2010. From 2010 to 2030, the model then projects a stabilisation and then slight decline of prices until 2030.

Table 5: Main livestock product prices in the EU in the baseline. Source: GLOBIOM

World prices	Hist. average	GLOBIOM			
	2009-2011	Calibration 2000	2010	2020	2030
(€/tonne carcass weight)					
Bovine meat	3491	2481	3331	3313	3295
Sheep and goat meat	5187	4544	5757	5418	5006
Milk	321	258	358	357	356
Pig meat	1258	1178	1590	1445	1381
Poultry meat	1434	1268	1667	1575	1507
Poultry eggs	1036	900	1218	1189	1165

Note: Historical producer prices in current EUR (source FAOSTAT, reference France). GLOBIOM prices corresponds to average producer prices in the EU or Brazil, expressed in real terms. Exchange rate fluctuations between EUR and USD since 2000 are accounted for.

2.2.11 Biofuel prices

Prices of biofuels in the EU28 are strongly correlated with feedstock prices. Ethanol price is calculated in the model as around EUR 0.50/l over the period 2010–2030. Biodiesel prices have been strongly fluctuating over the past decade due to the high price volatility of vegetable oil in the period 2000-2010, which leads to a spike in the price of biodiesel that later stabilises around a value of EUR 0.80/l.

Table 6: EU28 average biofuel prices in the baseline. Source: GLOBIOM

EU28 biofuel prices	Historical prices 2009-2011	Calibration 2000	2010	2020	2030
(€/liter)					
Ethanol	0.45-0.70[a]	– [b]	0.54	0.53	0.51
Biodiesel	0.55-1.10[c]	0.49	1.13	0.89	0.8

[a] Ethanol prics varied within a 0.45-0.70 EUR/l range over the period, with average yearly value of 0.5 EUR/l in 2009, 0.55 EUR/l in 2010, 0.65 EUR/l in 2011 (source: Platts, Ethanol T2 Rotterdam).

[b] No bioethanol consumption for EU28 in 2000 in GLOBIOM.

[c] Biodiesel producer price significantly varied over the period within a 0.55-1.10 EUR/liter range. Yearly average were observed around 0.6 EUR/l in 2009 and 1 EUR/liter in 2011 (source: UFOP).

Note: Historical producer prices in current EUR (source FAOSTAT, reference France). GLOBIOM prices corresponds to average producer prices in the EU or Brazil, expressed in real terms. Exchange rate fluctuations between EUR and USD since 2000 are accounted for.

3 Description of scenarios and sensitivity analysis

3.1 Introduction

Following the construction of the modelling baseline as described in the previous chapter, this chapter describes the various scenarios that are modelled against the baseline. A large number of scenarios are modelled. Firstly, a series of crop-specific scenarios for the main conventional and advanced biofuel crops as well as the deployment of separate cereal, starch and oilseed crop groups are modelled. Also, aggregated scenarios of 9.4% EU biofuel consumption following the National Renewable Energy Action Plans (NREAPs)[22] (8.6% conventional plus 0.8% advanced biofuels), as well as a scenario that includes a maximum cap on the consumption of conventional biofuels of 7% , are modelled. In the latter scenario, a total of 9.4% biofuels is modelled of which 7% consists of conventional biofuels and the rest of advanced biofuels, taking account of the EU RED double counting provision.[23] In addition to this, some explorative scenarios are modelled: increased use of abandoned land in the EU, lower than expected worldwide deforestation plus a ban on peatland drainage, and higher than expected worldwide deforestation.

In the baseline, we assume a biofuel consumption of 3.2%, which equals the consumption level in 2008. Feedstock-specific scenarios are compared with the baseline by modelling separately for each feedstock an increased consumption of 1% biofuels as a share of total road transport fuels, or 3 Mtoe. The NREAP scenarios and explorative scenarios are modelled by applying a 'shock' of 6.2% additional biofuel consumption as compared to the baseline biofuel volume of 3.2%. An overview of the various scenarios as compared to the baseline is provided in Figure 12 below.

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[22] As submitted by Member States to the European Commission in 2010-12. http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans

[23] EU RED Article 21(2) states that biofuels produced from wastes, residues, lignocellulose and non-food cellulose material count twice towards national targets for renewable energy in transport.

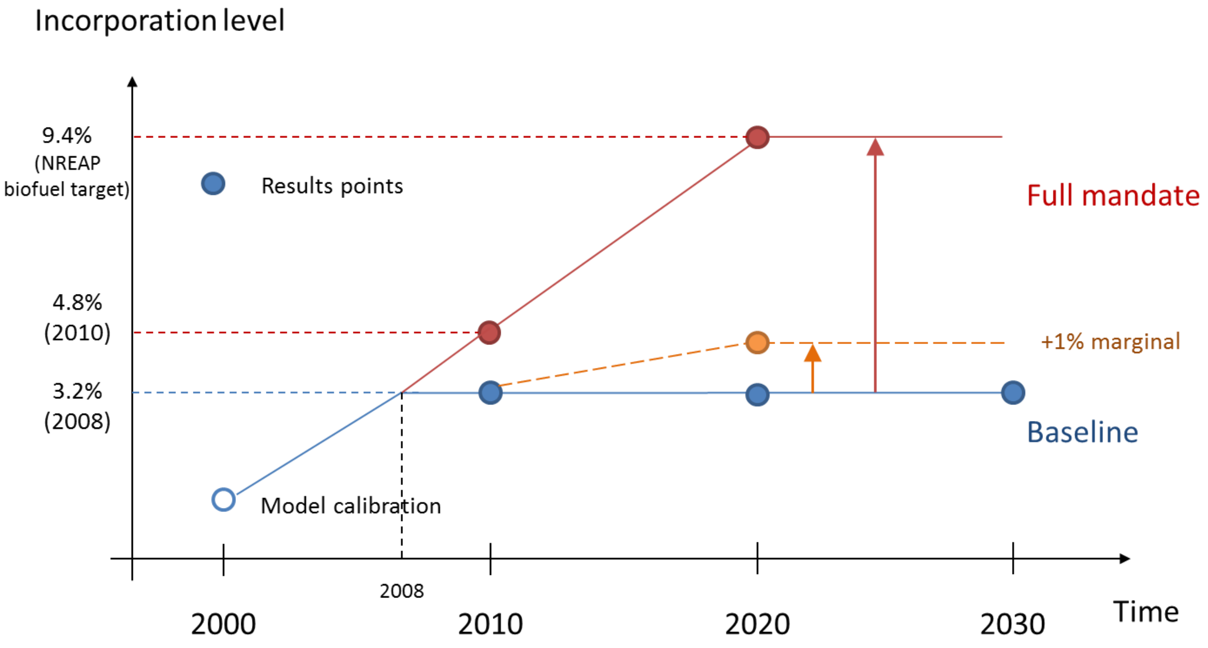

Figure 12: Scenario setting for the modelling of biofuel policies between 2000 and 2030. Two scenario types are considered: feedstock specific shocks (+1%) and policy shocks (full mandate). Plain dots indicate years for which the model generates results

3.2 Crop-specific scenarios

A total of 14 feedstock-specific scenarios are modelled in which a shock of 1% biofuel consumption from each feedstock (123 PJ) as part of total road transport fuels in the EU in 2020is compared to the baseline. The feedstock-specific scenarios are modelled for the following biofuel feedstocks:

Table 7: Overview of feedstock-specific scenarios

Conventional biofuels	Advanced biofuels
Wheat ethanol	Miscanthus biodiesel
Maize ethanol	Short rotation plantation biodiesel
Barley ethanol	Forest residue biodiesel
Sugarbeet ethanol	Straw ethanol
Sugarcane ethanol	
Silage maize biogas	
Sunflower oil biodiesel	
Palm oil biodiesel	
Rapeseed oil biodiesel	
Soybean oil biodiesel	

For straw ethanol, an alternative approach is used because, due to relatively high transport costs, we do not assume an EU-wide market for straw, and straw trade with countries outside the EU is negligible. The modelling of straw ethanol takes into account this fragmented market situation. Straw removal potential is assessed in three regions with different straw availability: Hungary, Great Britain (excluding Northern Ireland) and Northern France around Paris. The 1% shock is applied for these regions[24] and results are subsequently aggregated at EU level. For all other regions in the world, level of biofuel demand is kept constant. Therefore, no change in biofuel consumption level can serve as a buffer to divert more biofuel to the EU market. The approach taken for straw is described in more detail in Section II.1 of Annex II.

3.3 EU 2020 biofuel mix scenario without and with 7%

EU 2020 biofuel mix scenario assumes that the 10% target on renewable energy in transport is fulfilled with 9.4% biofuels (before double counting) following the National Renewable Energy Action Plans (NREAPs) that were submitted to the European Commission by EU Member States in 2010–11. While it is generally recognised that many of the NREAPs are outdated, no other official projections on biofuel consumption in 2020 for each EU Member State is available.

The NREAPs provide an overall forecast on the level of biofuel consumption in 2020 and a split between conventional and advanced biofuels. According to article 21(2) of the EU directive on Renewable Energy Sources, biofuels produced from wastes, residues and[25] cellulosic material count twice towards national targets. This lowers the overall quantity of biofuels required to meet the target. The NREAPs assume a very limited uptake of advanced biofuels, including UCOME (biodiesel from used cooking oil), TME (biodiesel from animal fats) and other double counting biofuels of 0.8%. This means that the projected 9.4 % biofuels in the NREAPs represent an actual food crop based biofuel consumption in volume of 8.6% of EU transport fuels.

The NREAPs do not provide an estimated split in biofuel feedstocks used. In fact, it is difficult to obtain a reliable picture of the EU biofuel feedstock mix, since the biofuel industry generally does not share information on their feedstock mix and most Member States (except the UK, Germany and the Netherlands) do not publish the feedstock mix of consumed biofuels. The consortium invited the industry to provide this information, but in the end had to rely on estimates by EU FAS posts (USDA 2014). More transparency on this would certainly help to improve the estimate of land use change emissions of the total EU biofuel mix in 2020 and beyond. This study bases the assumed feedstock mix on USDA estimates for 2013 and keeps this constant up to 2030. The shares and mix of advanced biofuel feedstocks, are determined endogenously by the model based on least cost optimisation. Based on the above, the following EU biofuel consumption level and and feedstock mix are assumed:

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[24] In the case of Central France, the 1% shock is applied to the entire country of France. This has little impact on modelling results as abundant straw is only available in Central France. This is further explained in Section II.1 in Annex II.

[25] The estimates in this USDA report is collected by USDA Foreign Service Officers stationed in EU Member States (EU FAS posts). The method of information collection is not known, but we assume that it is based on public information, such as press releases, magazines, combined with interviews.

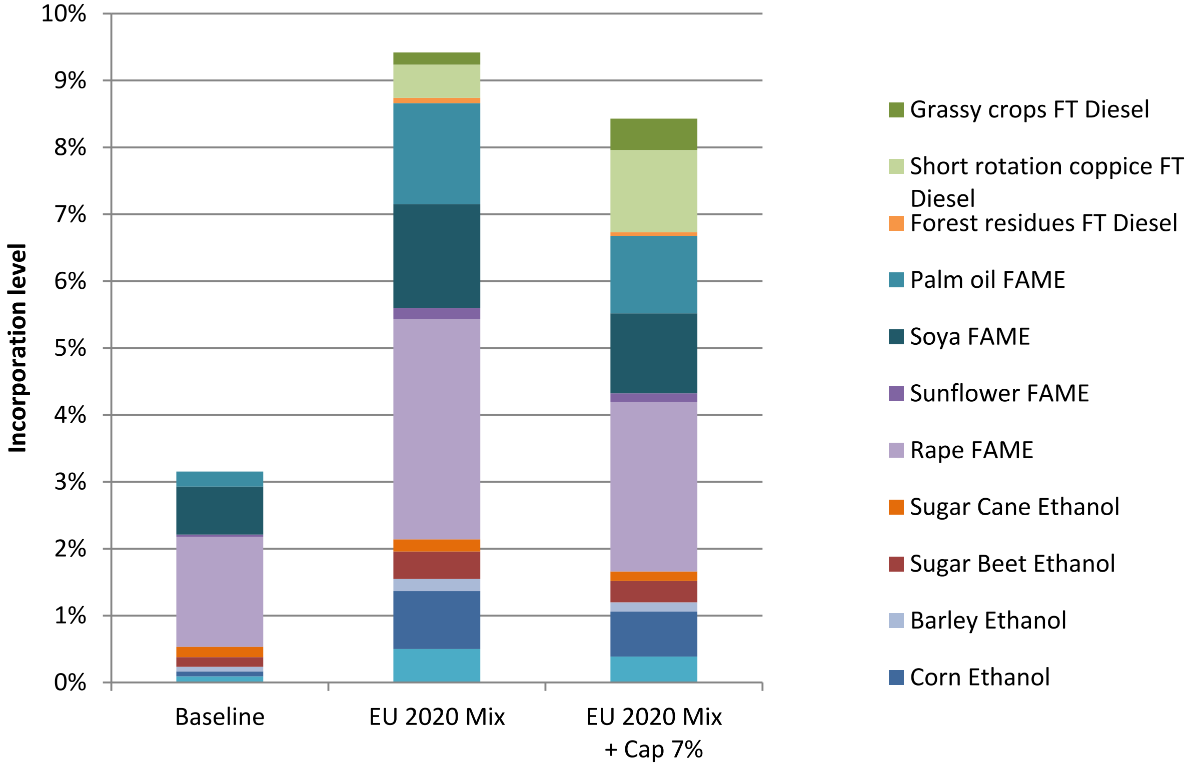

Figure 13: Feedstock composition in the baseline and EU 2020 biofuel mix scenarios

The default EU2020 biofuel mix scenario without constraints placed on the consumption of conventional biofuels is characterised by a more than marginal share of palm oil in 2020 (16% of total biofuel mix), used both for biodiesel (FAME) and drop-in renewable diesel (Hydrotreated Vegetable Oil or HVO), as can also be seen in Figure 14 below. Indeed, we assume that one third of additional vegetable oil used in the mandate comes from palm oil, based on USDA observation on recent change in composition mix. The rather substantial share of palm oil found by USDA is rougly equal to the quantity found in a biofuel sample analysis study performed by UFOP in Germany, which estimated that around 14% palm oil was used in German biodiesel consumption in 2013 or around 12% in the total biofuel mix.[26] However, as stated above, no better data on the EU-wide feedstock mix are available than the USDA data.

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[26] Union zur Förderung von Oel- und Proteinpflanzen e.V, Rohstoffbasis der Biodieselanteile in Dieselkraftstoffen (2014). This study estimated that, based on samples taken at fuel stationsin 2013, around 14% of palm oil was used in biodiesel in Germany. German government agency BLE however reports that 26.316TJ of palm oil was used for biofuels consumed in Germany in 2013, which equals 21% of total German biodiesel consumption. .

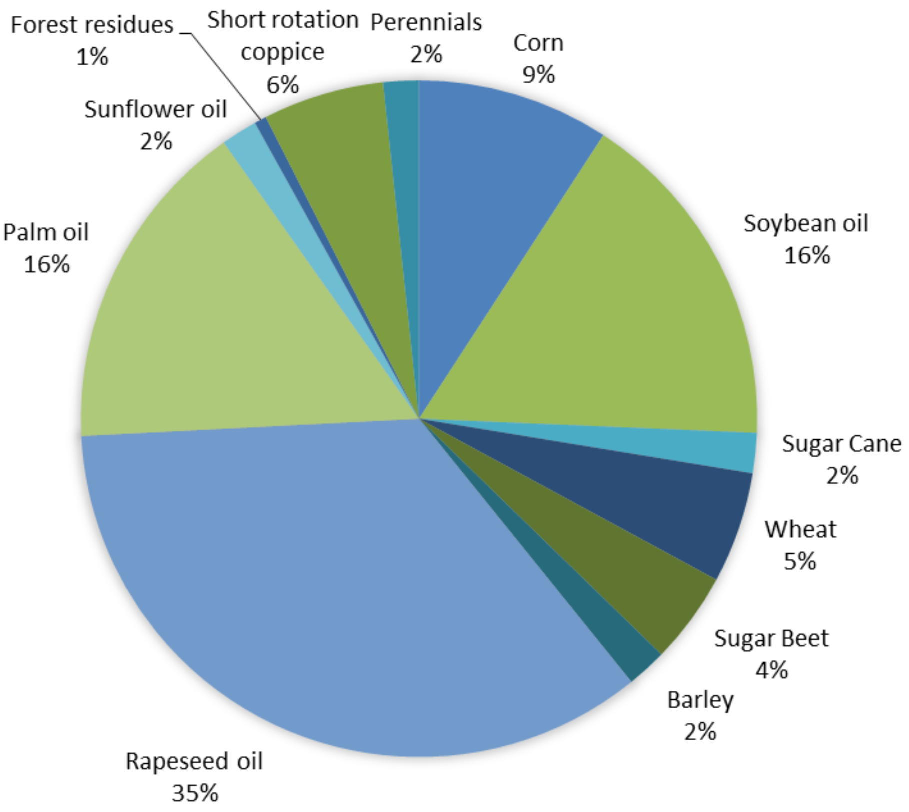

Figure 14: Feedstock composition as share of energy consumed in the EU 2020 biofuel mix (baseline + shock)

We also consider one alternative policy scenario corresponding to the political agreement on ILUC between the Council and the European Parliament reached in April 2014 modifying biofuel incorporationby limiting the contribution of conventional biofuels to 7%.

The introduction of maximum levels (cap of 7%) of incorporation of conventional biofuels modifies the fuel mixes initially prescribed by NREAPs, potentially increasing the share of advanced biofuels to some extent. It is likely that the introduction of new - and the increase of existing- multipliers when counting the use of renewable electricity in road and rail may reduce significantly or even remove the 1.6 % gap between the "cap" and the NREAP scenario for conventional biofuels. The 7% cap is introduced in each Member State. As some Member States did not plan in their NREAP to reach 7% from conventional biofuels (e.g. Belgium, the Netherlands, Denmark, etc.), the aggregated share of conventional biofuels equals 6.7% at the EU27 level under this scenario, instead of 8.6%. Because advanced biofuels and renewable electricity are subject to multiple counting, the total level of biofuel consumption in real energy terms decreases in the 7% cap scenario, as the incorporation limit becomes more restrictive for conventional biofuels: It drops from 9.4% to 8.4% (figure 13).

3.4 Explorative scenarios: abandoned land and lower or higher deforestation

In order to better understand the role of some of the contextual elements on the results of the assessment, some explorative scenarios are now presented that complement the previous calculations. These scenarios look at some particular elements for which uncertainty is high and that can influence the response of agricultural production and land use emissions in response to a biofuel policy incentive: i) restoration of agriculture on abandoned land in the European continent ii) different developments of deforestation policies and their enforcement level.

To test to what extent **abandoned land** in the European continent can help buffer some impacts of biofuel deployment, we construct the C1 scenario on abandoned land restoration. This scenario is implemented in the context of the 'EU 2020 biofuel mix scenario', because restoration of abandoned land with free entry of low price feedstocks on the EU market leads to very limited effect on abandoned land in the model: imports of feedstocks remain in that case the preferred option, even with some form of support on EU feedstocks. The scenario tests a dedicated incentive in EU biofuels policy for increased use of abandoned land in the EU. We represent this scenario by a combination of abandoned land restoration with restrictions on feedstock use: biofuel based on palm oil, soybean oil and sugar cane can no longer be used in the feedstock mix beyond the baseline levels, which increases the reliance on feedstocks produced in the EU. This restriction is complemented by a decrease in conversion costs to other natural land and a subsidy on conversion of new land with low carbon stocks. This scenario is then compared to the baseline (A0).

To study the impact of **deforestation** context, we follow a quite different approach. The cost of conversion of forest into agricultural land are decreased (High deforestation scenario) or increased (Low deforestation scenario, Very low deforestation scenario), with all scenarios being based on the central 'EU 2020 biofuel mix scenario' including the same assumed feedstock mix. We consider additionally for the case of low deforestation two levels of carbon prices as an incentive against deforestation: USD 10 /tCO_2 (Low deforestation) and USD 50/tCO_2 (Very low deforestation). As a consequence, land expansion in these scenarios is more likely to occur into other natural vegetation rather than into forest. The deforestation rates associated with these modified baselines are displayed in the table below. Note that these rates corresponds only to the net deforestation, ie. forest natural regrowth is accounted for in the tropics, and represents only the share attributed in GLOBIOM to agricultural drivers.

Table 8: Worldwide deforestation patterns in different baselines and shocks depending on deforestation context

Region	A0 (baseline)	A0 + High deforestation	A0 + Low deforestation	A0 + Very low deforestation
Baseline 2010-2030 (kha)	-62,500	-88,900	-10,200	-1,400
Impact of the NREAP shock by 2020 (kha)	-1,132	-1,920	-1,210	-170

We additionally modelled the Very low deforestation scenario with a ban on peatland drainage in Indonesia and Malaysia, both for current and new concessions for oil palm plantations expansion.

3.5 Sensitivity analysis

In order to test how models depend on the different assumptions in the modelling, it is useful to explore further simulation results where the model assumptions are varied. Such extensive sets of simulations are called sensitivity analyses. Different sensitivity analysis techniques can be used. For instance, it is possible to vary each crucial parameter around its central value, one after the other, to test first order effect responses. Another, slightly more resource consuming, approach, consists of approximating each of the parameter distributions by a Gaussian curve and running a few points of the Gaussian. We followed here an even more comprehensive approach, called Monte-Carlo analysis. For this approach, a large number of initial simulations are run repeatedly with randomly varied parameters. In the present case, 300 runs have been performed for each of the feedstock specific scenarios A, A1, A2 and the EU 2020 biofuel mix scenario. To perform this analysis, 11 parameters were varied along the specifications reported in Table 9.

The first set of parameters to be varied relate to the modelled behavioral responses. These responses or parameters depend on how the model functions. Elasticities were varied for demand response, trade response, expansion reponse, vegetable oil substitution and impact of the biofuel policy on the feedstock yield. These elasticities determine how much land use change occurs and in what regions.

A second set of parameters concerns biophysical characteristics. These parameters are direct model inputs on some resource or product properties. Co-product protein content is the first important one, as it determines the extent of substitution of co-products with other oilseed meals. Additional testing was applied on the impact of removing yield residues on yield and soil organic carbon. Degree of water availability to expand irrigated systems was also varied. Finally, the emission factors for peat land, as well as the share of (palm oil) plantation expanding into peat land, were varied for Indonesia and Malaysia.

In the Monte Carlo analysis, the chosen parameters are randomly varied, but this still involves a pre-defined distribution shape[27]. Some parameters are varied between -50% and +100%. For parameters that are known with more accuracy, the range and shape of variation is pre-set in line with the data used in the modelling, as described in Annex IV and in the model improvement descriptions provided in Annex II.

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[27] Most values are varied along a loguniform distribution, because the central value is not necessarily more plausible than other points in the distribution. Biophysical parameters were varied along different distribution shapes, either uniform when no better information was known, or along the distribution determined in the Improvement document (Annex II).

Table 9: Parameter variation used for the Monte-Carlo analysis

Parameter	Value range		Motivation for parameter selection
	Minimum	Maximum	
Behavioral parameters			
Demand elasticity	- 33%	+50%	Determines the degree of food consumption adjustment
Trade elasticity	-50%	+100%	Determines trade response patterns
Vegetable oil substitution elasticity	-50%	+100%	Determines the degree of substitution between different vegetable oils
Land expansion elasticity	-50%	+100%	Determines ease of expansion into the different land use types
Yield response on feedstock	Elasticity model – 0.05	Elasticity model + 0.2	Determines the degree of adjustment of yield to prices
Expansion response of palm into peat land	12%	54%	Determines the degree of expansion of palm plantation into peatland in Indonesia and Malaysia
Biophysical parameters			
Co-product protein content	-10%	+10%	Determines the degree of substitution of co-products
Soil carbon impact straw	-10%	0%	Determines the impact of straw removal beyond sustainable levels on soil organic carbon
Yield impact straw (mean value -2%)	-4%	0%	Determines the impact of straw removal beyond sustainable levels on soil organic carbon
Peat land emissions factor	27 tCO_2 ha^{-1} yr^{-1}	113 tCO_2 ha^{-1} yr^{-1}	Determines the level of peatland emissions in Indonesia and Malaysia
Water availability	-50%	+100%	Determines the possibility of intensification through more irrigation

4 Modelling results

4.1 Summary of modelling results

This section presents the modelling results of all 27 modelled scenarios, both in terms of land use change area effect and the resulting greenhouse gas impact.

The results of this study, commonly referred to as 'ILUC values', are in fact a mix of direct and indirect emission effects, in the sense of traditional life cycle analysis. The modelling does not show to what extent the land conversion is caused directly or indirectly. For this reason, this study speaks about 'LUC values' rather than 'ILUC values' and about land use change rather than direct or indirect land use change. Indeed, when looking at the impact of a policy against a counterfactual, the notion of direct and indirect effect only depends on the subjective choice of where the boundaries are set on the system of analysis. In life cycle analysis, the systems analysed are usually limited to the sites of production, transformation and consumption of the products, and GHG emission accounting is limited to sources identified within these boundaries. In a global economic model, no geographical boundaries apply, because all emissions from countries around the globe are simultaneously accounted for. From this perspective, our approach can be considered comprehensive. However, some limitations still apply in the scope of the analysis along two dimensions: GHG emission accounts, and temporal horizon. Regarding GHG emission accounting, it is important to note that the term 'land use change emissions' covers a certain number of emissions sources that go beyond the most usual source of living biomass carbon emissions. In our final results are also included some other stocks of carbon, such as those in agricultural biomass and in mineral or organic soils. Agricultural biomass carbon sequestration is deducted from the land use change related emissions, to obtain the LUC values. For each modelled scenario, we provide a precise breakdown of the result into various contributing factors. Soil organic carbon emissions from crop management can also be indirectly related to feedstock cultivation. Accounting for these emissions leads to higher emissions for expansion of new cropland in Europe, as well as more foregone sequestration as discussed below. A more comprehensive presentation of system boundaries used for this study and a comparison with the MIRAGE model used by IFPRI is provided in Box 2.

Box 2: GHG emission accounting scheme in this study and system boundaries

Five categories of emissions are accounted for in this report, which correspond to a subset of GHG emission sources directly associated to the Agriculture, Forestry and Land Use Change sector (AFOLU) of the IPCC guidelines. The selection of these sources was discussed and agreed with the European Commission's steering committee to be in line, and better comparable with the past literature on ILUC.

GHG fluxes from these sources are related to the following carbon pools:

- Carbon from living biomass above and below ground
- Carbon in dead wood and litter in forest
- Organic carbon in mineral soil
- Carbon in organic soils

These fluxes are analysed in this report according to five categories:

1. "Natural vegetation conversion": fluxes associated with the emission or sequestration of carbon in living biomass, dead wood and litter when land use is converted (can be positive in case of deforestation or negative if managed grassland expands into fallow land);
2. "Natural vegetation reversion": fluxes associated to the natural regrowth of living biomass on previously abandoned land. This source is accounted for separately to factor in the uncertainty of C growth rate and the importance of timing;
3. "Agricultural biomass": fluxes associated to the sequestration in agricultural living biomass (cropland) when agricultural activities expand. This flux can be negative (sequestration) if palm tree expand into grassland, or positive (emissions) if sugar cane is replaced by soybeans.
4. "Soil organic carbon": this source accounts for all change in soil organic carbon stocks from agricultural land, forest and other natural vegetation. The methodology for such accounting is explained in more details in Appendix II.5;
5. "Peatland oxidation" corresponds to release of mineral carbon in organic soil associated with drainage of peatland. In this study, these emissions are only accounted for in Indonesia and Malaysia. They are subject to significant uncertainties and studied in more details in Appendices II.3 and II.4.

Our accounting is performed as follows: categories 1, 2 and 3 are accounted for based on emissions calculated by the model on the basis of land cover changes for the period of the simulation. Carbon stock variation is then divided by 20 years to obtain annual emission flows. Categories 4 and 5 are directly accounted for as annual emission flows, on the basis of difference between drained peatland areas in the scenario and in the baseline, or between cultivated areas under different tillage for soil organic carbon (IPCC tier 1 assumes release of soil organic carbon on a 20 year period).

We do not account in this report for sources other than those listed above due to the focus on land. In particular, non-CO_2 GHG emission associated to agriculture or to LUC are not reported (for instance emissions from fertiliser related to intensification of agricultural production). A part of them are covered in the direct accounting of the EU renewable energy directive.

The LUC values provided in this chapter are single, central emission value estimates which should be considered with greatest prudence when they are considered separately. The central emission values are complemented with a much more comprehensive distribution of results that stem from the sensitivity analysis on model parameters, as explained in Section 3.5 and Annex V.

Figure 15, below, shows the LUC emission values for each of the modelled scenarios and their break-down between various emission sources. The part of each bar above zero on the y-axis represents a quantity of emissions, while the part of the bar below zero represents negative emissions that are deducted from the emissions. The resulting net LUC-emission value is represented by the small triangle in each bar and by the number on top of each bar. Positive emission sources are commonly peatland oxidation (by peatland drainage), soil organic carbon emissions (carbon stored in soils), forest reversion (foregone sequestration, see below) and natural vegetation conversion (removal of above and below ground living biomass in converted land). Negative emission sources are commonly agricultural biomass (carbon stored directly in cultivated feedstocks) and soil organic carbon sequestered during feedstock cultivation.

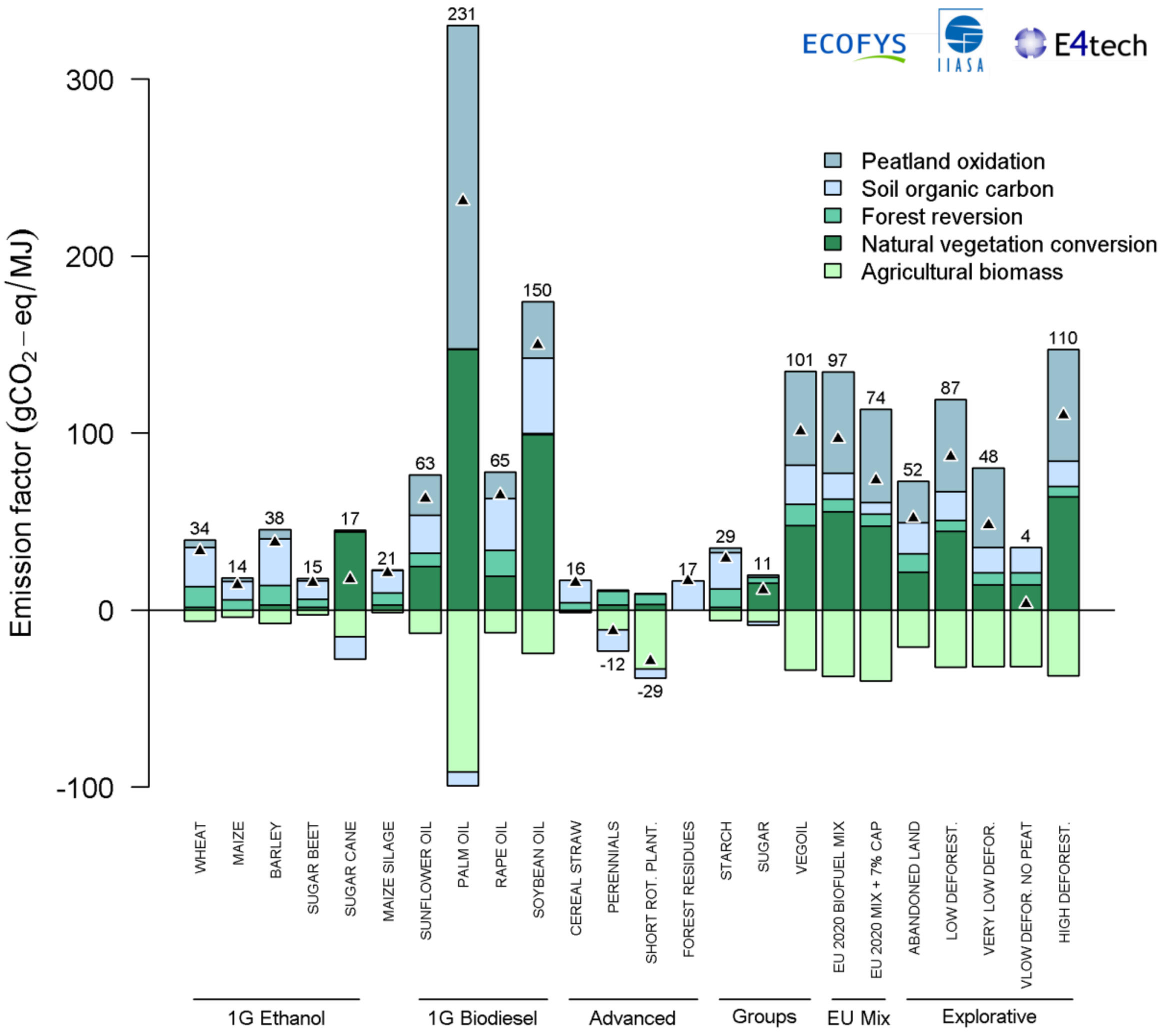

Figure 15: Overview of modelling results: LUC emissions per scenario. Source: GLOBIOM

4.1.1 Results for crop-specific scenarios

- Conventional biodiesel feedstocks have high LUC effects compared to the direct emissions resulting from the biofuel production process, with very high emissions for palm oil (231 gCO_2e/MJ biofuel), high emissions for soybean oil (150 gCO_2e/MJ) and 63 and 65 gCO_2e/MJ for sunflower and rapeseed oil respectively. For all oil crops and in particular for palm oil, peatland conversion is a large contributor to LUC emissions. Due to substitution effects, the use of other oil crops also leads to some conversion of peatland and related LUC emissions. However, the more limited substitution assumed among vegetable oils leads to higher differentiation of results for the different oil types;
- Even with a moderate substitution of palm oil in the model on the demand side, the link to oil markets operates by replacement of soybean meals. Less soya is then cultivated and the missing soya oil is then replaced by cheaper palm oil. A slight increase in plantation acreage immediately leverages considerable quantities of peatland emissions under a mid-range assumption on peat expansion patterns and emission factors; this emphasises the ambiguous effect of DDGS[28] return on the protein meal market, which can on one side save land for soybean producer countries, but at the same time can generate additional emissions in other parts of the world and possibly degrade the environmental balance further;
- Conventional ethanol feedstocks, sugar and starch, have much lower LUC emission impacts, with 14, 34 and 38 gCO_2e/MJ biofuel for maize, wheat and barley, 17 gCO_2e/MJ for sugarcane and 15 gCO_2e/MJ for sugarbeet;
- The LUC value for maize is lower than for wheat or barley due to its higher average yield and higher protein substitution of wheat co-products with other protein sources, leading to some small oil palm plantation expansion. Additionally, maize transformed into ethanol performs better than maize silage transformed into biogas, partly through the coproduct effect and agricultural biomass contribution; however, the ambiguous effect of coproducts leads to a larger spread of results as for maize silage;
- Advanced biofuel crop production leads to low, or even negative, LUC emissions, because emissions are compensated by carbon credits related to carbon sequestered in the new land covers, or in carbon sequestered in soil resulting from no-till practices for feedstocks. This is, however, under the condition that feedstocks do not expand into carbon-dense areas, as occurs for some sensitivity analysis cases for sugar cane. Additionally, because the foregone sequestration accounting is aligned on the biofuel reference period of 20 years, we do not consider the full regrowth of forest as a counterfactual, which masks significant opportunity costs for long term sequestration. Forestry residues have relatively high soil organic carbon emissions of 17 gCO_2e/MJ biofuel, but no LUC emissions. The LUC value for straw is 16 gCO_2e/MJ with unsustainable straw removal and zero gCO_2e/MJ when not more than 33-50% of straw is removed;
- In general, crops with higher energy yield per hectare (corn, sugar cane, sugar beet) have lower indirect impacts on LUC and GHG emissions. However, a notable exception is palm oil, a high yielding crop whose performance is strongly impacted by GHG emissions from deforestation and, in particular, peatland conversion;

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[28] Distiller's dried grains with solubles.

- In Europe, a trend exists of cropland being abandoned, with abandoned land partly turning into forests and partly into grasslands. An increase of cultivation of biofuel crops in Europe leads to a slower pace of land abandonment. This has a carbon impact, because it implies that carbon sequestration through natural vegetation and young forest regrowth does not take place. This "foregone sequestration" on abandoned land in the EU contributes LUC emissions. It should be noted however that some strong uncertainties exist on the extent to which this effect occurs in reality, as discussed in the Executive Summary.
- Modelling results are distributed over a 20 year period. Most LUC emissions take place shortly after the conversion of previously non-agricultural land to agricultural land and it makes little sense to allocate all emissions to the first year after the conversion and to have much lower LUC emissions in year two. If a longer allocation period were chosen, for example 30 or 50 years, LUC emission values would be lower for some sources, since the total land use change emissions associated with a certain quantity of biofuels would be divided over larger number of years. However, annual flows from peatland and future foregone sequestration would not be reduced before 50 to 100 years (time for peat to be fully oxidised or forest to be fully regrown). Given the significant contribution from continued peatland oxidation, the LUC emissions from 50 year perspective is overall significant higher than from the 20 year perspective. If total LUC emissions would be amortised over 50 instead of 20 years, annual emissions would amount to 79 gCO2e/MJ in the EU 2020 biofuel mix scenario. More background is provided in Annex III.

4.1.2 Results for aggregated policy and explorative scenarios

- The EU 2020 biofuel mix scenario assumes that the 10% target on renewable energy in transport is fulfilled with 9.4% biofuels, of which 8.6% are conventional biofuels. The assumed increase in each feedstock (see also Section 3.3) leads to a total LUC of 8.8 Mha, of which 8 Mha are devoted to new crop and perennial cultivation and the remaining 0.8Mha consists of short rotation plantations on existing cropland. From the 8.8 Mha, 2.9 Mha of conversion takes place in Europe through less land abandonement and 2.1 Mha takes place in Southeast Asia under pressure from oil palm plantations, the latter for 50% at the expense of tropical forest and peatland. 8.8 Mha is equivalent to 0.6% of the total global crop area in 2012 of 1,395 Mha (FAO). The 8 Mha new cropland for biofuels to be used in the EU compares to a total 64 Mha of new cropland for all uses of agricultural biomass due to overall increased demand during the same time span, i.e. 2008-2020.[29] The resulting LUC emissions mainly relate to deforestation and peat land conversion for palm plantations, which provide vegetable oils for direct replacement of volume consumed by biofuels and compensate for the soybean production decrease due to co-products substitution. The LUC emission value of the scenario is 97 gCO_2e/MJ;
- The introduction of a maximum percentage ('cap') for conventional biofuel consumption in the EU could significantly lower the LUC emissions. A cap of 7% results in an LUC value of 74 gCO_2e/MJ biofuel, with the same assumed feedstock mix for conventional biofuels as in the EU 2020 biofuel mix scenario. The decrease is mainly caused by an increase in the share of advanced biofuels, which have lower or even negative LUC emissions. To assess the overall ILUC mitigation by the ILUC Directive agreed upon in 2015, one has to add the fact that not only the

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[29] Extrapolated from the 53 Mha projected by the model on 2010-2020.

LUC intensity of the biofuels used in the EU declines but that also less biofuels are needed in quantitive terms to achieve the 10% target for renewable energy in transport (see section 3.3 and figure 13);

- Abandoned land can provide acreage for biofuel expansion in the EU. This is the case already in the 'EU 2020 biofuel mix' scenario, especially in the explorative 'Abandoned land in the EU' scenario, which considers a larger use of abandoned land in the EU for biofuel feedstock cultivation. This scenario reduces LUC emissions from 97 gCO_2e/MJ biofuel to 52 gCO_2e/MJ. This reduction is caused both by increased use of abandoned land, and a restriction on feedstock use: biofuel based on palm oil, soybean oil and sugar cane can no longer be used in the feedstock mix beyond the baseline levels, which increases the reliance on feedstocks produced in the EU. However, 52 gCO_2e/MJ remains large compared to emissions from the biofuel production process. Partly this is due to the fact that greater use of land in the EU still removes carbon stock from natural vegetation – present or future in case of abandoned land – and soil, in part because the substitution of co-products with other protein meals still lead to some displacement of land in other parts of the world. It should be noted that, in reality, land is often not completely unused but rather underused, used extensively by local smallholders who cut grass for their animals, or the land is not used for crop cultivation but ploughed once every year in order to obtain CAP subsidies. This means that in many cases, abandoned land will not refer to forest or grassland and can be used for crop production with limited emission effects. The use of abandoned land can be an effective LUC mitigation strategy in cases where it is currently 'underused', for example as grassland with relatively low carbon stocks where reversion to forest is being prevented. Our abandoned land scenario focuses on improved access to abandoned land in Europe. This means we take a conservative approach on the potential positive effect of restoring abandoned land for agriculture expansion;
- A serious effort to limit deforestation and expansion into peat land leads to a significant lowering of LUC effects. The 'Very low deforestation' scenario leads to LUC emissions of the EU 2020 biofuel mix of 47 gCO_2e/MJ biofuel instead of 97 gCO_2e/MJ. On the other hand, in a high deforestation scenario, biofuels induced expansion into forest and peat land also increases. The LUC impact therefore increases alongsideincreasing from 97 gCO_2e/MJ to 110 gCO_2e/MJ, an increase of 15%. The intermediate 'low deforestation' scenario leads to a LUC value of 90 gCO_2e/MJ. As explained in Section 3.4, the low deforestation scenario assumes a carbon price of USD 10/t as an incentive to stop deforestation. This incentive is shown by the modelling to be insufficient to reduce deforestation rates drastically, mainy because commodities such as palm oil are so profitable that converting the land remains economically beneficial. (See also: Deiniger et al. in 2010). The USD 50 incentive in the very low deforestation scenario is much more efficient. LUC emissions of the EU 2020 biofuel mix can be reduced dramatically to just 5 gCO_2e/MJif the USD 50 incentive in the very low deforestation scenario is combined with an effective ban on peatland drainage.

4.1.3 Results comparison on distribution of response to the shock

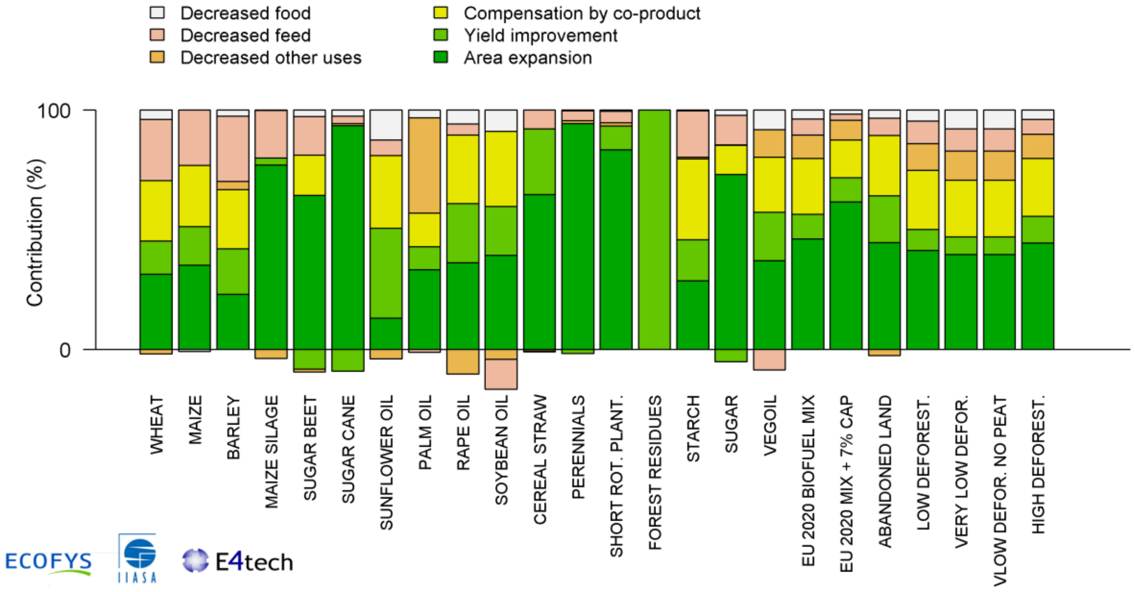


Figure 16: Overview of distribution of effects between demand side and supply side adjustments for all crops modelled in GLOBIOM (aggregated by ton dry matter) and for all scenarios

Figure 16 provides an overview of how the agricultural system reacts to the shocks from the different scenarios. The demand side reacts mostly on feed, because food demand is more inelastic than feed demand, especially for cereals. In the case of oilseeds, feed response is lower and sometimes even negative (soybean), because the yield of protein meals per unit of fuel is stronger than the yield of DDGS for cereals based ethanol and boosts the consumption of other feedstuffs. Co-products themselves are accounted for in a different category (yellow bars) and are directly related to the technical coefficients in the crushing or biofuel supply chain. In many cases, yield is found to be an important contributor. However, some crops do not respond in yield in the model response, in particular sugar crops, because marginal yields are found to be lower than average yields for these crops. For cereal straw, yield response corresponds to use of unsustainable removal rates where straw was previously harvested within sustainable rate limits. Perennials and short rotation crops mainly provide the extra production though area increase, because only one management type is considered for these in the model.

As stated above, yield increases induced by additional biofuel demand are significant. How does the estimated yield on ‘new’ arable land compare with the average yield on the baseline arable area? The table below shows the marginal yield effect for each of the feedstock specific scenarios.

Table 10. Marginal production increase divided by marginal harvested area increase for the different feedstocks in each of the feedstock specific scenarios [t fresh matter per ha]. Only regions with production increases are shown. For perennial crops, newly planted areas are also accounted.

	Wheat	Maize	Barley	Maize silage	Sugar beet	Sugar cane	Rape seed	Soybeans	Sunflower	Palm oil	Perennial grasses
Latin America	4.7	5.9				69.5		3.2	2.0		
South Asia	3.4					46.6			1.0		
North America	6.6		4.7				3.3	4.2	3.1		
EU28	4.9	8.2	4.9	44.3	64.1		3.8	2.3	1.9		9.2
East Asia									3.4		
Southeast Asia		5.6						2.3		13.1	
Russia and neighbouring countries formerly part of the USSR	3.6							2.5	1.5		
Sub-Saharan Africa										3.9	
Oceania							1.4				
Middle-East North Africa	2.6		2.5						2.7		
Eastern Europe	4.7		2.8						2.4		
World	**4.9**	**7.5**	**4.6**	**44.3**	**64.1**	**67.4**	**3.2**	**3.7**	**1.9**	**12.8**	**9.2**

When coming to policy and explorative scenarios, all the different effects above balance across feedstocks and contribute to the mitigation of the shock.

4.1.4 Results comparison on land use change

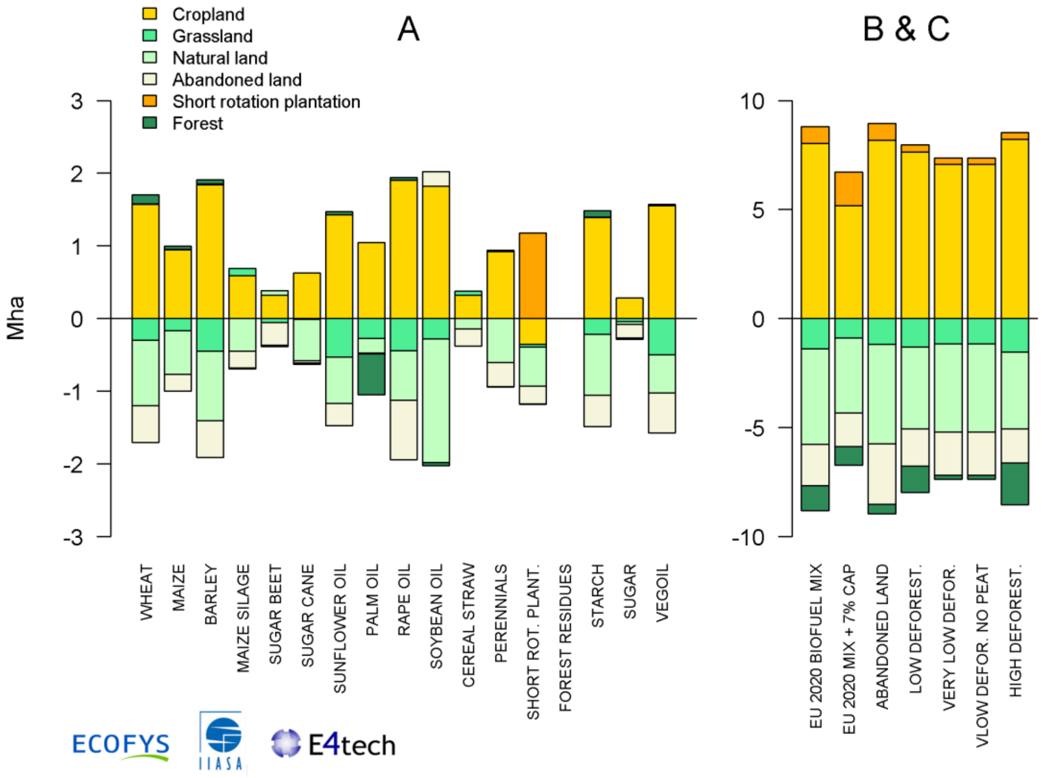


Figure 17: Overview of land use changes in the model in 2020 in feedstock scenarios (A) and policy and explorative scenarios (B & C) compared to the baseline

Figure 17 shows the differential amount of land use expansion in each cover type between the scenario and the baseline in 2020. Cropland reports all crop cultivation increases, but do not account for short rotation coppices that are singled out as energy plantations. This figure illustrates well the contrast in land use impact between high yielding crops (sugar beet, sugar cane, maize) and lower yielding crops (soybean, barley, sunflower, and (imported) rapeseed). It is noteworthy that forests are little affected for feedstock specific scenarios, with the exception of the palm oil scenario. Deforestation is, however, more impacted by the large land use changes associated with the policy and the explorative scenarios, except when some particular assumptions are made to limit its extent (abandoned land scenario and low deforestation scenarios for example).

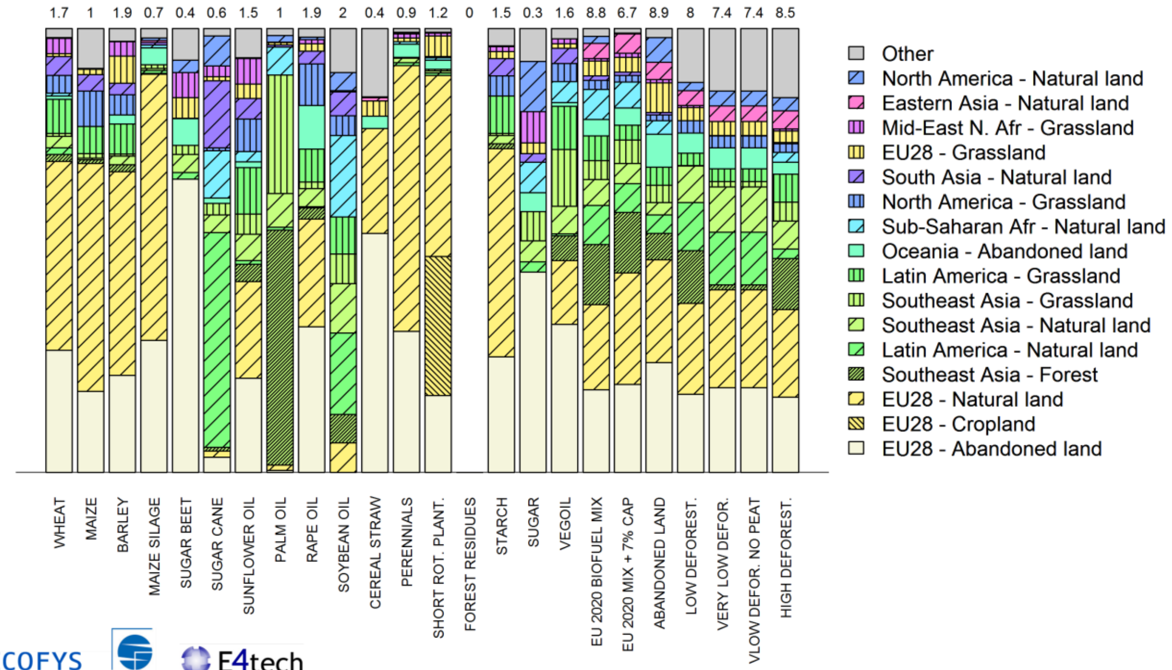


Figure 18: Overview of land use converted in different locations by 2020 in all scenarios compared to the baseline. Numbers on the top of the nar indicate the extent of total land use conversion in Mha

Figure 18 provides more detail about the location of LUC. Contribution of EU abandoned land is significant in most scenarios, with the exception of palm oil, sugar cane and soybean oil, for which the feedstocks are not grown in the EU. Among most converted land cover types outside of the EU, forest in Southeast Asia comes first, followed by other natural land and grassland in Latin America, other natural land and grassland in Southeast Asia, and only later comes changes in Oceania, Sub-Saharan Africa, or North America.

4.2 Detailed results by feedstock

The following pages present LUC emission results for the different conventional and advanced biofuel feedstocks in the form of factsheets. Some pages also look at feedstock group results (sugar crops, starch, vegetable oils) and policy scenario results (full NREAP, NREAP with a 7% incorporation limit for conventional biofuels). Each feedstock factsheet first provides information on the energy efficiency performance of the feedstock, usually a good indicator of the land use requirements. This efficiency corresponds to the amount of biofuel that can be produced from one hectare of land, assuming for each feedstock the average yield in the EU, according to the modelled yield projections, by 2020. The model results are then presented under the form of two indicators: land requirement/TJ (requirement of cropland and requirement of total agricultural land, i.e. cropland + grassland) and LUC emissions, which includes both “direct” and “indirect” land use emissions.

The impact of the shock is decomposed in each factsheet through a series of three graphs. The first graph (left hand-side) looks at the contribution of different channels that can buffer the initial area requirement for the additional biofuel feedstocks: i) demand change ii) co-product feedback on supply iii) yield response iv) area response. The first three elements are ‘ILUC dampening effects’, which limit the ILUC-effect. They are calculated directly on the basis of the model results on how much demand changes in response to the shock, and how much co-product is generated. The last effect, area response, leads to increased cultivation of feedstocks leading to changes in LUC and to GHG emissions (see paragraphs below). This decomposition is conducted for the feedstock demand, yield and co-product responses for the targetgroup alone (left bar) and for all crops contributions (right bar). The different elements of the decomposition always sum to 100%.

The second graph (central bar chart) represents the extent of LUC associated with the shock. This decomposition is obtained by summarising the land that disappears in each world region to be allocated to new agriculture or forestry uses. The total LUC is reported above the bar; it corresponds to a gross change, not to the net change (at the global level, land disappearance in one region, e.g. grassland in Brazil can be compensated by land expansion in another one, e.g. grassland in Europe). Since several types of land cover can expand in the model (cropland, grassland, plantations, abandoned land, etc.), the total land conversion should not be confused with cropland or even agricultural land expansion.

The third graph (right hand-side bar chart) corresponds to the cumulative change in terms of GHG emissions over the period of the shock in the different land use carbon stocks scrutinised in the study. Four carbon pools are monitored: i) living biomass in natural vegetation (forest, other natural vegetation, grassland) – this one is decomposed between emissions from land conversion and sequestration from vegetation reversion, ii) living biomass in crops and perennials, iii) soil organic carbon, iv) mineral carbon in organic soils (peat lands). The net cumulative emissions (including negative flows) are reported on the top of the bar. In addition, foregone sequestration is taken into account.

The descriptive text below the graphs further details the dynamics at play, firstly at the level of the feedstock market and subsequently for all feedstock markets and for global LUC.

Explanation of scenario result sheet

Biofuel type

Land use impact indicators

Energy productivity 2020: xx GJ ethanol/ha

Cropland and agricultural land displacement: xx ha/TJ and xx ha/TJ

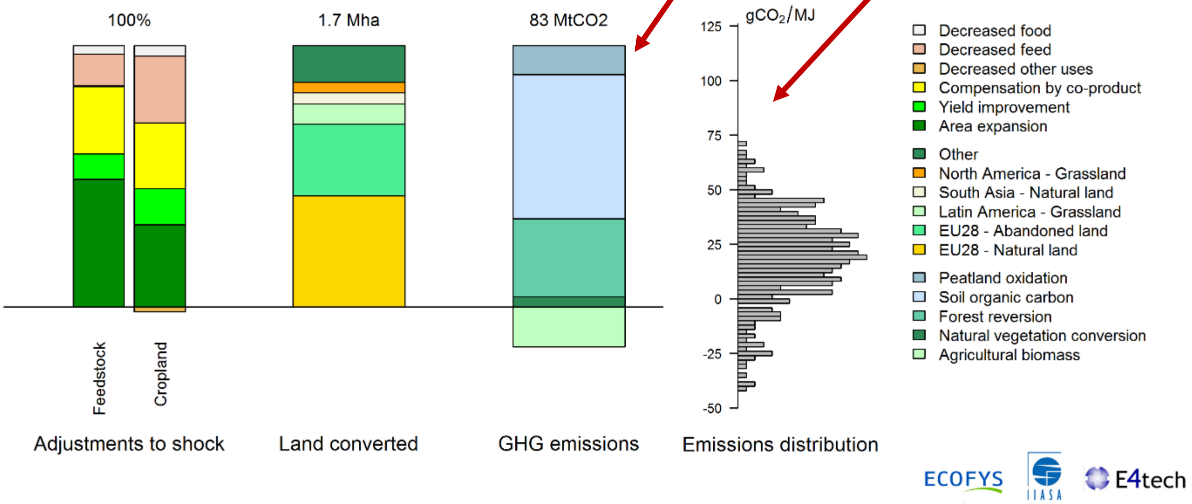
Land use emissions: xx gCO_2/MJ

Response to shock for target feedstock and for all crops

Land newly put in production

Total LUC-related GHG emissions (incl. agricultural biomass)

Land use change results with sensitivity analysis



Explanatory text

1) New feedstock requirements and decomposition of the response to the shock

Additional demand of 1% ethanol (123 PJ) is produced from

…

2) Feedstock new land requirement

Additional feedstock production is located in…

…

3) Adjustments in production and demand on global markets

Overall agricultural production is affected by…

…

4) Global land use change impacts

Land expansion requires…

…

5) Global land use emissions

Land use emissions are mainly associated to…

…

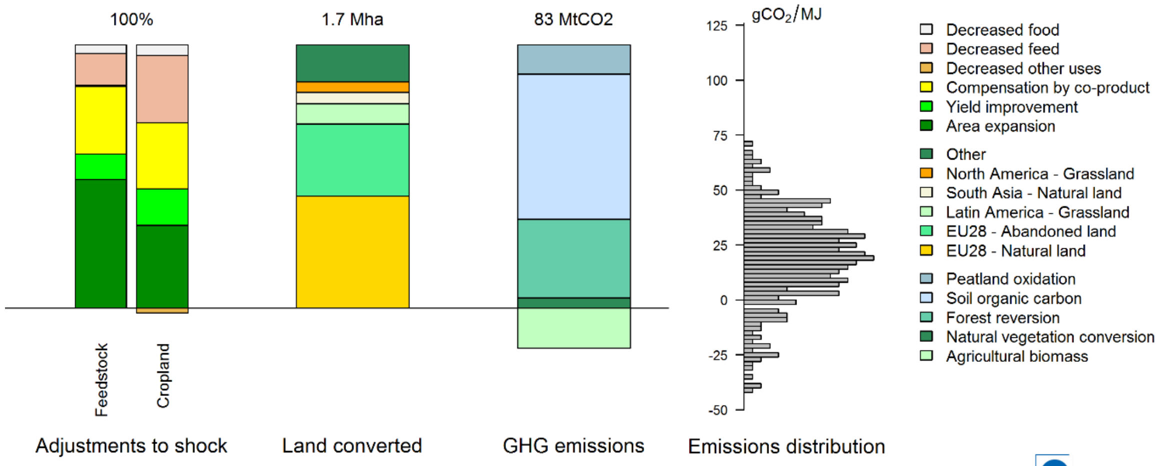
6) Land use change emission factor for a reference period of 20 years

Total land use emissions of 123 PJ additional wheat ethanol are…

…

4.3 Wheat ethanol

Energy productivity 2020	42 GJ ethanol/ha (equals 2000 litres/ha. EU28 avg., before accounting for co-products)
Cropland and agricultural land displacement: 12.8 ha/TJ and 10.4 ha/TJ	
Land use emissions:	**34 gCO_2/MJ**



ECOFYS IIASA E4tech

Additional demand of 1% ethanol (123 PJ) is produced from 16 million tons (Mt) of wheat, with 57.5% of additional production taking place in the EU. This shock leads to a price increase of wheat of 12% in the EU and 1.8% at the global level.

Adjustments to the shock

The additional feedstock supply is achieved 15% through a decrease in feed and, to a lesser extent, food demand; 26% by displacement of purpose-grown feed by co-product of ethanol; and 59% by extra production, with yield increase contributing 10% and area 49%. At the total cropland level, due in part to the impact on the livestock sector, feed demand declines even further (26%) and only 46% additional supply is required.

Additional feedstock production is located in the EU (7.2 Mt), North America (2.3 Mt), Latin America (1.5 Mt), and Russia, Ukraine and rest of Europe[30] (1.2 Mt). This new production requires an acreage of 1.5 million ha (Mha) in the EU, 340 kha in North America, 310 kha in Latin America and 310 kha in Russia, Ukraine and rest of Europe.

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[30] Rest of Europe designates here European Union neighbours, to the exception of Ukraine and states from the Commonwealth of Independent States (in particular Russia, Belarus, Moldova…), represented as two separate regions.

Overall agricultural production is affected by the expansion of wheat demand and total demand for cereals decreases by 3.6 Mt due to higher prices. Demand for protein meals (incl. DDGS) increases by 2.8 Mt as a result of the extra supply of biofuel co-products on the market.

Land Use Change effect

Land expansion requires conversion of 1.7 Mha of land globally, of which 1.6 Mha becomes new cropland. In the EU, cropland expands by 1.2 Mha, of which 490 kha is sourced from abandoned land by 2020 and 750 kha from other natural vegetation. North America and Latin America, extra wheat is produced on the current cropland, whereas in Ukraine and the rest of Europe, cropland expands at the expense of other natural vegetation (-100 kha). Oil palm plantation expands globally, because when DDGS displaces protein meals, it also decreases the production of their vegetable oil co-products and this triggers an increase in palm oil production.In Indonesia and Malaysia, new plantations represent 34 kha.

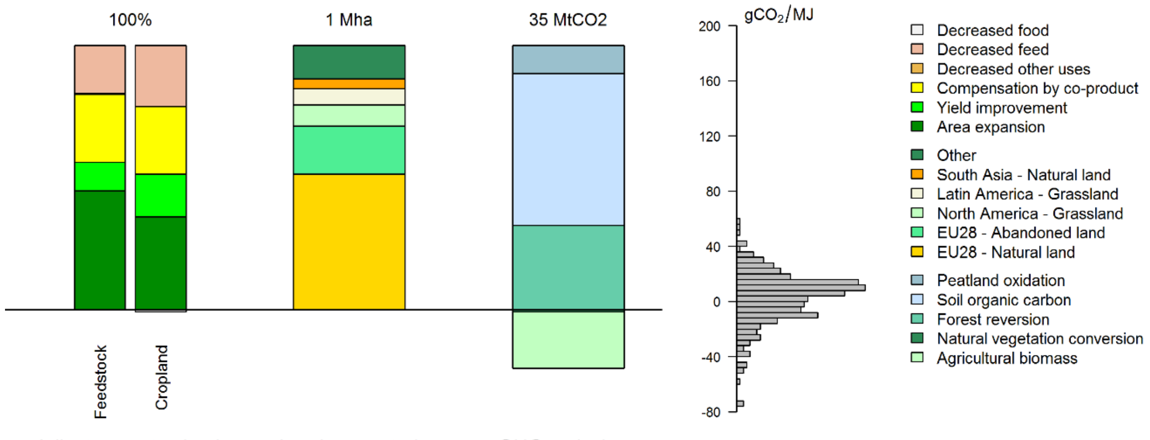
Land use change emissions

Land use emissions are mainly associated to soil organic carbon emissions with 54 $MtCO_2e$. Foregone carbon sequestration of abandoned land in the EU also increases by 29 $MtCO_2e$ following the shock due to expansion of cropland while additional carbon sequestration in crop biomass decreases emissions by 15 $MtCO_2e$.

Total land use emissions are 123 PJ. Additional wheat ethanol emissions are found to be 83 $MtCO_2e$. With an assumed 20 year amortisation this results in an LUC emissions factor of 34 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at 54 $MtCO_2e$, and the LUC emission factor would be 22 gCO_2e/MJ.

4.4 Maize ethanol

Energy productivity 2020:	64 GJ ethanol/ha (equals 3030 litres/ha. EU28 avg., before accounting for co-products)
Cropland and agricultural land displacement: 7.7 ha/TJ and 6.4 ha/TJ	
Land use emissions:	**14 gCO_2/MJj**



Additional demand of 1% ethanol (123 PJ) is produced from 14.2 Mt of corn, with 82% of additional production taking place in Europe. The shock leads to a price increase of 4% in the EU and 0.4% at the global level.

Adjustments to the shock

The additional feedstock supply is achieved 18% through a decrease in feed, with food demand hardly impacted, 26% by displacement of feed by co-products of ethanol, and 56% by extra production, where yield increases account for 11%.

Additional feedstock production is located in Europe (9.6 Mt), and Latin America (1 Mt). This new production requires acreage of 1.2 Mha in the EU, and 130 kha in Latin America.

Overall agricultural production is affected by maize acreage expansion and grain demand decreases of 2.8 Mt, while demand for protein meals (including DDGS) increases by 3.1 Mt.

Land use change effect

Land expansion requires 950 kha of additional land globally for cropland, most of it coming from the EU. In the EU, cropland expands 700 kha into other natural vegetation, whereas 250 kha are sourced from abandoned land. In Latin America, extra corn production substitutes soybean production, which is substituted by corn DDGS, and no cropland expansion is necessary.

In North America, production of soybean meal is also decreased and the decreased price of protein meals leads to more substitution for grain-based production systems, and 110 kha of grassland is returned to other natural vegetation.

Palm oil production increases to replace displaced soybean oil due to protein meal substitution and palm plantations expand globally by 10 kha.

Land use change emissions

Land use emissions are mainly associated with soil carbon changes on cropland (26 $MtCO_2$), most of it taking place in the EU, and emissions from foregone sequestration (14 $MtCO_2$). Carbon sequestration in agricultural crops decreases emissions by 10 $MtCO_2$.

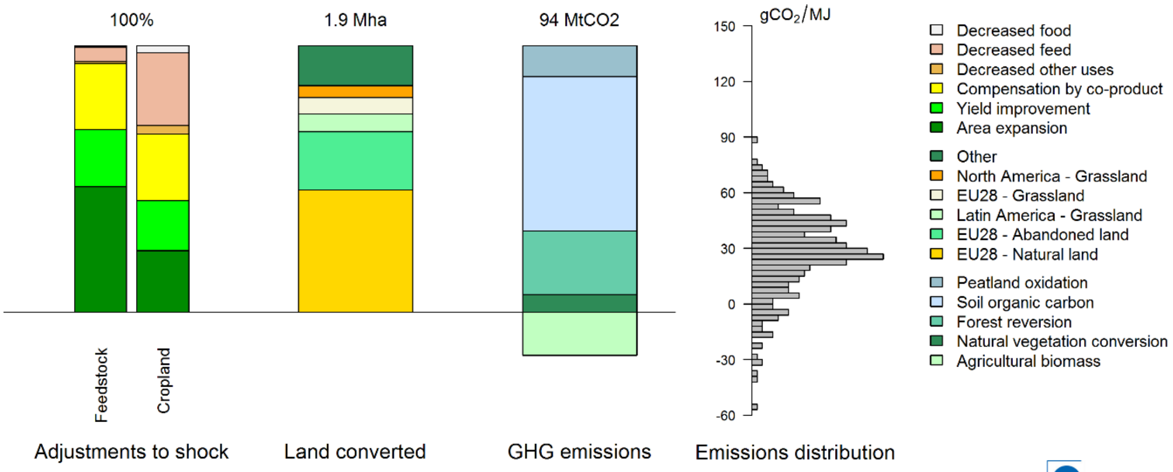
Total land use emissions of maize ethanol are found to be 35 $MtCO_2e$. With an assumed 20 year amortisation this results in an LUC emissions factor of 14 gCO_2e/MJ. One can note that this emission factor is much lower than for wheat. This can be explained by several reasons: first, corn yield in the EU28 is 40% higher per hectare than wheat yield in terms of energy productivity. This is the result of more heterogeneous yields for wheat across the EU. Additionally, maize DDGS contains less protein than wheat DDGS, so additional maize implies less soybean substitution (than in the case of wheat) and hence less decrease in soybean oil production. This in turn leads to less replacement by palm oil and thus less palm oil expansion. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower at 21 $MtCO_2e$ and the LUC emission factor would be 9 gCO_2e/MJ.

4.5 Barley ethanol

Energy productivity 2020: 38 GJ ethanol/ha (equals 1770 litres/ha. EU28 avg., before accounting for co-products)

Cropland and agricultural land displacement: 15.0 ha/TJ and 11.5 ha/TJ

Land use emissions: 36 gCO_2/MJ



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Additional demand of 1% ethanol (123 PJ) is produced from 16 Mt of barley, with 82% of additional production taking place in the EU. This shock leads to a price increase of barley of 18% in the EU and 6% at the global level.

Adjustments to the shock

Extra production from barley comes from 7% from demand, mainly feed, 25% from co-products and 69% from production, where yield increase account for 21% and area expansion for 47%.

Additional feedstock production is located in the EU (12.7 Mt), in North America (1 Mt) and in Ukraine and rest of Europe (0.4 Mt). This new production requires acreage of 2.6 Mha in the EU, 220 kha in North America and 150 kha in Ukraine and rest of Europe.

Overall agricultural production is also affected by decrease in demand for grains of 4.2 Mt globally and 4.9 Mt considering the EU alone. Demand for protein meals and DDGS increases by 2.7 Mt.

Land use change effect

Land expansion requires 1.9 million ha of additional land, which comes predominantly from conversion of other natural vegetation and grasslands to cropland. In the EU, cropland expands by 1.5 kha, of which 950 kha are sourced from other natural vegetation, 460 kha from abandoned land and 130 kha from grassland. Cropland increases in Ukraine and rest of Europe expand by 110 kha but global forest area decreases by only 60 kha overall. Oil palm plantations expand as a result of co-product substitution, with an increase of 40 kha in South East Asia.

Land use change emissions

Land use emissions are mainly associated with emission from soil organic carbon (65 $MtCO_2e$), emissions from foregone sequestration on abandoned land (27 $MtCO_2$), and peat land emissions (13 $MtCO_2e$). Agricultural crops sequester additional 18 $MtCO_2e$.

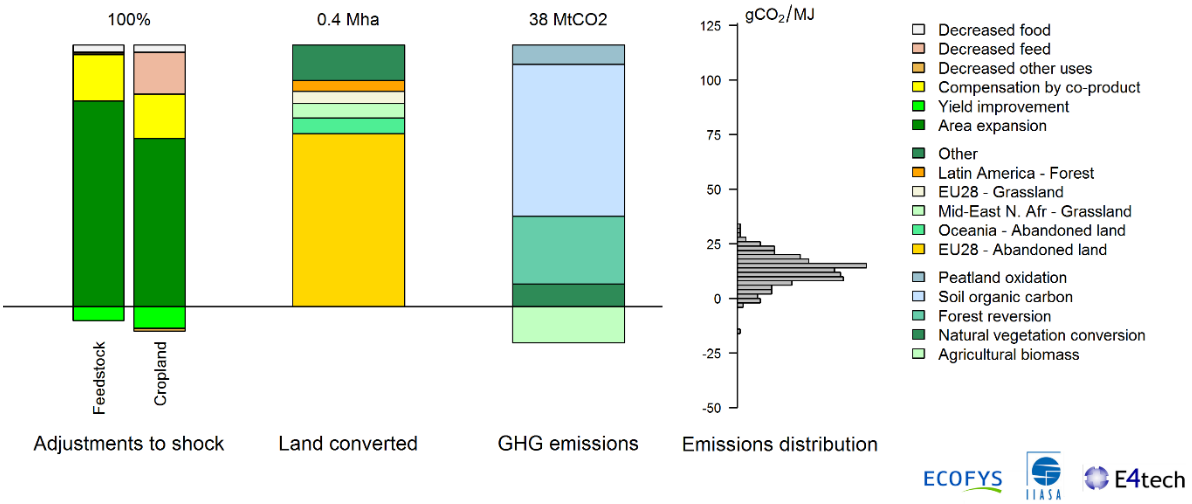
Total land use emissions of barley ethanol are found to be 94 $MtCO_2e$. With an assumed 20 year amortisation this results in an LUC emissions factor of 38 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at 67 $MtCO_2e$, and the LUC emission factor would be 27 gCO_2e/MJ.

4.6 Sugar Beet ethanol

Energy productivity2020: 145 GJ ethanol/ha (equals 6840 litres/ha. EU28 avg., before accounting for co-products)

Cropland and agricultural land displacement: 2.6 ha/TJ and 2.2 ha/TJ

Land use emissions: **15 gCO_2/MJ**



Additional demand of 1% ethanol (123 PJ) is produced from 58 Mt of sugar beet, with 100% of additional production taking place in the EU. This shock leads to a price increase of 7.4% at the European level.

Adjustments to the shock

The additional feedstock is achieved 4% through a decrease in food and feed demand, 19% by displacement of feed by co-product of ethanol and 77% by extra production, which occurs fully through expansion. Slightly lower yield in the newly producing land contributes negatively to the adjustments (-6%).

Additional feedstock production is exclusively located in Europe (55 Mt) and requires acreage of 860 kha.

Overall agricultural production is also affected by the additional sugar beet demand and global demand for grains. Beside the decrease in sugar crop demand of 3.0 Mt, cereals demand decreases by 3.2 Mt. Protein meals and DDGS increase by 3.0 Mt, while vegetable oil demand is barely impacted (-0.1 Mt).

Land use change effect

Land expansion leads to 320 kha of additional cropland globally, which expands mostly into abandoned land. Cropland expands by 220 kha, of which 200 kha are sourced from abandoned landand other natural vegetation and 20 kha is sourced from grassland.

Land use change emissions

Land use emissions are mainly associated with soil carbon changes in cropland (26 $MtCO_2$). Reversion in natural vegetation accounts for 11 $MtCO_2$ and carbon sequestration in agricultural crops decreases emissions by 6 $MtCO_2$.

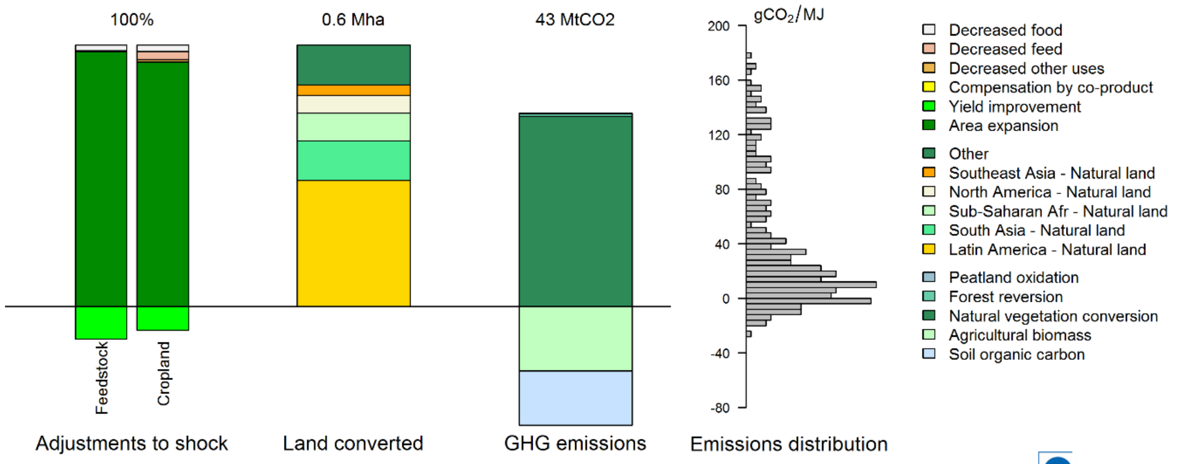
Total LUC emissions of sugar beet ethanol are found to be 38 $MtCO_2e$. With an assumed 20 year amortisation this results in an LUC emissions factor of 15 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower at 27 $MtCO_2e$ and the LUC emission factor would be 11 gCO_2e/MJ.

4.7 Sugar Cane ethanol

Energy productivity 2020: 118 GJ ethanol/ha (equals 5,570 litres/ha)

Cropland and agricultural land displacement: 5.1 ha/TJ and 5.0 ha/TJ

Land use emissions: 17 gCO_2/MJ



Additional demand of 1% ethanol (123 PJ) is produced from 69 Mt of sugar cane, taking place mainly in Latin America. This shock leads to a price increase of 0.8% in Brazil, but has negligable impact at the global level.

Adjustments to the shock
The additional feedstock is mostly achieved through extra production (97%), with a slight decrease in yield due to lower suitability of land used by marginal expansion (-14%).

Additional feedstock production is predominantly located in Latin America (63 Mt), which requires acreage of 900 kha, and 4 Mt in South Asia (90 kha).

Overall agricultural production is also affected by a decrease in sugar crop demand of 0.7 Mt in Latin America and 0.8 Mt in South Asia. At the global level, sugar crop demand decreases by 2.1 Mt and grains demand decreases by 500 kt in response to some slight price increases in Brazil and its trade partners.

Land use change effect
Land expansion totals 0.6 Mha of net land expansion globally. The majority of this total expansion takes place in Latin America, where cropland expands 320 kha at the expense of other natural vegetation. In South Asia, where sugar cane yield are much lower, cropland expands by 70 kha, also at the expense of other natural vegetation.

Land use change emissions

Land use emissions are mainly associated with the conversion of other natural vegetation and primary forests (109 $MtCO_2$). Soil organic carbon stock increase by 31 $MtCO_2e$ globally, driven by the expansion of sugar cane, and 37 $MtCO_2$ are sequestered in biomass.

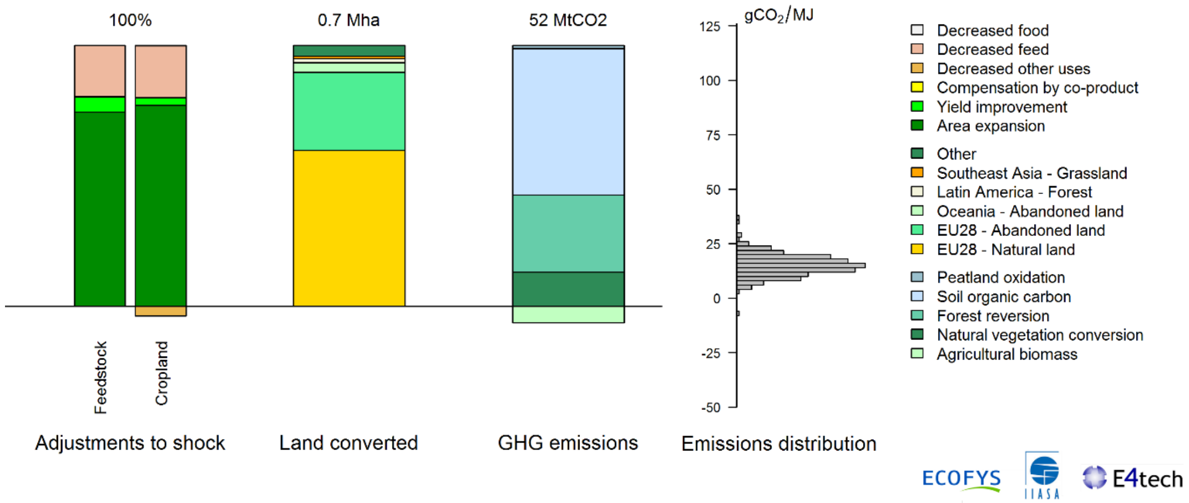
Total land use emissions of sugar cane ethanol are found to be 43 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of 17 g CO_2e/MJ. Changing assumptions on the natural vegetation regrowth on abandoned agricultural land in absence of biofuels does not affect the final result here.

4.8 Silage Maize biogas

Energy productivity 2020: 123 GJ biogas/ha (EU28 avg., before accounting for co-products)

Cropland and agricultural land displacement: 4.8 ha/TJ and 5.6 ha/TJ

Land use emissions: 21 gCO_2/MJ



Additional demand of 1% biogas (123 PJ) is produced from 41.4 Mt of silage maize (fresh matter), with 100% of additional production taking place in the EU. This shock leads to a price change of 29.5% at the EU level.

Adjustments to the shock

The additional feedstock is achieved 20% through a decrease in feed demand, 74% by area expansion and 6% through yield increase.

Additional feedstock production is located in the EU (33.2 million tonne). This new production requires acreage of 750 kha in Europe.

Overall agricultural production in the EU is also affected by a decrease in demand of 570 kt of grains, 171 kt of sugar crops and 240 kt of protein meals.

Land use change effect

Land expansion leads to conversion of 0.7 Mha globally, if which 590 kha are needed for additional cropland and 100 kha for grassland globally. In the EU, cropland expands by 560 kha and grassland by 70 kha, of which 210 kha are sourced from abandoned land and 420 from other natural vegetation. Land use in regions outside the EU is hardly affected.

Land use change emissions

Land use emissions are mainly associated with soil organic carbon,with 31 $MtCO_2e$ emitted globally following the shock. Foregone carbon sequestration in the EU also comes as a significant emission source (16 $MtCO_2e$).

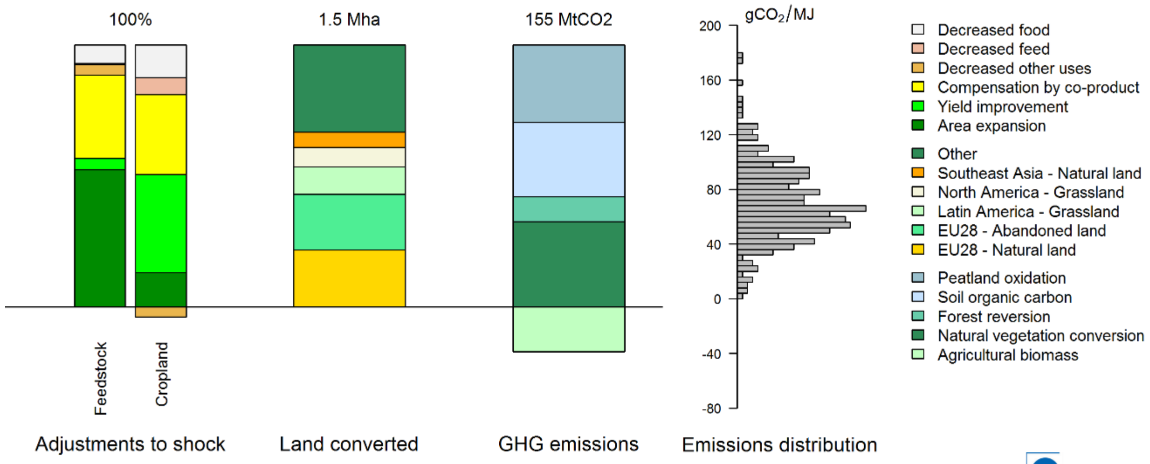
Total land use emissions of silage maize biogas are found to be 52 $MtCO_2e$. With an assumed 20 year amortisation this results in an LUC emissions factor of 21 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower and the LUC emission factor would be 15 gCO_2e/MJ.

4.9 Sunflower oil biodiesel

Energy productivity 2020: 24.5 GJ biodiesel/ha (equals 740 litres/ha. EU28 avg., before accounting for co-products)

Cropland and agricultural land displacement: 11.6 ha/TJ and 7.3 ha/TJ

Land use emissions: 63 gCO_2/MJ



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Additional demand of 1% FAME (123 PJ) is produced from 3.5 Mt of sunflower oil, with 28% of additional production taking place in the EU. This shock leads to a price increase of 8.1% on sunflower seeds, and 16.7% on sunflower oil in Europe. At the global level, the price impacts are 5.2% and 8.3% for sunflower seed and oil, respectively.

Adjustments to the shock

The additional feedstock is achieved 12% through a decrease in food and feed demand, 32% by displacement of feed by sunflower meal and 57% by extra production, of which 52% is from area expansion and 4% from yield increase.

Additional feedstock production requires 6.1 Mt of sunflower globally, located in the EU (1.7 Mt), Ukraine and rest of Europe (1.7 Mt), in Russia and its neighbouring countries formerly part of the USSR (1.3 Mt) and in Latin America (0.9 Mt). This new production requires acreage of 870 kha in the EU, 660 kha in Ukraine and rest of Europe, 860 kha in Russia and its neighbors and 450 kha in Latin America.

Overall agricultural production is also affected globally by an increase in consumption of 2.1 Mt of protein meals and the displacement of 530 kt of vegetable oils on the demand side. Extra availability of protein meals leads to increased feed consumption. Meat production increases by 130 kt globally and milk by 120 kt.

Land use change effect

Land expansion leads to 1.5 Mha of additional land conversion globally, mainly for cropland. In the EU, cropland expands by 625 kha of which 290 kha are sourced from abandoned land and 290 kha from other natural vegetation. In Ukraine and rest of Europe, cropland expands by 270 kha mainly into other natural vegetation. Global grassland also decreases by 530 kha as protein meals availability favors grain-based production systems instead of grass-based ones, in particular in Latin America (-140 kha). At the same time, palm oil plantation expands by 160 kha in Southeast Asia, which leads to 50 kha of extra deforestation in the region. Deforestation however decreases in Latin America by 100 kha, due to lower expansion of grassland.

Land use change emissions

Land use emissions are mainly associated to soil carbon changes in cropland (53 $MtCO_2$), natural vegetation conversion emissions (61 $MtCO_2e$) and peatland emissions (56 $MtCO_2e$). Carbon sequestration in agricultural crops decreases emissions by 32 $MtCO_2$.

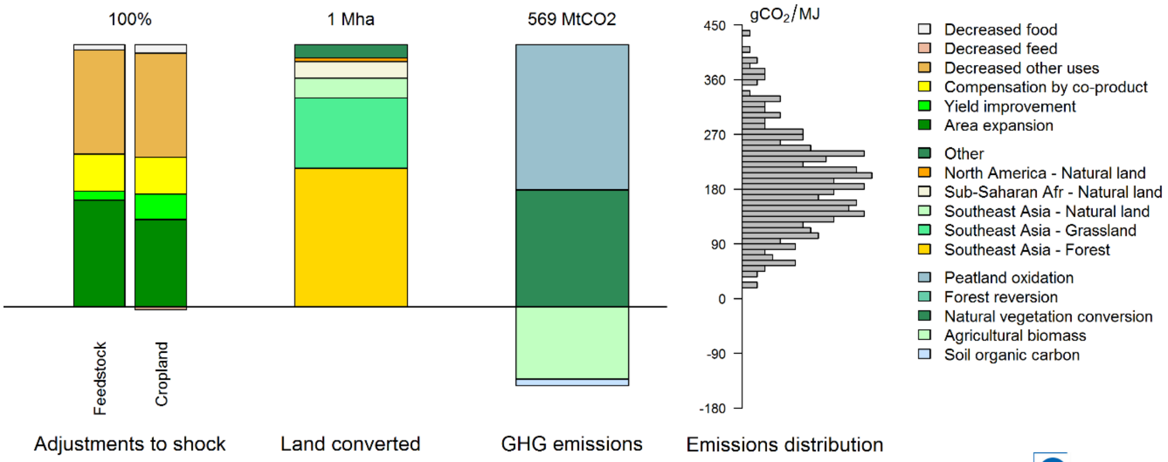
Total land use emissions of sunflower FAME are found to be 155 $MtCO_2e$. With an assumed 20 year amortisation this results in a resulting LUC emissions factor of 63 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at 137 $MtCO_2e$, and the LUC emission factor would be 56 gCO_2e/MJ.

4.10 Palm oil biodiesel

Energy productivity 2020: 88 GJ biodiesel/ha (equals 2660 litres/ha)

Cropland and agricultural land displacement: 8.5 ha/TJ and 6.3 ha/TJ

Land use emissions: 231 gCO_2/MJ



Additional demand of 1% FAME (123 PJ) is produced from 3.5 Mt of palm oil. This shock leads to a price increase of 3.1% on palm fruit in Southeast Asia and 4.2% on the price of palm oil regionally. At the global level, impact on palm oil price is 2.1%.

Adjustments to the shock

The additional feedstock is achieved 42% through a decrease in food (2%) and other uses (40%) demand, 14% through co-product substitution (palm kernel) and 44% by extra production.

Additional feedstock production is mainly located in South East Asia (3.1 Mt) and requires acreage of 1.2 Mha palm oil plantations.

Overall agricultural production is also affected globally by a decrease in demand of 0.6 Mt of sugar crops and the displacement of 210 kt of grains and 270 kt of vegetable oils on the demand side.

Land use change effect

Land expansion leads to 1.0 Mha of additional land conversion globally, with new cropland at the expense of grassland, other natural vegetation and forest area. In Southeast Asia, cropland expands by 930 kha, of which 290 kha are sourced from grassland, 80 kha from other natural vegetation and 570 kha from primary forest. Increase in palm oil plantations remains more limited in other regions, with only 40 kha in Sub-Saharan Africa.

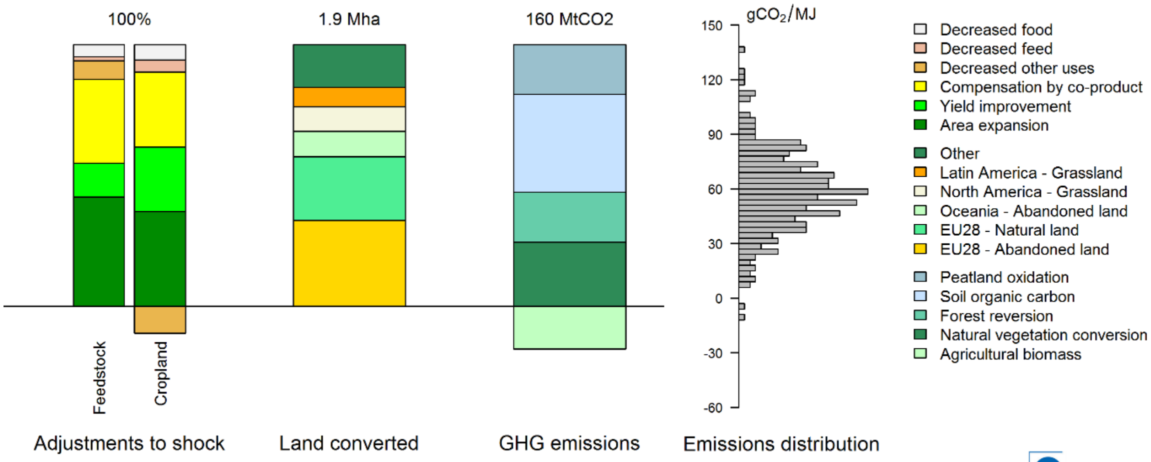
Land use change emissions

Land use emissions are mainly associated to natural vegetation conversion emissions (362 $MtCO_2e$) and peat land emissions (450 $MtCO_2e$). Carbon sequestration in biomass (-224 $MtCO_2e$) and soil carbon sequestration (-19 $MtCO_2e$) decrease emissions.

Total land use emissions of palm oil FAME are found to be 569 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of 231 gCO_2e/MJ. Changing assumption on the natural vegetation regrowth on abandoned agricultural land in absence of biofuels does not affect the final result here.

4.11 Rapeseed oil biodiesel

Energy productivity 2020:	52 GJ biodiesel/ha (equals 1570 litre/ha. EU28 avg., before accounting for co-products)
Cropland and agricultural land displacement: 15.5 ha/TJ and 11.9 ha/TJ	
Land use emissions:	**65 gCO_2/MJ**



Additional demand of 1% FAME (123 PJ) is produced from 3.5 Mt of rapeseed oil, with 41% of additional production taking place inside the EU. This shock leads to a price increase of 25% for the price of rapeseed and 28% for the price of rapeseed oil in the EU. At the global level, impacts on seed and oil prices are 5.3% and 7%, respectively.

Adjustments to the shock

The additional feedstock is achieved 13% through a decrease in food and feed demand, 32% by displacement of feed by co-product of biodiesel and 54% by extra production.

Additional feedstock production corresponds to 6.2 Mt of rapeseed, mainly located in the EU (3.0 Mt), North America (2.6 Mt) and Oceania (0.5 Mt). This requires acreage of 790 kha in the EU, 780 kha in North America and 350 kha in Oceania.

Overall agricultural production is also affected globally by an increase in consumption of protein meal of 2.3 Mt and the decrease of 720 kt in vegetable oil demand. Grain demand increases by 1.1 Mt to serve as feed complement to newly consumed protein meals, whereassugar crops demand decreases by 1.7 Mt. The livestock sector benefits from the extra feed production and meat and milk production increase globally by 130 kt and 330 kt, respectively.

Land use change effect

Land expansion requires 1.9 Mha of additional cropland globally. In the EU, cropland expands by 1.1 Mha, of which 630 kha is into abandoned land and 470 kha is into other natural vegetation. Global grassland decreases by 440 kha as protein meal availability favors grain-based production systems over grass-based ones, in particular in Latin America (-140 kha) and North America (-180 kha). At the same time, palm oil plantation expands by 110 kha in Southeast Asia, which leads to 50 kha of extra deforestation in the region. Deforestation, however, decreases in Latin America by 80 kha, due to lower expansion of grassland.

Land use change emissions

Land use emissions are mainly associated with soil carbon changes (72 $MtCO_2e$), peatland emissions (36 $MtCO_2e$) and foregone sequestration (36 $MtCO_2e$). Carbon sequestration in palm plantations decreases emissions by 31 $MtCO_2e$.

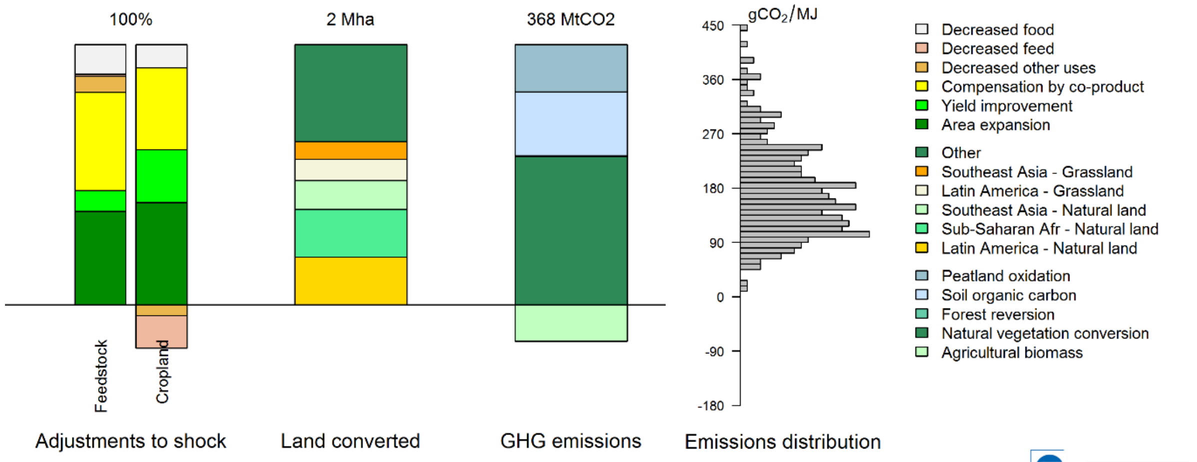
Total land use emissions of rapeseed FAME is found to be 160 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of 65 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at 124 $MtCO_2e$, and the LUC emission factor would be 50 gCO_2e/MJ.

4.12 Soybean oil biodiesel

Energy productivity 2020: 17 GJ biodiesel/ha (equals 530 litres/ha. EU28 avg., before accounting for co-products)

Cropland and agricultural land displacement: 14.8 ha/TJ and 12.6 ha/TJ

Land use emissions: **150 gCO$_2$/MJ**



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Additional demand of 1% FAME (123 PJ) is produced from 3.5 Mt of soybean oil, with 9.8% of additional production taking place inside the EU. This shock leads to a price increase of 2.3% for soybean and 10.8% for soybean oil at the global level.

Adjustments to the shock

The additional feedstock is achieved 18% through a decrease in food and feed demand, 38% by displacement of feed by soybean meal and 44% by extra production, in which area expansion accounts for 36% and yield increase for 8%.

Additional feedstock production requires 7.3 Mt of extra soybeans locally, mainly located in North America (4 Mt) and Latin America (2.7 Mt). This requires an area of 960 kha in North America and 860 kha in Latin America. Inside the EU, soybean production increases by 570 kt, which corresponds to 250 kha.

Overall agricultural production is also affected globally by an increase in consumption of protein meal by 5.9 Mt and the decrease of 1.4 Mt in demand for vegetable oils. Grain demand increases by 1 Mt to serve as feed complement to newly consumed protein meals, whereas sugar crops demand decreases by 0.9 Mt. The livestock sector benefits notably from the extra feed production and meat and milk production increase globally by 620 kt and 1,280 kt, respectively.

Land use change effect

Land expansion leads to 2.0 Mha of land conversion globally, 1.8 Mha of which corresponds to additional cropland. In Latin America, cropland expands (500 kha) mainly into other natural vegetation (420 kha), whereas grassland decrease (-190 kha) due to protein meal availability, which favors grain-based production systems instead of grass-based ones. As a consequence, deforestation decreases by 120 kha. The same effect is observed North America, where cropland expansion (190 kha) partly benefits from grassland decrease (-100 kha) and expands into other natural vegetation for only 90 kha. At the same time, palm oil plantation expands by 240 kha in Southeast Asia and cereal production also grows to provide more animal feed. This leads to 560 kha of cropland expansion in the region, replacing 160 kha of grassland, 150 kha of primary forest and 260 kha of other natural vegetation.

Land use change emissions

Land use emissions are mainly associated with LUC emissions (244 $MtCO_2e$), soil carbon changes (105 $MtCO_2e$) and peatland emissions (78 $MtCO_2e$). Carbon sequestration in biomass decreases emissions by 60 $MtCO_2e$.

Total land use emissions of soybean FAME are found to be 368 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of 149 gCO_2e/MJ. Changing assumption on the natural vegetation regrowth on abandoned agricultural land in absence of biofuels does not affect the final result here.

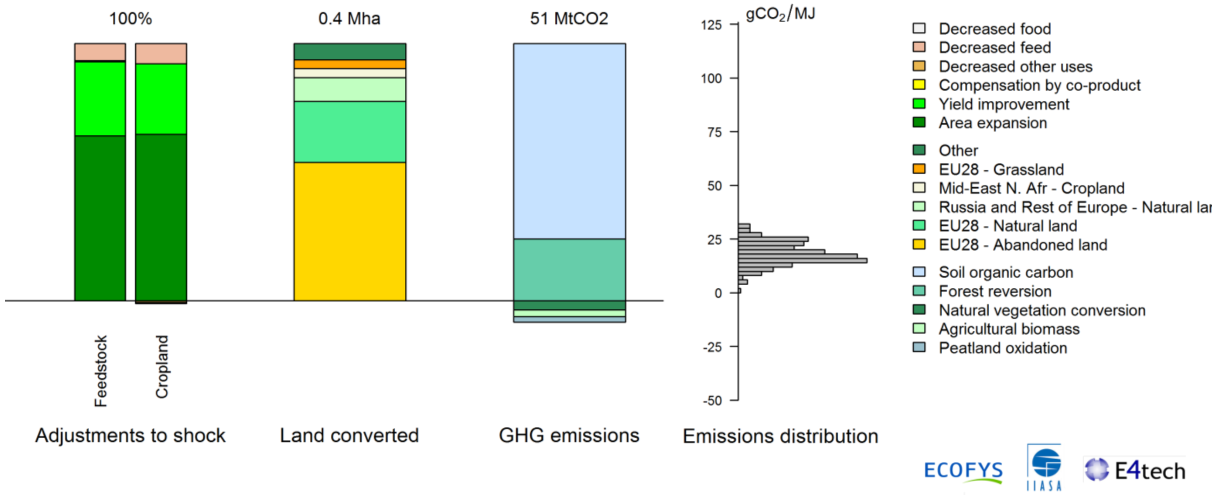
4.13 Cereal straw ethanol produced in the EU

Full EU28 1% shock

Energy productivity 2020: 15 GJ ethanol/ha (EU28 avg., equals 710 litres/ha)

Cropland and agricultural land displacement: 2.0 ha/TJ and 2.3 ha/TJ

Land use emissions: 16 gCO$_2$/MJ



Additional demand of 1% straw ethanol (123 PJ) in the EU is produced from 20.5 Mt of cereal straw, with 100% of additional production taking place in Europe.

Adjustments to the shock
Most of the new demand is fulfilled through extra production (93%), although 7% comes from a decrease in animal demand and other uses. Expansion of area where residues are harvested contributes 64% of the biofuel demand through sustainable systems and 29% from intensification of removal in countries where sustainable removal is not sufficient to meet demand.

Additional feedstock production amounts to 19.1 Mt and requires residues to be removed from an additional 7.3 Mha in the EU. Harvesting management also varies, to accommodate the new demand. In total, 5.0 Mha are newly harvested under sustainable management (see Appendix II.1 for the definition of this type of management in each region). In addition, 2.3 Mha corresponds to removal rates of more than 33-50%, with corresponding yield and soil organic carbon impacts. This unsustainable removal mainly occurs in the Netherlands, Belgium, Greece, Hungary, Ireland, Italy, Poland and the UK. In the Netherlands, Lithuania and Portugal, supply even reaches its limit, leading to substitution of straw in the livestock sector.

Overall agricultural production is only marginally affected by the additional cereal straw demand. Grain production is affected by some yield decrease in cases where more than 33-50% of straw is removed, but the additional market value for cereal production coming from residues also leads to a decrease in price of wheat (-1.3%) in Europe, and an overall increase in grain production of 0.3 Mt.

Land use change effect

Land use conversion amounts to 0.4 Mha. This only concerns cropland expansion in the EU for extra cereals, two thirds of which isinto abandoned land and one third in other natural land.

Land use change emissions

Land use emissions result from this conversion of land for new cropland and from the soil organic carbon impact of removing residues in case of unsustainable management. Soil organic carbon emissions account for 42 $MtCO_2e$ and foregone sequestration from forest reversion for 13 $MtCO_2e$.

Total land use emissions are found to be 51 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of 16 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at 38 $MtCO_2e$, and the LUC emission factor would be 11 gCO_2e/MJ.

Country specific results

Due to the heterogeneity of situations in straw market across Europe, we present below some additional results showing contrasting situations in different EU countries. We look at the impact of removing residues for three specific regions: Hungary, where the market is particularly tight and the sustainability threshold is met; the UK, where straw is largely used and additional production could push the production beyond the sustainability threshold, and France, where a large reserve of residue supply exists. The impacts for these three regions are provided in Figure 19 below.

In Hungary, the shock of straw ethanol demand leads to some large effects, as most of the additional straw comes from unsustainable management and impacts soil organic carbon and yields. The span of LUC impact ranges for the full distribution, from -75 to 150 gCO_2/MJ, with an average impact of 60 gCO_2/MJ. Most values are in the range 13-113 gCO_2/MJ (without first and last decile).

In the UK, 40% of the supply can be obtained by increase removal of straw under sustainable management, but 60% is sourced from removal above 40%. As a result, impacts on yield and soil organic carbon occur and the range of impact goes from -30–80 gCO_2/MJ, with most of the distribution in the range 4–39 gCO_2/MJ. The average value for the UK is 20 gCO_2/MJ, which is close to the average EU effect presented above.

In contrast, in France, all the additional straw supply occurs through increase of straw removal well below the sustainable removal rate. Impacts are then invisible, with an average value of 0 gCO_2/MJ.

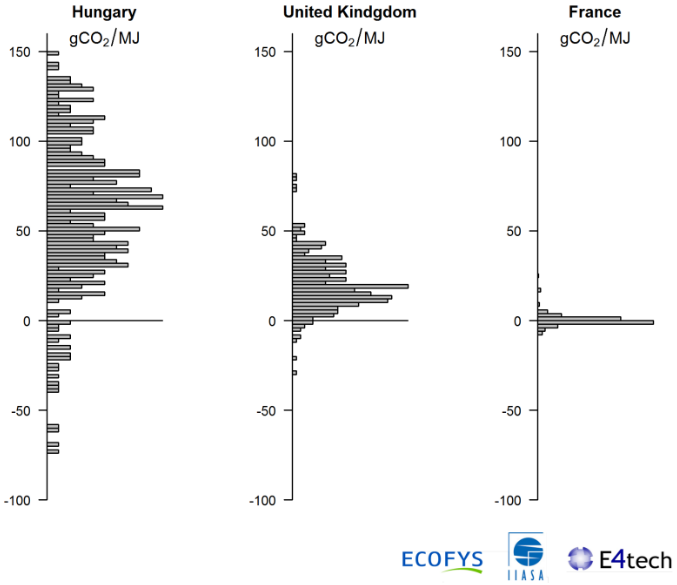


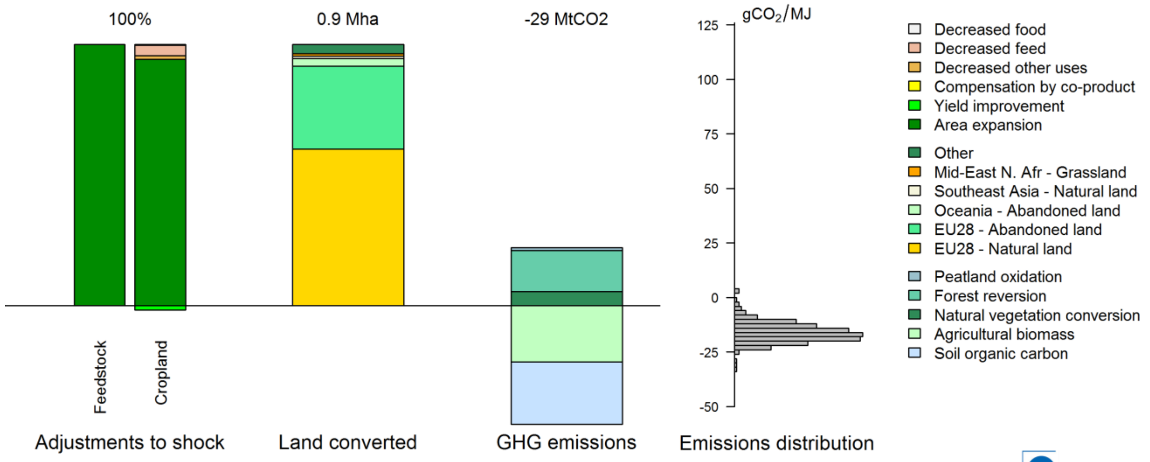
Figure 19: Impact on LUC emissions of 1% incorporation of straw ethanol in national transportation targets of Hungary, UK and France

4.14 Miscanthus and switchgrass FT biodiesel produced in the EU

Energy productivity 2000-2030: 90 GJ biodiesel/ha (EU28 avg., without accounting for co-products)

Cropland and agricultural land displacement: 7.5 ha/TJ and 7.7 ha/TJ

Land use emissions: -12 gCO$_2$/MJ



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Additional demand of 1% FT diesel (123 PJ) is produced from 13.1 Mt DM of annual grassy crops (miscanthus, switchgrass), with 100% of additional production taking place in the EU.

Adjustments to the shock

All the grassy crop expansion comes from acreage increase but other crops adjust through demand (8%). Yield contributions are slightly negative (-3 %).

Additional feedstock production is located in the EU (13.1 Mt). This new production requires acreage of 1.4 Mha in the EU. Production is based mainly on switchgrass (9.3 Mt) in Western, South and Central EU, and miscanthus (3.9 Mt) in Northern EU. Average yield for miscanthus/switchgrass is assumed to be 10.5 t dry matter/ha in Northern Europe, 9.2 t dm/ha in Central Europe and 9 t dm/ha in Western Europe. Switchgrass is assumed yield of 7.4 t dm/ha in Southern Europe, 8.7 t dm/ha in Eastern Europe and 10.1 t dm/ha in Western Europe.

Overall agricultural production is also affected by additional feedstock demand and grain demand decreases of 360 kt globally. Moreover, 100 kt of sugar crops, 40 kt of protein meals, 70 kt of meat and 170 kt of milkare displaced on the demand side.

Land use change effect

Land expansion requires 920 kha of additional cropland and 20 kha of grassland globally. In Europe, cropland expands by 890 kha, of which 300 kha is sourced from abandoned land and 580 kha from other natural vegetation. Outside Europe, only a small LUC takes place.

Land use change emissions

Land use emissions are mainly associated with the forgone carbon sequestration in Europe (19 $MtCO_2e$) and LUC emissions (7 $MtCO_2e$). Soil organic carbon stocks increase by 30 $MtCO_2e$ following the shock. Additional carbon sequestration in agricultural crops increases by 27 $MtCO_2e$.

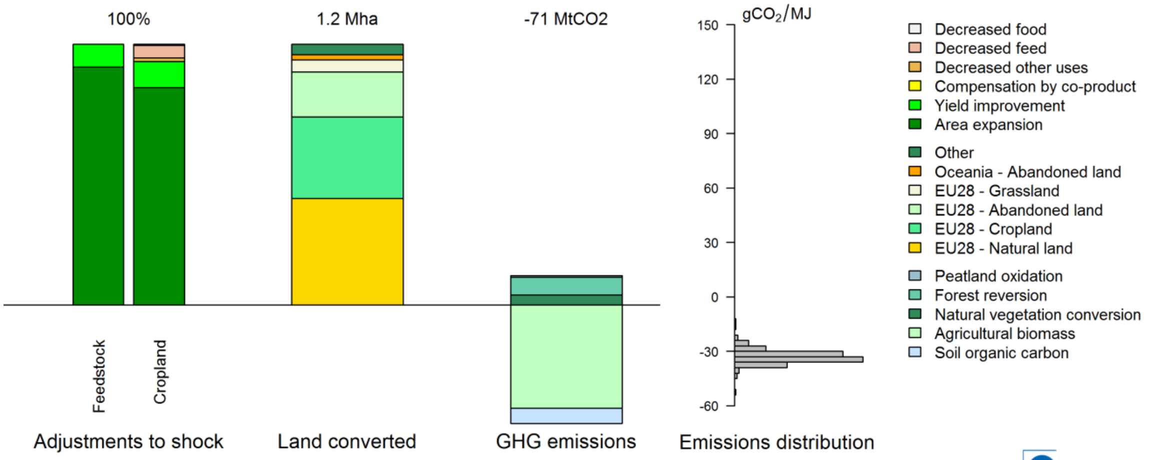
Total land use emissions of grassy FT biodiesel are found to be --29$MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of -12 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at -48 $MtCO_2e$, and the LUC emission factor would be -20 gCO_2e/MJ.

4.15 Short Rotation Plantation FT biodiesel produced in the EU

Energy productivity 2000-2030: 97 GJ biodiesel/ha (EU28 avg)

Cropland and agricultural land displacement: -2.85 ha/TJ (excluding SRC) and 6.4 ha/TJ (including SRC).

Land use emissions: -29 gCO_2/MJ



Additional demand of 1% FT diesel (123 PJ) is produced from 13.1 Mt of woody biomass (short rotation coppice), with 100% of additional production taking place in the EU.

Adjustments to the shock

Extra supply occurs 91% through increase in planted areas and 9% through increase in yield of coppice produced in the EU.

Additional feedstock production is located in the EU and requires acreage of 1.2 Mha in the EU.

Overall agricultural production is also affected by additional decreases of 240 kt in demand for grains inside the EU. Moreover, 160 kt of sugar crops, 50 kt of meat products and 180 kt of milk are displaced on the demand side, which shows the effect of competition between energy plantations and cropland.

Land use change effect

Land expansion requires 1.2 Mha of additional land globally, of which 1.2 Mha areplantations in the EU. Cropland decreases by 390 kha, grassland by 60 kha, other natural vegetation by 510 kha and abandoned land by 220 kha. Inside the EU, plantations mainly displace green fodder and fallow (-190 kha), wheat (120 kha) and oats (40 kha). Outside EU, only small LUC takes place (below 10 kha).

Land use change emissions

Land use emissions are mainly associated to carbon sequestration through afforestation (-82 $MtCO_2e$) and soil carbon change (-12 $MtCO_2e$), while emissions from forgone carbon sequestration on abandoned land increase by 14 $MtCO_2e$ globally.

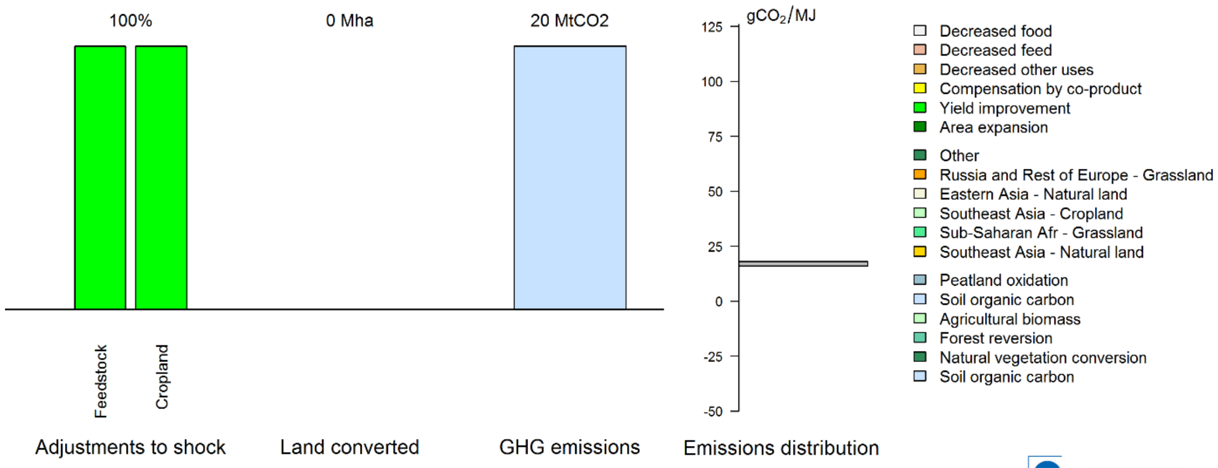
Total land use emissions of short rotation coppice FT biodiesel are found to be -71 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of -29 gCO_2e/MJ**.** If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at -89 $MtCO_2e$, and the LUC emission factor would be -35 gCO_2e/MJ. However, it should be kept in mind that short rotation plantations can only sequester more carbon than a regrowing forest if short period of time are considered. If accounting for forest regrowth for time periods beyond 20 years, the short rotation plantation would quickly become less efficient from a sequestration standpoint than a forest plantation.

4.16 Forest residues FT biodiesel produced in the EU

Energy productivity 2020: 5.8 GJ diesel/ha/y (EU28 avg.)

Cropland and agricultural land displacement: 0 ha/TJ and 0 ha/TJ

Soil organic carbon emissions: 17 gCO_2/MJ



Note: parameters tested in the sensitivity analysis do not change the results of this shock.

Residue availability from forest under sustainable management practice are estimated to be about 14.4 million m^3 in the EU28, which corresponds to about 7.2 million tons. Therefore, we apply a shock of only 0.5% for forestry residues (62 PJ), which corresponds to 6.6 Mt of forestry residues demand.

Forest residues considered here include: i) losses from the harvesting of roundwood at the harvesting site (i.e. rotten wood, piece of wood unsuitable for roundwood), excluding the bark (bark is assumed to be harvested and delivered to industry with roundwood); ii) all branches attached to the stem; iii) tops when dimensionally unsuitable for production of roundwood (threshold adjusted by country, e.g. 7-10 cm of diameter). No stumps are included. The amount of available residues we assume in our modelling is rather low because residues that are already in use for existing purposes are not taken into account. These sustainably harvested residues with no current uses can be processed into 68 PJ of biodiesel, which equals just over 0.5% of total EU transport fuel consumption in 2020. See Appendix III.3 for background surveys and literature on the various impacts of changing management.

Adjustments to the shock

Additional demand of 0.5% FT diesel (62 PJ) is produced from 13.1 Mm^3 of forest residues, being entirely sourced from Europe forests. For cases where countries demand more than their country can provide, adjustments through trade takes place at the EU level from countries with excess of residues to countries with residue deficits.

Additional feedstock production is located in managed forest area in the EU (9.4 Mha). Main producers of forest residue FT biodiesel are Northern Europe (28 PJ), Western Europe (14 PJ), Southern Europe (11 PJ).

Overall agricultural production is not impacted by the additional forest residue harvesting with no observed land expansion. Therefore, for a shock of 0.5%, production costs remain below competitive feedstocks and only direct effects are recorded. Under such practices, however, the soil organic carbon is impacted by removal of residues.

Land use change effect

No change in land cover is observed in this scenario, but land management is affected in managed forest.

Soil organic carbon emissions

No LUC emissions take place. However, collecting forestry residues does lead to a soil carbon change which amounts to 20.4 $MtCO_2e$ over a 20 year period. This soil organic carbon loss results from the removed residue no longer decomposing in the soil. We consider here only the removal of residues for areas that are not ecologically vulnerable. In these areas, 60-70% of available residues are removed, depending on the harvesting method. As we do not know if the soil carbon response is linear with the extraction rate, we cannot determine if the emission level per quantity of residue would be lower or higher for a more limited extraction rate. See Annex III.3 for further details.

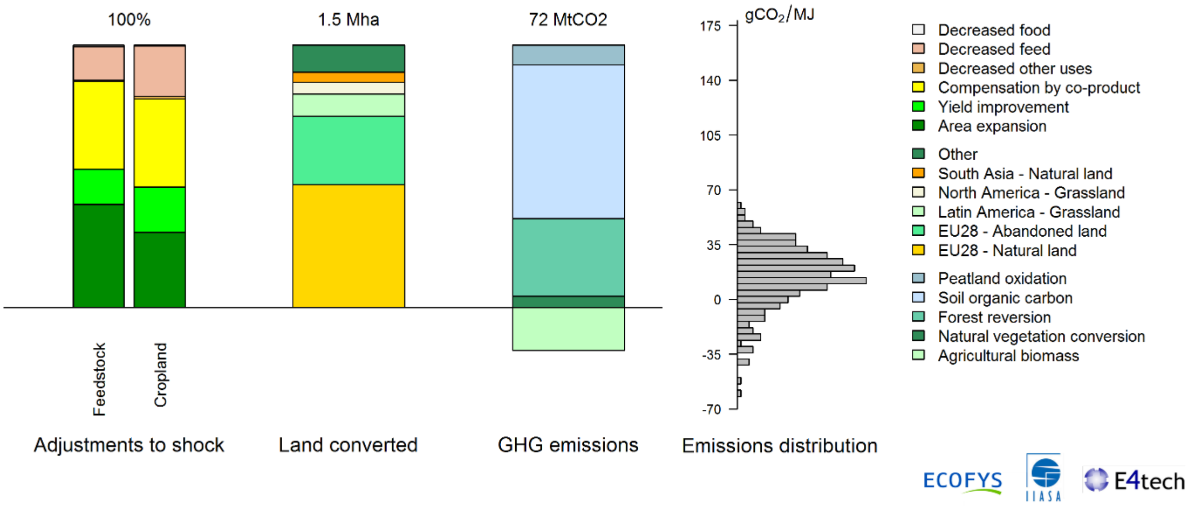
Total soil organic carbon emissions of forestry residues FT biodiesel are found to be 20.4 $MtCO_2e$. With an assumed 20 year amortisation, this results in an soil organic carbon emissions factor of 17 gCO_2e/MJ. Changing assumption on the natural vegetation regrowth on abandoned agricultural land does not affect the final result here.

4.17 Starchy crops group

Energy productivity 2000-2030: 51 GJ ethanol/ha (EU28 avg., before accounting for co-products)

Cropland and Grassland displacement: 11.3 ha/TJ and 9.6 ha/TJ

Land use emissions: **29 gCO_2/MJ**



Additional demand of 1% ethanol (123 PJ) is here distributed across the feedstocks proportionally to their historical proportion. We do not consider substitution here, which would then go fully for adoption of rye. Feedstocks used are here maize (7.9 Mt), wheat (5.2 Mt) and rye (1.9 Mt), coming for most part from the EU. The shock has limited price impact on cereals (2% in the EU and 0.2% globally) and food prices are unaffected.

Adjustments to the shock

The additional feedstock is achieved 20% through a decrease in food and feed demand, 34% by displacement of feed by co-product of ethanol, and 46% by extra production, of which yield accounts for 17% and area expansion 29%.

Additional feedstock production is mainly located in the EU (9.2 Mha), followed by Latin America (1.3 Mha) and North America (0.8 Mha).

Overall agricultural production is also affected by a decrease in demand for cereals of 2.7 Mt globally and 3.8 Mt considering the EU only. On the other side, the displacement leads to an increase of 3.1 Mt in protein meal for cattle. As a result, meat production increase globally by 100 kt and milk production by 290 kt.

Land use change effect

Land expansion requires 1.5 Mha of additional land globally, mainly cropland. In Europe, cropland increases by 1.3 Mha, which leads to 790 kha of forest losses and 440 kha of abandoned land recovery.

Land use change emissions

Land use emissions are increasing very slightly (15 $MtCO_2e$) through LUC, but soil carbon emissions play a larger role in this scenario, although of small absolute magnitude (50 $MtCO_2e$). Emissions from peatland coming from co-product substitution in the oilseed market amount to 7 $MtCO_2e$.

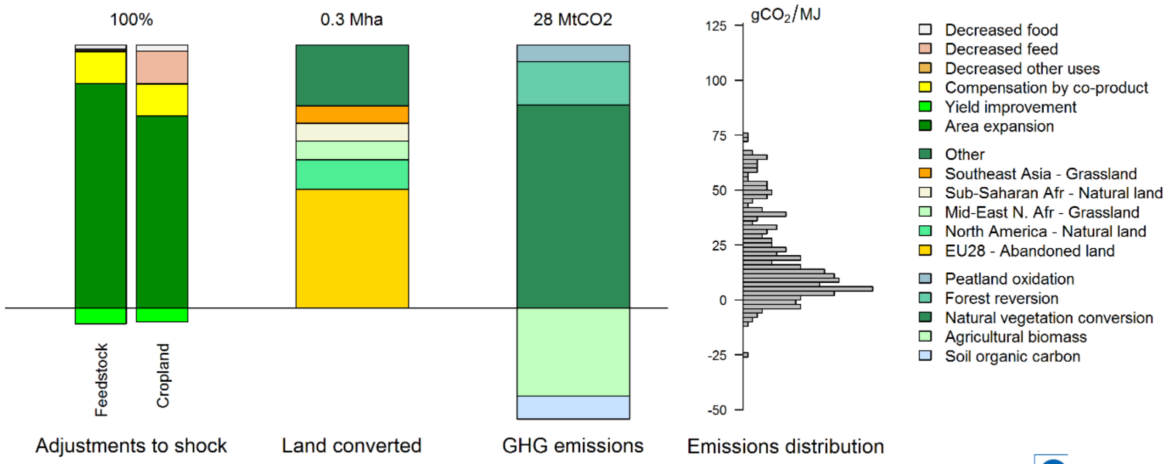
Total land use emissions of starchy crops are found to be 72 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of 29 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at 46 $MtCO_2e$, and the LUC emission factor would be 19 gCO_2e/MJ.

4.18 Sugar crops group

Energy productivity 2020: 135 GJ ethanol/ha (EU28 avg., before accounting for co-products)

Cropland and agricultural land displacement: 2.3 ha/TJ and 2.0 ha/TJ

Land use emissions: 11 gCO_2/MJ



Additional demand of 1% ethanol (123 PJ) from sugar crops is here distributed across the feedstocks proportionally to their historical proportion. As for starch, we do not consider substitution here, which would imply that only sugar cane remains. Feedstocks uses would be two-thirds sugar beet (40 Mt) and one third sugar cane (21 Mt), mostly imported. The shock has no significant impact on sugar products globally, with the exception of the EU where sugar beet price increases by 4.7%. Food prices are found to be unaffected.

Adjustments to the shock

The additional feedstock is achieved 16% through a decrease in food and feed demand, 13% by displacement of beet pulp and 71% by extra production, with a negative contribution from yield of 5%, due to lower marginal yields than the average yields.

Additional feedstock production is mainly located in the EU (0.6 Mha), followed by Latin America (0.3 Mha). Occupied areas are considerably smaller than for some other feedstock scenarios.

Overall agricultural production is also affected by a decrease in demand globally of 2.4 Mt for cereals and 1.9 Mt for sugar crops. Cattle benefit from the shock through higher inputs of co-product (2.1 Mt).

Land use change effect

Land expansion is relatively limited for this scenario, with high yielding feedstocks. Cropland expands by 0.3 Mha globally. In Europe, expansion is notably limited, with only 125 kha of cropland increase.

Land use change emissions

Land use emissions increase moderately in this scenario (37 $MtCO_2e$) through LUC. Soil carbon emissions in the shock for EU amount to about 12 $MtCO_2e$, but are compensated by sequestration in soil carbon in Latin America (-22 $MtCO_2e$).

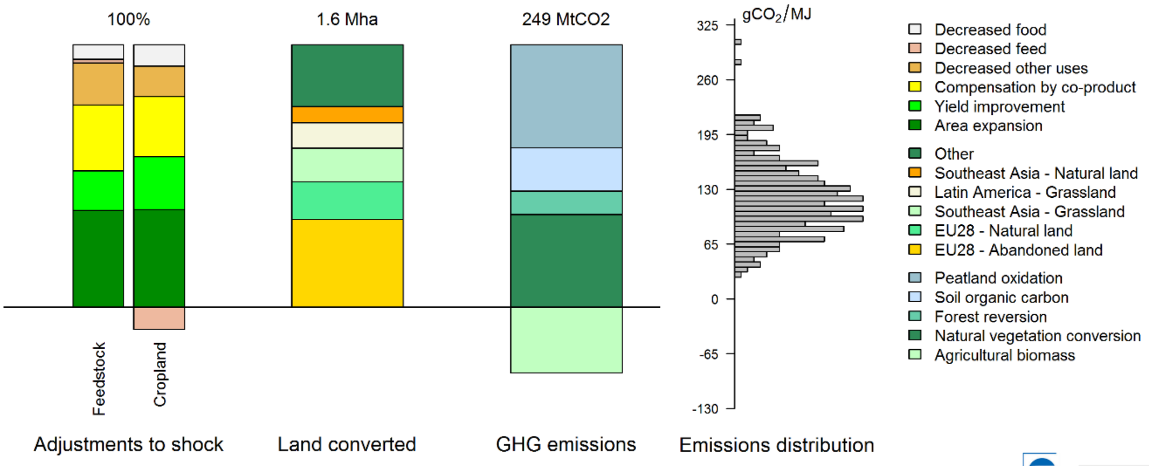
Total land use emissions of sugar crops are found to be 28 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of 11 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at 20 $MtCO_2e$, and the LUC emission factor would be 8 gCO_2e/MJ.

4.19 Vegetable oil group

Energy productivity 2020: 37 GJ biodiesel/ha (EU28 avg., before accounting for co-products)

Cropland and agricultural land displacement: 12.6 ha/TJ and 8.6 ha/TJ

Land use emissions: **101 gCO_2/MJ**



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Additional demand of 1% biodiesel (123 PJ) from oilseeds is here again distributed across the feedstocks proportionally to their historical proportion. We do not consider substitution, which would then imply that only palm oil would be used in this group. Feedstocks used under this scenario are 50% rapeseed oil, 24% soybean oil, 23% palm oil and 3% sunflower oil, for a total of 3.5 Mt. The shock increases vegetable oil prices by 2.9% globally and 12% in the EU. Global crop prices increase by 0.2% and the world food price index by 0.1%.

Adjustments to the shock

The additional feedstock provision is achieved 12% through a decrease in food and feed demand, 25% by displacement of feed by protein meals and 63% by extra production.

Additional feedstock production is mainly located in the EU (0.5 Mha), followed by North America (0.3 Mha) and Southeast Asia (0.4 Mha).

Overall agricultural production is affected globally by this shock, in particular through the provision of the protein meals (+2.2 Mt). The boost to the livestock sector also drives an increased demand for grains (1.2 Mt), in particular in Latin America, where they serve as a complement to protein meals excess. Meat consumption increases by 200 kt globally and milk by 460 kt.

Land use change effect

Land expansion under this scenario leads to 1.6 Mha of land conversion globally, most of it (1.6 Mha) for additional cropland. In the EU, expansion is 780 kha, whereas Southeast Asia expands land by 390 kha, most of it through expansion of oil palm plantations. At the same time, grassland decrease globally by 500 kha, mainly in Latin America and Southeast Asia. Tropical forests increase in Latin America by 100 kha compared to the basline, but decrease in Southeast Asia by 90 kha.

Land use change emissions

Land use emissions are significant in this scenario for Southeast Asia (72 $MtCO_2e$) due to LUC and reach 117 $MtCO_2e$ globally. Peatland emissions amount to about 131 $MtCO_2e$ and soil organic carbon drives additional emissions of 55 $MtCO_2e$ globally.

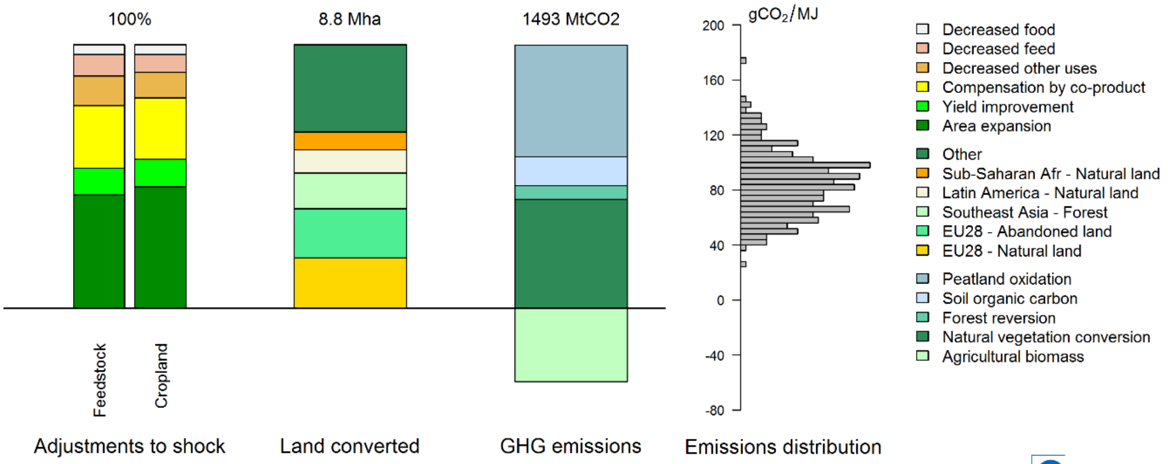
Total land use emissions of vegetable oils are found to be 249 $MtCO_2e$. With an assumed 20 year amortisation, this results in an LUC emissions factor of 101 gCO_2e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total land use emissions would be lower, at 219 $MtCO_2e$, and the LUC emission factor would be 89 gCO_2e/MJ.

4.20 EU 2020 biofuel mix scenario (all feedstocks)

Energy productivity 2020: 48 GJ ethanol/ha (EU28 avg., without accounting for co-products)

Cropland agricultural land displacement: 10.4 ha/TJ / 9.6 ha/TJ

Land use emissions: 97 gCO_2/MJ



Additional demand of biofuels for a full EU 2020 biofuel mix is coming from a mix of 11.1 Mt of corn, 6.6 Mt of wheat, 15.4 Mt of sugar beet, 5.8 Mt of rapeseed oil, 4.5 Mt of palm oil, 2.9 Mt of soybean oil and more minor uses of sunflower oil, sugar cane andbarley. We distributed feedstocks proportionally to their historical shares. To reach their commitments, Member States deploy some second generation biofuels, and 7.8 Mt of short rotation coppice and 2.1 Mt of grassy crops are established for biofuel production in this scenario. Due to the large contribution of palm oil and soybeans, only 37% of total additional feedstocks under this scenario are produced in the EU. This shock leads to a price change globally of 9.3% for vegetable oil and 0.8% for cereals, while protein meal prices decrease by 12%. In the EU, the prices of these products change by 38%, 4.6% and -24% respectively. Overall, crop prices increase by 0.5% globally and food prices by 0.3%.

Adjustments to the shock

The additional feedstock is achieved 22% through a decrease in food and feed demand, 26% by displacement of feed by co-products and 52% by extra production, in which yield accounts for 13%.

Additional feedstock production is located in the EU (2.9 Mha), Southeast Asia (2.2 Mha), Latin America (1.3 Mha) and to a more limited extent in Ukraine and rest of Europe, North America, Sub-saharan Africa, and Oceania (0.4 Mha for each).

Overall agricultural production is also affected by a decrease in demand of 6.5 Mt for cereals in Europe and 9.2 Mt globally. Additionally, 2.4 Mt vegetable oils are no longer consumed globally. Protein meal consumption increasesmassively by 13 Mt, which boosts milk production by 1 Mt and meat production by 0.2 Mt.

Land use change effect

Land expansion requires an additional 8.8 Mha of land conversion globally compared to the reference case – 8 Mha for additional cropland and the rest of short rotation plantations for advanced biofuels. In Europe, less cropland is abandoned and crop area increase by 2.9 Mha. In Southeast Asia, cropland expands by 2.1 Mha under the pressure of palm plantation, 50% of this is at the expense of tropical forest. At the same time, grassland decreases by 1.4 Mha globally, mainly in Latin America, Southeast Asia and the EU.

Land use change emissions

Land use emissions are mainly associated with LUC emissions (855 MtCO$_2$e) and peatland emissions (880 MtCO$_2$e). Carbon sequestration in biomass decreases emissions by 480 MtCO$_2$e, however, through new palm trees, mainly in Southeast Asia. Soil organic carbon release 228 MtCO$_2$e over the period and foregone sequestration in natural vegetation accounts for 110 MtCO$_2$e.

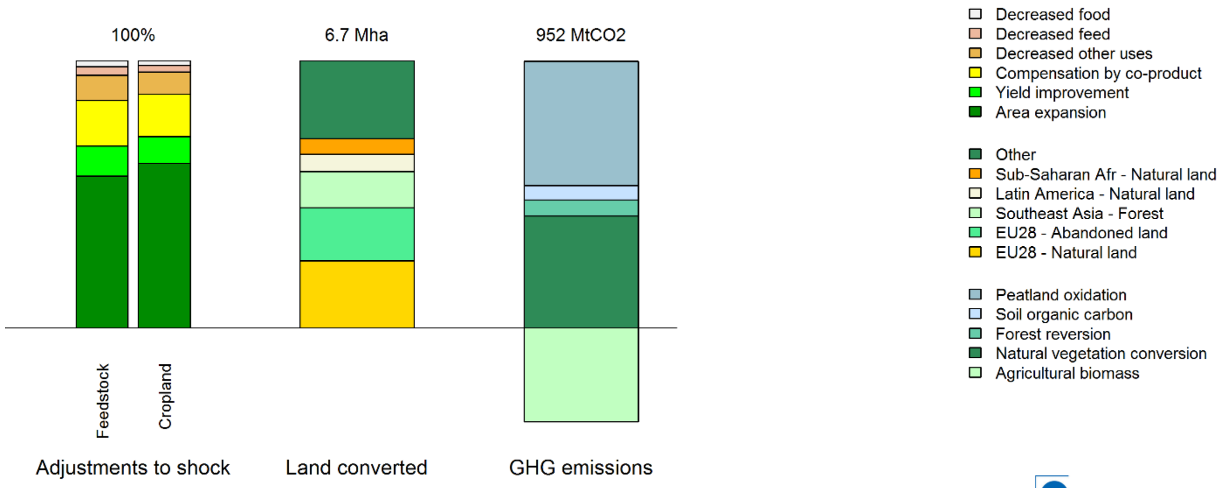
Total LUC emissions for the EU 2020 biofuel mix scenario reach a total of 1,493 MtCO$_2$e over the full 20 year period, which corresponds to an LUC emissions factor of 97 gCO$_2$e/MJ. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total LUC emissions would be lower, at 1,385 MtCO$_2$e, and the LUC emission factor would be 90 gCO$_2$e/MJ.

4.21 EU 2020 biofuel mix scenario with 7% cap on conventional biofuels

Energy productivity 2000-2030: 60 GJ ethanol/ha (EU28 avg., before accounting for co-products)

Cropland and Grassland displacement: 8.0 ha/TJ and 9.0 ha/TJ

Land use emissions: 74 gCO_2/MJ



Additional demand when implementing a EU 2020 mix with 7% cap on first generation comes from a more important share of second generation bioenergy. Under this scenario, 17 Mt of woody biomass is sourced from short rotation coppice and 6.1 Mt from grassy crops. The largest feedstocks used after these are sugar beet (10 Mt), maize (8.4 Mt) and wheat (4.8 Mt), with palm oil importance decreased at 3.3 Mt. This shock lowers the impact of the policy on the feedstock markets (1.1%) and no food price increase is observed on average.

Adjustments to the shock

Additional feedstocks are provided 17% through a decrease in food and feed demand, 22% by displacement of feed by co-products and 61 % by extra production, in which yield accounts for 17%.

Additional feedstock production is located in the EU (2.3 Mha), Southeast Asia (1.8 Mha), Latin America (0.6 Mha for each), and Ukraine and the rest of Europe, Oceania and Sub-saharan Africa (0.3 Mha each).

Overall agricultural production is also affected globally by a decrease of 2.1 Mt in demand for cereals and 2.8 Mt for sugar crops. Protein meal demand increases by 6.5 Mt, whereas demand for vegetable oil is less affected (-1.5Mt). Meat and milk demand increase globally by 0.2 and 0.6 Mt, respectively.

Land use change effect

Land expansion leads to 6.7 Mha of land conversion globally, of which 5.2 Mha are used for additional cropland and 1.5 Mha for short rotation coppice. In the EU, cropland expands by only 1.8 Mha, half at the expense of abandoned land and half through other natural vegetation. Southeast Asia (1.6 Mha) and Latin America (0.6 Mha) are the two other regions where most cropland changes are taking place, although to a lower extent than in some other scenarios. At the same time, grassland decreases by 0.9 Mha globally, mainly in Latin America, Southeast Asia and in the EU.

Land use change emissions

Land use emissions from living biomass conversions are more contained in this scenario at 617 $MtCO_2$. The EU is almost neutral on this source (6 $MtCO_2$) through expansion of woody biomass plantations. However, peatland emissions are still high (684 $MtCO_2e$), although plantations sequester 517 $MtCO_2e$. Some foregone sequestration on other feedstock still amounts to 89 $MtCO_2e$ globally and soil carbon losses reach 81 $MtCO_2e$ globally.

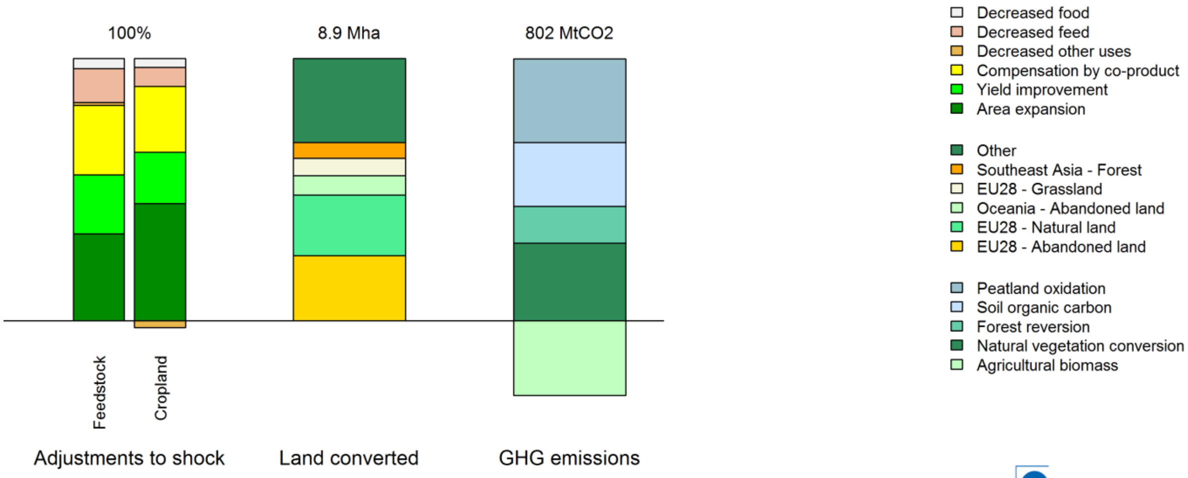
Total land use emissions of the EU 2020 scenario with 7% cap are found to be 952 $MtCO_2e$, therefore resulting in an LUC emissions factor of 74 gCO_2e/MJ for the EU policy. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the total LUC emissions would be lower, at 865 $MtCO_2e$, and the LUC emission factor would be 67 gCO_2e/MJ.

4.22 Abandoned land in the EU

Energy productivity 2020: 51 GJ ethanol/ha (EU28 avg., before accounting for co-products)

Cropland and and agricultural land displacement: 10.6 ha/TJ and 10.0 ha/TJ

Land use emissions: **52 gCO_2/MJ**



In order to assess the impact of better use of land, we explore the effect of an alternative setting on the policy scenario EU 2020 biofuel mix, now with restrictions on the import of feedstocks other than those traditionally grown in the EU and with further possibilities for expanding cropland into abandoned land and other natural vegetation in Eastern Europe and Ukraine.

Additional demand when implementing the EU 2020 scenario with more reliance on EU feedstocks leads to a larger part of bioenergy sourced from rapeseed, sugar beet and cereals. The feedstocks the most used are then rapeseed oil (422 PJ), maize (82 PJ), wheat (61 PJ), short rotation coppice (66 PJ) and sugar beet (38 PJ). This shock leads to an impact of about 1% on prices of these feestocks.

Adjustments to the shock

Additional feedstock are provided 11% through a decrease in food and feed demand, 33% by displacement of feed by co-products and 56% through extra production, composed of 22% of yield increase and 35% of extra area.

Additional feedstock production is located to a larger extent in the EU (4.0 Mha compared to 2.9 Mha in the EU2020 scenario). Other regions where feedstocks are grown are Ukraine and rest of Europe (1.7 Mha), Southeast Asia (1.2 Mha), Latin America (0.8 Mha) and Russia and its neighbouring countries (0.8 Mha).

Overall agricultural production is also affected globally by a decrease of 8.0 Mt in demand for cereals and 6.5 Mt for sugar crops. Protein meal demand increases by 14.9 Mt, whereas demand for vegetable oil decreases by 2.1 Mt.

Land use change effect

Land expansion leads to 8.9 Mha of land use conversion globally, with 8.2 Mha used as additional cropland, mainly at the expense of abandoned land (2.8 Mha), grassland (1.2 Mha) and other natural vegetation (4.5 Mha). In the EU, cropland increases by 4.0 Mha and abandoned land is reduced by 2.1 Mha. Ukraine and rest of Europe increase their cropland at the expense of other natural vegetation (former abandoned land) by 0.8 Mha. At the same time, some deforestation still occurs (-0.4 Mha) due to the effect of co-products on the oilseed market. .

Land use change emissions

Land use emissions from living biomass conversion amount in this scenario to 333 $MtCO_2$ additional emissions compared to the baseline. The EU is a significant emitter of soil carbon emissions (204 $MtCO_2$) and foregone sequestration in this region totals 145 $MtCO_2e$. Peatland emissions still constitute the largest source globally (359 $MtCO_2e$, whereas plantations sequester 321 $MtCO_2e$), but this source is still reduced by more than half compared to the full EU 2020 biofuel mix peatland emissions (880 $MtCO_2$). However, it is noteworthy that emissions in the EU increase by one third (145 $MtCO_2e$ for soil organic carbon and 110 $MtCO_2e$ for natural vegetation reversion in the EU 2020 mix scenario).

Total land use emissions of the abandoned land restoration scenario are found to be 802 $MtCO_2e$, therefore resulting in an LUC emissions factor of 52 gCO_2e/MJ for the EU policy. The scenario slightly improves the overall emissions level through avoided expansion in carbon rich areas (Latin America), and reduces the induced deforestation in Southeast Asia, although leaked emissions remain large. The LUC of 52gCO_2/MJ associated to this shock is to be compared to 97 gCO_2/MJ for the EU 2020 biofuel mix alone. If no natural vegetation were to regrow on abandoned agricultural land in absence of biofuels, the LUC emission factor would be 42 gCO_2e/MJ.

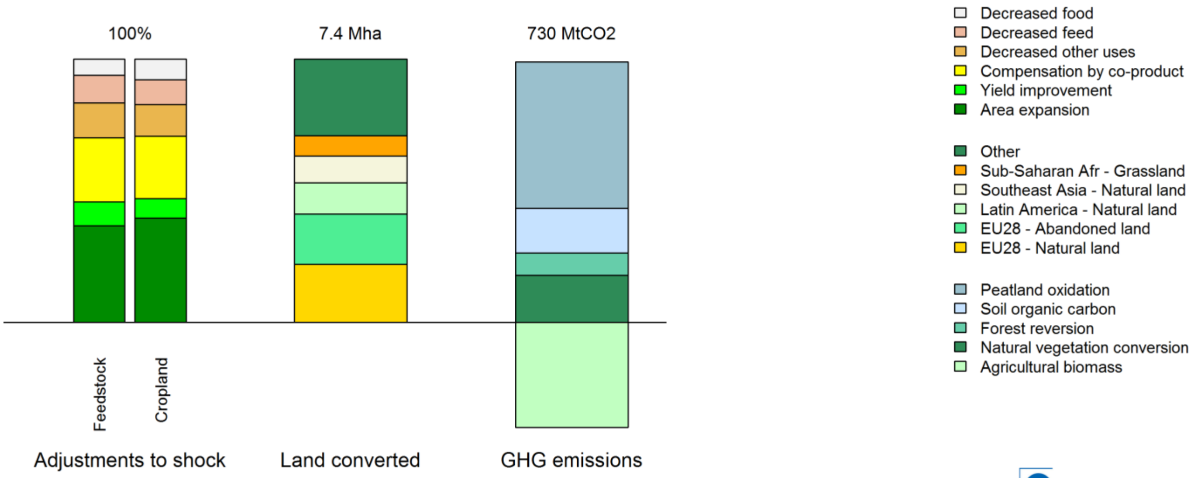
4.23 Lower deforestation

Energy productivity 2020: 49 GJ biofuel/ha (EU28 avg., before accounting for co-products)

Cropland and agricultural land displacement: 9.2-9.9 ha/TJ and 7.7-8.2 ha/TJ

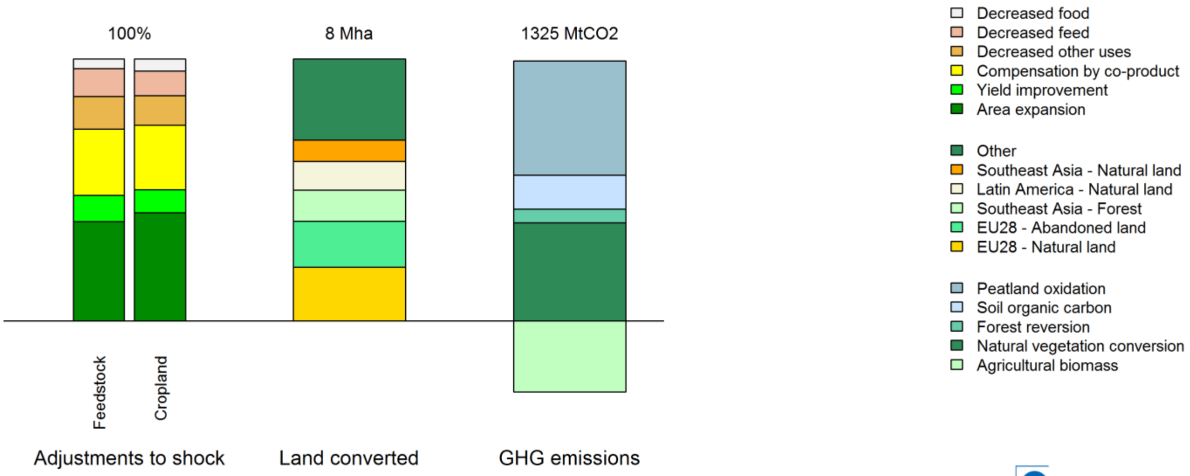
Land use emissions: 87 gCO_2/MJ (low) and 48 gCO_2/MJ (very low)

Very low deforestation scenario



We observe that at a very high level of protection of forests (USD 50/tCO_2), most deforestation is seriously halted and the LUC effect is drastically reduced (to 48 gCO_2/MJ), even if some significant emissions from peatland drainage can still occur. These latter emissions account for 689 $MtCO_2e$. Indeed, peatland is not limited to forested areas and some additional protection measures are necessary to limit its drainage.

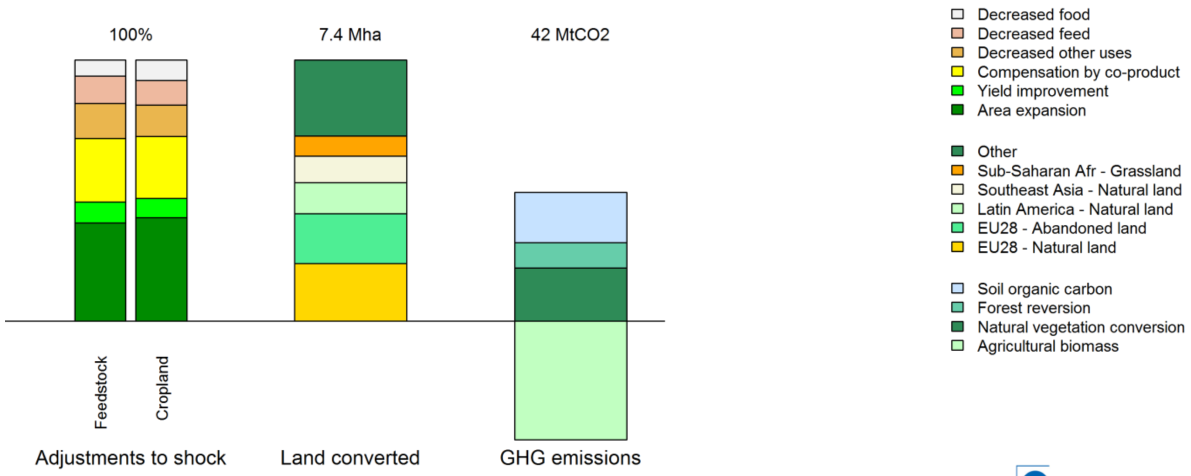
Low deforestation scenario



The low deforestation scenario includes a more moderate carbon price to disincentivise deforestation of USD 10/tCO$_{2.}$ This moderate incentive is sufficient to limit a part of deforestation seen in the baseline, but is less effective in preventing deforestation associated with palm oil expansion, as this type of agricultural activity can remain more profiable than the conservation alternative. The obtained LUC emission value is 87 gCO$_2$/MJ.

4.24 Very low deforestation with no peatland drainage

Energy productivity 2020:	49 GJ biofuel/ha (EU28 avg., before accounting for co-products)
Cropland and agricultural land displacement: 9.2 ha/TJ and 7.7 ha/TJ	
Land use emissions:	**4 gCO_2/MJ**



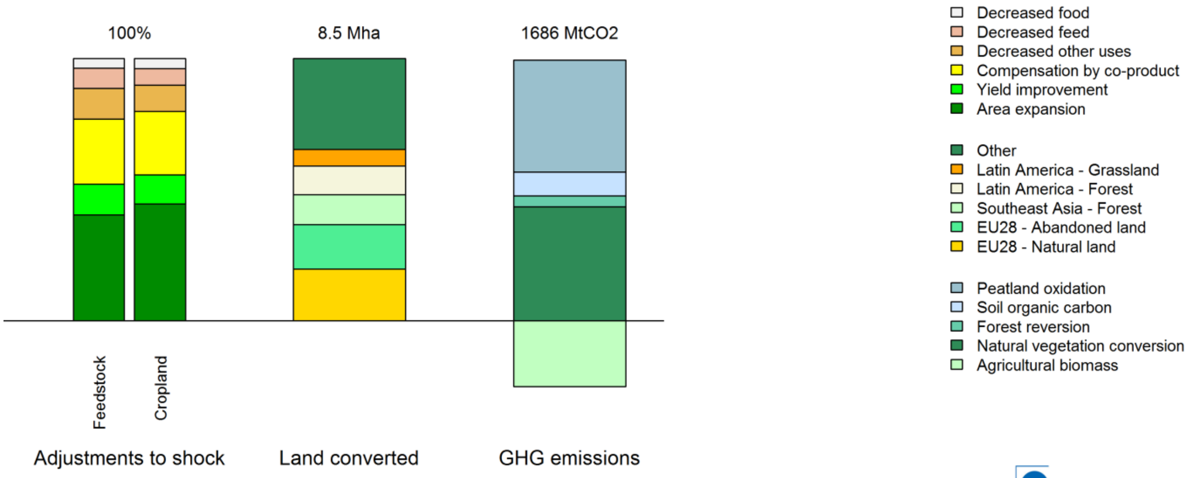
For the case where peat land emissions are not considered and deforestation is very low, the overall effect of a shock has a quite different outcome. The total LUC effect is drastically reduced (4 gCO_2/MJ), because carbon sequestered in palm trees compensates for a part of the LUC emissions, soil organic carbon and forest reversion carbon that is emitted as a result of the shock. Only 55 $MtCO_2e$ are emitted under low deforestation and peatland protection, much less than the baseline situation.

4.25 Higher deforestation

Energy productivity 2000-2030: 51 GJ biofuel/ha (EU28 avg., beforeaccounting for co-products)

Cropland and Grassland displacement: 9.9 ha/TJ and 8.8 ha/TJ

Land use emissions: 110 gCO_2/MJ



When considering a baseline with higher deforestation, the level of encroachment into forest is nearly doubled, with 1.9 Mha of forest disappearance as a result of the full mandate shock. This deforestation takes place in particular in Latin America (-0.9 Mha) and Southeast Asia (-1 Mha). Palm plantations in Southeast Asia increase in such scenario by 2.6 Mha, which means that land use types other than tropical forest are also converted to palm plantations. This scenario leads to LUC emission value of 110 gCO_2/MJ biofuel consumed in the EU.

4.26 Comparison of results with previous LUC assessments

This is not the first study which assesses the LUC impacts of biofuel feedstocks. Some previous assessments have been performed in the EU, and more often in the US, where the literature is prolific. An overview is presented below of the way that the results of of the current study compare to previous assessments published by environmental agencies or in peer-reviewed journals. We provide some external sources for a more exhaustive overview of LUC model results (e.g. De Cara et al., 2012 covering 485 estimates from various studies).

Table 11: Selected values from the literature on LUC emission factors from biofuel feedstocks

Study	Location	Feedstock	LUC result	Amortisation period	LUC 20 years
Searchinger et al. (2008)	USA	Corn	104 gCO_2e/MJ	30 years	156 gCO_2e/MJ
Keeney and Hertel (2009)	USA	Corn	27 gCO_2e/MJ	30 years	40 gCO_2e/MJ
CARB (2009)	USA	Corn	30 gCO_2e/MJ	30 years	45 gCO_2e/MJ
CARB (2009)	USA	Soybean	62 gCO_2e/MJ	30 years	93 gCO_2e/MJ
US EPA (2010)	USA	Corn	30 gCO_2e/MJ	30 years	45 gCO_2e/MJ
US EPA (2010)	USA	Soybean	40 gCO_2e/MJ	30 years	60 gCO_2e/MJ
Britz and Hertel (2011)	EU	Rapeseed	42 gCO_2e/MJ	30 years	63 gCO_2e/MJ
Plevin et al. (2012)	US	Corn	21-142 gCO_2e/MJ	15-45 years	47-106 gCO_2e/MJ [a]
Taheripour and Tyner (2013)	US	Corn	13.3 gCO_2e/MJ	30 years	20 gCO_2e/MJ

The only existing study that focuses on multiple conventional biofuel feedstocks for biofuels consumed in the EU is the study from Laborde (2011). The emission values resulting from this study are compared with results from the current study in the figure below.

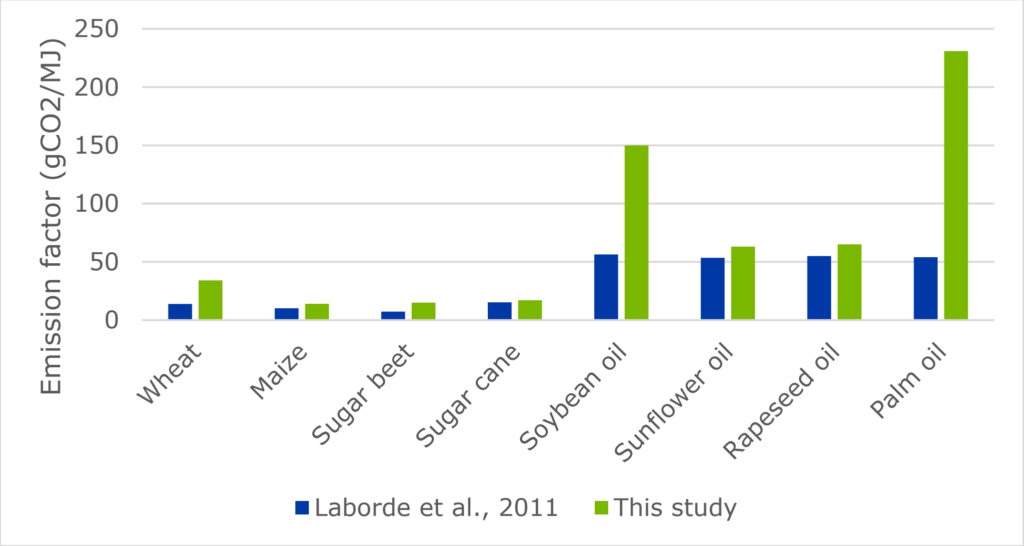


Figure 20: Comparison of results from Laborde et al. (2011) with central estimates from this study

The following conclusion can be drawn based on this comparison:

1. There is a consensus that vegetable oil feedstocks have higher associated LUC emissions compared with cereals or sugar feedstocks. This is due to the following reasons:
   - Vegetable oils are more directly connected to expansion of palm oil in Southeast Asia;
   - Increases in vegetable oil transformation do not proportionally increase the production of protein meals (extra supply comes in part from more crushing but also from vegetable oil diversion), whereas increase in cereals transformation into ethanol generates proportional increase in DDGS.

2. There are strong similarities on the results of some feedstocks:
   - Sugar beet, sugar cane central values are between 7 and 17 gCO_2/MJ for both studies;
   - Cereal central values (wheat and maize) are between 10 and 34 gCO_2/MJ for both studies; in both studies, LUC from wheat is higher than LUC from maize due to lower energy efficiency yield. In the case of GLOBIOM, DDGS protein content and forest reversion patterns also explain some of the differences – see next paragraph;
   - Rapeseed and sunflower oils are between 53 and 65 gCO_2/MJ in both studies

3. Some significant differences appear on two vegetable oil feedstocks, palm oil and soybean oil, which are associated much higher emission factors in our study. This is explained by the lower elasticity of substitution assumed for our central case in the EU28 following the dedicated improvement (Annex II.9). As a consequence, demand for palm and soybean based oils leads to more import of these type of oils in our study than in Laborde (2011). Additionally, it should be kept in mind when comparing results with other sources from the US literature that the EU soybean oil can have a very dfferent impact from the US one, because the former is imported, for a part from Latin America, whereas the US benefits from a large domestic production. This being said, it should be reminded that emission factors for soybeans were also found to be large in the US studies, in particular the one from CARB in 2009, which obtained LUC emissions of 62 gCO_2e on a 30 year basis, equating to 93 gCO_2e on a 20 year basis.

4 Strong similarities exist in what sources contribute to emissions when looking at natural vegetation biomass, organic carbon in mineral soil and peatland emissions. However, emissions sources are accounted for in our study with inclusion of reversion carbon and agriculture biomass. This contributes to some differences, for instance in the case of wheat, where reversion has a relatively high contribution.

5 Our central EU2020 scenario (97 gCO_2e/MJ) results differ significantly from the results in Laborde (2011), who finds 38 gCO_2e/MJ for the biofuel mix. There are several reasons for this:

- Some feedstocks have higher emission factors in the current study than in Laborde (2011);
- More palm oil and soybean oil are used in our scenarios than in Laborde (2011);
- No sugar cane is used in our scenario, whereas Laborde (2011) uses it as a large source to fill the full mandate;
- Emissions factors are non-linear in GLOBIOM response and the EU2020 emissions increase with the size of the mandate. The weighted sum of single feedstock LUC for the EU2020 mix leads to 88 gCO_2/MJ, instead of 97 gCO_2/MJ, because two times more deforestation occurs in the EU2020 scenario than would have been anticipated based on the marginal 1% scenario as EU abandoned land is being used (see Table 12).

Table 12: Comparison of EU 2020 land use change and ILUC effect with weighted sum of feedstock specific scenarios

Scenario	Land use change compared to baseline (Mha)						LUC emissions (gCO_2/MJ)
	Cropland	Grassland	Natural land	Abandoned land	Short rotation plantation	Forest	
EU2020 Mix results	8,038	-1,380	-4,381	-1,906	761	-1,133	97
Feedstoc specific results (weighted avg. with EU2020 shares)	7,856	-1,714	-4,226	-1,954	657	-619	88

6 Much larger uncertainty ranges are identified in our study than in Laborde (2011). In particular, some possible negative emission factors are found for cereals, due to the role of co-products, and some ambivalent impacts appear for sugar cane (higher values are possible if leakage occurs to Amazon), soybean oil (high uncertainty on the expansion pattern on deforestation frontier) or palm oil (possibly low emission factors if low expansion in peat and forest).

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6 Glossary

This Glossary contains brief descriptions of terms used in the study report. More technical terms used in the Annexes are not included here.

Abandoned land: land reported as abandoned in GLOBIOM results corresponds to land used as cropland or grassland in the year 2000, but no longer used in the baseline due to decrease in harvested areas. Land already abandoned in 2000 is represented in the other natural land category. For more details, see appendix II.11.

Behavioural parameters: parameters that are independent from the model used

C-growth rate: rate of accumulation of carbon in living biomass above and below ground due to vegetation regrowth. See appendix II.6.

Cropland: we designate by cropland the cultivated areas for annual crops and permanent crops such as palm plantations or semi-perenials (sugar cane, miscanthus, etc.). An important exception is short rotation coppice that are cultivated for energy purpose and accounted as energy plantation. Because GLOBIOM only model 18 crops globally, it should be kept in mind that GLOBIOM only represents a part of the cropland (about 70%).

Cultivated area: physical area on which one or several crops can be cropped in one year, subsequently (multi-cropping) or simultaneously (inter-cropping).

Equilibrium model: A macro-economic model in which supply and demand sides of certain sectors in the economy are represented, with supply and demand being equal at a certain price level.

Endogenous: the value of a parameter is determined by other parameters in the model. E.g. Food demand is endogenous in GLOBIOM and depends on population size, gross domestic product (GDP) and product prices.

Exogenous: the value of a parameter comes from a dataset and is fixed, not impacted by the model.

Foregone sequestration: carbon sequestration that occurs in the baseline, but not in the scenario.

Gaussian Curve: a bell shaped distribution typical for input parameters and results.

General Equilibrium Model: An equilibrium model (see above) that considers the whole global economy.

Grassland: grassland (or pasture) is used in this report to designate áreas occupied a part of the year by grawing animals. In our approach, grassland accounts for 1.6 Gha and therefore does not comprehend some open áreas classified as cropland in the FAO definition.

Harvested area: Total area of land that has been harvested in one year. In case of multi-cropping, harvested area is greater than cultivated area.

Other natural land: land not classified as cropland, grassland or forest in the initial land cover data of GLOBIOM. This includes abandoned agricultural land in the dataset (i.e. in year 2000), but this does not include land voluntarily set-aside (included in cropland). Land abandoned in the model projections (2000-2030) is accounted separately and not mixed with other natural land. For more details, see appendix II.11.

Partial Equilibrium Model: An equilibrium model that focuses on specific sectors of the economy, with more detail then general equilibrium models.

Monte Carlo Analysis: uncertainty analysis, through random testing of a large range of input values.

Substitution effects: the effect that co-products of a biofuel conversion process can substitute other commodities elsewhere in the global economy.

World prices: in this study world prices for agricultural commodity corresponds to world consumer prices, and not to world market prices. World consumer prices are calculated as consumption-weighted prices, which covers parts of the consumption whose prices are not directly correlated to world market prices.

Annex I Description of GLOBIOM and comparison with MIRAGE-BioF (IFPRI)

This annex provides a detailed comparison of main features of the GLOBIOM and compares the model with the MIRAGE-BioF model used by IFPRI for their study to LUC emissions associated with EU, their respective strengths and limitations, written from the perspective of the GLOBIOM model. The version of GLOBIOM used for the comparison is the model as it stands at the end of this project.[31] We compare this with the version of the MIRAGE-BioF model as used in the IFPRI 2011 study for the European Commission.[32] The purpose of this comparison is not to argue that one of the two models is better than the other, but merely to give an insight into how GLOBIOM works, partly by comparing it with MIRAGE-BioF.

The main features of both models are presented, focusing on data and mechanisms that play an important role in the assessment of LUC impacts of biofuels. The following aspects are discussed in detail: the representation of bioenergy processing chains and their co-products, the dynamics of LUC and the response of agricultural yield or food demand to change in domestic and international market prices. These aspects are taken into consideration when presenting GLOBIOM and comparing it to MIRAGE-BioF in this annex (Figure 21).

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[31] Note that this version features a detailed representation of the European Union and may differ from some earlier standard versions used for global level assessments. The description presented in this appendix also features the improvements developed in this project and is updated compared to the report "Description of the GLOBIOM (IIASA) model and comparison with the MIRAGE-BioF (IFPRI) model" published in October 2013 on www.globiom-iluc.eu.

[32] The model may have been changed in the course of other projects in the meanwhile but no documentation was accessible on these changes at the time of writing this document.

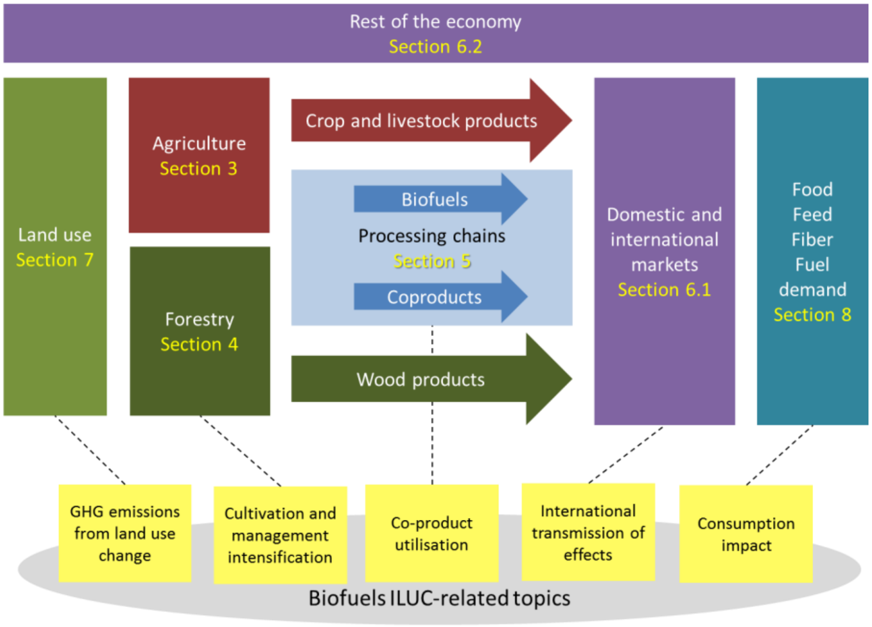

Figure 21: Main steps in the biofuel supply chain, how they relate to the model description in this report and what their associated LUC issues are

The following questions will be addressed in this annex:

1. How does the model represent the important elements of the ILUC debate?
2. What advantages can GLOBIOM bring?
3. What are the current shortcomings and how can they be addressed?

Models are complex and the use of technical terms is inevitable at times. This annex aims to clearly describe the GLOBIOM model, outline the main differences between this and MIRAGE-BioF as well as note any implications to interested stakeholders. Experienced readers can find more technical information in the final sections I.8 and I.9.

I.1 Summary of differences between GLOBIOM and MIRAGE-BioF

GLOBIOM and MIRAGE-BioF belong to two different families of economic models. None of the two models is a priori superior to the other, but depending on the topic addressed, some characteristics can be important. GLOBIOM is a model designed to address various land use related topics (bioenergy policy impacts, deforestation dynamics, climate change adaptation and mitigation from agriculture, long term agricultural prospect). MIRAGE-BioF, besides its use for biofuel policies, is generally used to assess trade policy impacts and impacts of agricultural policies on income and poverty in developing countries. The main differences between GLOBIOM and MIRAGE-BioF are summarised in Table 13. More technical descriptions can be found in Section I.9.

Table 13: Main differences between GLOBIOM and MIRAGE-BioF

	GLOBIOM*	MIRAGE-BioF*
Model framework	Bottom-up, starts from land and technology	Macroeconomic, starts from national accounting relations
Sector coverage	Detailed focus on agriculture (including livestock), forestry and bioenergy (Partial equilibrium)	All economic sectors represented with agricultural sector disaggregated (General equilibrium)
Regional coverage	Global (28 EU Member states + 29 regions)	Global (1 EU region + 10 world regions)
Resolution on production side	Detailed grid-cell level (>10,000 units worldwide)	Regional level, with land split into up to 18 agro-ecological zones
Time frame	2000-2030 (ten year time step)	2004-2020 (one year time step)
Market data source	EUROSTAT and FAOSTAT	GTAP economic accounts, harmonized with FAOSTAT
Factor of production explicitly modelled	More detailed on natural resources (land, water)	More detailed on economic resources (labour, capital, land)
Land use change mechanisms	Geographically explicit. Land conversion possibilities allocated to grid-cells taking into account suitability, protected areas.	Aggregated representation. Substitution of land use at regional and agro-ecological zone level. Allocation of agriculture and forest land expansion across other land covers using historical patterns
Representation of technology	Detailed biophysical model estimates for agriculture and forestry with several management systems Literature reviews for biofuel processing	Input-output coefficient from GTAP database or national statistics at regional level. Literature reviews for biofuel processing
Demand side representation	One representative consumer per region and per good, reacting to the price of this good.	One representative agent per region adjusting its consumption between different goods depending on prices and level of income
GHG accounting	12 sources of GHG emissions covering crop cultivation, livestock, land use change, soil organic carbon based on advanced accounting framework. Peatland IPCC emissions values revised upward based on exhaustive recent literature review (see Appendix II.3).	Only land use change emissions. Deforestation and soil organic carbon calculated with default IPCC emissions factors. Peatland IPCC emission values revised upward based on Edwards et al. (2010).

** GLOBIOM version with disaggregated EU as at the start of this project. MIRAGE-BioF as in Laborde (2011).*

As a model specialised in land use based activities, GLOBIOM benefits from a more detailed sectoral coverage, backed by a solid representation of production technologies and a geographically explicit representation of land use[33] and associated greenhouse gas emission flows (see Figure 22). GLOBIOM is a partial equilibrium model, meaning that the only economic sectors represented in detail are agriculture (including livestock), forestry and bioenergy. In MIRAGE-BioF, all sectors of the economy are represented but with a more limited level of detail on the supply side representation due to the use of socioeconomic accounting matrices.

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[33] By geographically explicit, we refer to the fact that the model makes allocation of production based on precise geographical data on land characteristics (> 10,000 spatial units).

Many of the modelling issues raised during the previous LUC assessment can be more easily and accurately addressed in GLOBIOM. Some GLOBIOM characteristics that differ from MIRAGE-BioF include:

- A more precise representation of LUC dynamics
- The robustness of biophysical relations for production, conversion and substitution processes
- The level of detail in the description of available technologies
- The representation of non-linear responses on land (for instance, fallow land can be used, but only up to a certain maximum level).

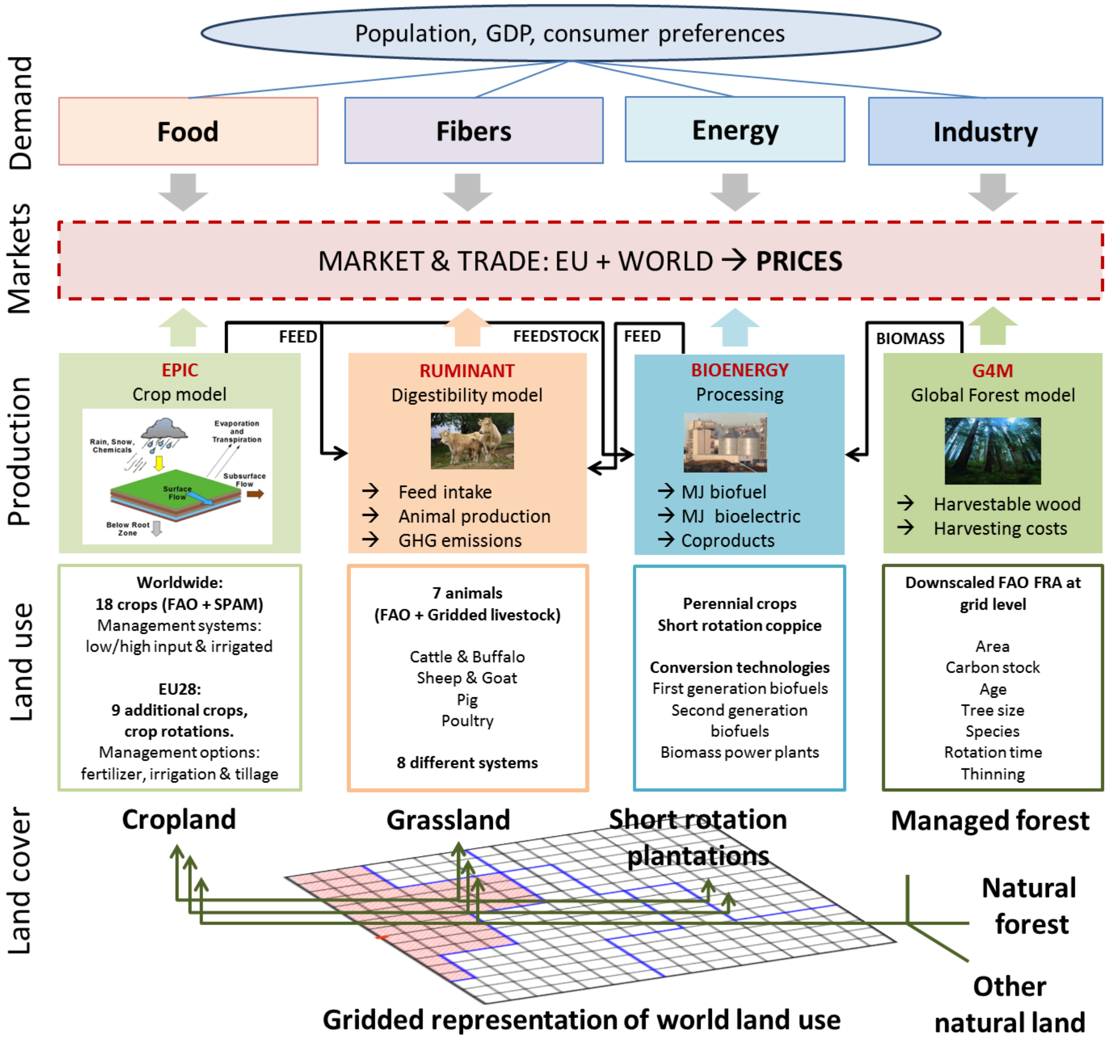

Figure 22: Overview of the GLOBIOM model structure

While GLOBIOM can address many modelling limitations raised in the ILUC debate, a limitation of GLOBIOM is the fact that it does not have some of the mechanisms that are present in MIRAGE-BioF, such as the macroeconomic effect of bioenergy policy on the fuel market or population income. These effects are discussed in more detail in Sections I.8 and I.9. We argue that these should remain of second order when compared with drivers of indirect land use change.

Beyond differences in modelling frameworks and their capacity to describe mechanism at play, a main challenge in ILUC modelling remains the treatment of uncertainties on parameters that are independent from the model used (behavioural parameters, emission factors, future technologies). These uncertainties receive particular attention in this study. A range of confidence is established for emission factors on the basis of literature review and other available information. Sensitivity analyses are performed on the behavioural parameters considered as the most critical for the final results (for instance, yield response or land conversion costs).

I.2 Representation of agriculture and yield development

As a model specialised on land use issues, GLOBIOM benefits from a greater level of detail in its representation of agriculture, with a larger number of crops and livestock systems represented than in MIRAGE-BioF. This increases the number of biofuel feedstocks that can be modelled, and allows for a more precise description of crop and livestock interaction, including co-products utilization. Like in MIRAGE-BioF, yields are sensitive to prices and farmers can intensify their production in response to market signals.

I.2.1 Crops

GLOBIOM represents 18 crops globally and 27 crops for the European Union. The full list of crops covered is detailed in Section I.9. Harvested areas are based on FAOSTAT statistics but are spatially allocated using data from the Spatial Production Allocation Model (SPAM).[34] In the case of the EU, crops are allocated across NUTS2 regions using data from EUROSTAT. This setting provides a very detailed framework compared to the previous modelling with MIRAGE-BioF, where Europe was represented as a single region and the number of crops more limited. MIRAGE-BioF relies on a modified version of the GTAP 7 database[35] that only contains 8 crop aggregates. IFPRI extended the number of these crops to 11 by disaggregating oilseeds and singling out corn (see full list in Section I.9).

The aggregated approach of MIRAGE-BioF is too coarse to trace all single crop substitutions, but allows a mapping of the total global harvested area. In GLOBIOM, the crop level approach is more precise but, as all crops are not represented, a small fraction of harvested areas is not explicitly modelled. Cultivated area currently represents in GLOBIOM around 84% of the total harvested area in the world. Harvested area for the non-covered crops is kept constant.[36] Global harvested area amounts to 78% of land classified by FAO as "Arable land and permanent crop" category, which shows the importance of abandoned land, idle land and temporary meadows in the definition of this category. The advantage of the GLOBIOM approach is that this "not harvested" arable land is also

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[34] See You and Wood (2008) and http://mapspam.info/

[35] The Global Trade Analysis Project (GTAP) database is a large database describing the world economy and compiled using national statistics and global trade datasets. This database is formatted to satisfy certain properties of consistency on economic accounts in order to be used by computable general equilibrium models, a class of macro-economic models to which MIRAGE-BioF belongs. For more details see Narayanan et al. (2012) and the GTAP website www.gtap.org .

[36] The five most harvested crops in FAOSTAT nomenclature subject to this assumption in GLOBIOM are in decreasing order: other fresh vegetable, coconuts, olive, coffee, natural rubber.

explicitly represented in the model. The standard assumption for model projections is to keep this area constant.

However, as explained in Section II.11 in Annex II, the representation in GLOBIOM of expansion into abandoned land has been improved during the study project, in order to represent more complex dynamics (for instance, decrease in fallow land).

In GLOBIOM, yields for all locations and crops are determined in a geographically explicit framework by the Environmental Policy Integrated Climate Model (EPIC). The yields are distinguished by crop management system and land characteristics by spatial unit.[37] They are however rescaled by a same factor to fit FAOSTAT average yield at the regional level, in order to catch other managements parameters not supplied to EPIC or other cause of yield mismatch. This approach with differentiated yields is different from the one in MIRAGE-BioF that assumes a homogenous yield within a region and agro-ecological zone.

Different crop management systems are distinguished in GLOBIOM. At the world level, four technologies can be used (subsistence, low input rainfed, high input rainfed and high input irrigated). In Europe, a larger set of options is available, with two different levels of fertilizer input, two levels of irrigation, and three different levels of tillage. EPIC has additionally been run for a large combination of different rotation systems for all NUTS2 regions.[38] This therefore allowed a more precise simulation of the yield achieved through optimisation of rotations, a practice well observed in Europe. Input requirements for each system and location are determined by EPIC (quantity of nitrogen and phosphorus, irrigated water). At the base year, production cost for these systems (i.e. all input costs plus the farmer margins) are calibrated using FAOSTAT producer price data at the national level, assuming that all units within the country supply the market at this price.
The representation of crop production is therefore much more detailed than the one used in MIRAGE-BioF, which is also consistent with FAOSTAT but has a more aggregated description at the regional level for output and at the agro-ecological level (AEZ) for land distribution.39 The production structure in MIRAGE-BioF relies on a single aggregate production function at regional level, describing how output can be obtained from various production factors and intermediate consumption interactions (see Box 3 below). The description of the link between output and land is therefore not based on any biophysical model and relies on a simplified relation of substitution between inputs. A specific treatment of fertilizer input has however been added to better represent the saturation effect of yield in case of excessive addition of fertilizer.[40]

Additionally to production of grains or fibres, GLOBIOM also represents the production of straw for some of the major crops (barley, wheat) and corn stover. Only a part of the residues produced is considered available because of the role of residues for soil fertilisation. The residues removed are

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[37] EPIC is run over a large number of spatial units covering the global land cover (over 200,000) that are then aggregated for model runs into around 10,000 larger units. See for more details.

[38] NUTS (Nomenclature of Units for Territorial Statistics) is the standardized format for administrative divisions in the European Union. The level 2 of NUTS (NUTS2) corresponds to 271 regions in Europe.
For more information see http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction

[39] More information on the GTAP-AEZ framework can be found in Lee et al. (2007). This framework relies on aggregation of input data from Ramankutty et al. (2008) database.

[40] See appendix 4 of Al Riffai et al. (2010).

used for the livestock sector and the industrial and energy uses. The impact of using agricultural residues as biofuel feedstock has been more precisely looked at in a specific improvement to the model (Annex II.1).

Several rates of residue removal are now considered and the effect of changing this rate on yield and carbon sequestration is now analysed using the EPIC model. Agricultural residues were not represented in the version of MIRAGE-BioF used in Laborde (2011).

I.2.2 Livestock

GLOBIOM is one of the most refined global models in its representation of the livestock sector. It includes in its dataset all relevant information from the Gridded Livestock of the World database[41] and represents eight animal types spatially distributed, and producing seven animal products (see for the list of animal and products). This allows for a more precise representation of the links between livestock production, feed requirements and the link to land through grazing needs. Livestock productivity for ruminants (buffalos, cows, sheep, goats) is estimated in GLOBIOM on the basis of animal feed ration using RUMINANT, a digestibility model.[42] The use of this model ensures consistency between the livestock sector input (grass, grains, stover, etc.) and output under different management systems.[43] For monogastric animals (pigs, poultry) the same consistency has been achieved using the results of a literature review to identify feed conversion efficiencies under two management systems (industrial and smallholder). Production costs for these systems are all based on FAOSTAT producer prices for product output and for grains input.

Grazing needs of ruminants depend on the rearing management system. For instance, cattle under mixed temperate systems spend a longer period of the year in stables and have lower grazing needs than cattle under extensive grazing management. A grassland map indicating levels of biomass production in the different regions is used to determine possible stocking densities of animals. The link between animals and land is therefore fully consistent, allowing the need for additional land in response to changes in the livestock sector to be traced.

This level of detail and consistency is an important asset when compared with the more simplified representation of the livestock sector in MIRAGE-BioF, where only two types of animals are distinguished: cattle and other animals (derived from the three sectors present in GTAP: cattle dairy, cattle other and other animals). A caveat of the GTAP approach is that animal numbers are not explicitly represented which makes the calculation of the feed requirement more complex.[44] Feed intake and conversion efficiencies are derived from the input/output relations observed in the economic statistics of the sector as a whole. Each sector is only represented through one aggregated production function, similar to the approach for crops.

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[41] See Wint and Robinson (2007)

[42] See Herrero et al. (2013)

[43] Eight production systems are used that are based on the classification from Seré and Steinfeld (1996)

[44] Animals in GTAP are assimilated to capital for these sectors.

I.2.3 Dedicated energy crops

In addition to the crops mentioned in Section I.2.1, GLOBIOM also contains yield information from EPIC to simulate deployment of dedicated energy crops, such as switchgrass and miscanthus. Because these crops are not cultivated at large scale in the base year, only their production potential is represented in the model. The use of the EPIC model to estimate the biophysical characteristics of the crops provides information on the suitability of land in different locations, as well as the fertilizer and water requirements.

Woody biomass can also be supplied on agricultural land using short rotation coppice. In the current version of the model, all short rotation woody biomass production is described through a single sector of short rotation plantation (Section I.3.1) that can be deployed on agricultural land or on other types of land.[45] These dedicated energy crops and woody biomass sectors in agriculture are not represented in MIRAGE-BioF.

I.2.4 Yield responses and intensification

The response of agricultural yield to market signals has been an important point of debate in the assessment of ILUC.[46] In both GLOBIOM and MIRAGE-BioF assumptions are made on technological changes that allow yields to increase over time independently from other economic assumptions (e.g. breeding, introduction of new varieties, technology diffusion, etc.) In addition both models represent yield responses to prices, although in a different way.

In GLOBIOM, crops and livestock have different management systems with their own productivity and cost. The distribution of crops, animals and their management types across spatial units determines the average yield at the regional level. Developed regions rely for most of their production on high input farming systems whereas developing countries have a significant share of low input systems and even, in the case of smallholders' subsistence farming with no fertilizer at all. Farmers can adjust their management systems and the production locations following changes in prices, which impact the average yields in different ways:

- shifts between rainfed management types (subsistence, low input and high input) and change in rotation practices;[47]
- investment in irrigated systems. This development is controlled through a simplified representation of the regional water supply potential;
- change in allocation across spatial units with different suitability (climate and soil conditions).

In MIRAGE-BioF, yield response to prices is described in a much more simple manner due to the aggregated production function that does not differentiate land suitability or management systems (see Box 3). When the relative price for land increases, yield can increase too by adding additional fertilizer, capital and labour. Hence, additional demand can be met while keeping land requirement constant. As explained in Section I.2.1, the production function has been modified to avoid

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[45] See Havlik et al. (2011)

[46] See for instance Keeney and Hertel (2009) or CARB (2011).

[47] Change in tillage practice can also intervene. However, the impact on yield is second order, this management most significant impact on the level of carbon stocked in the soil.

unrealistic responses of yield in case of strong fertilizer input increase. The yield response however remains based on a simplified representation without explicit link to the real biophysical potentials.

Box 3: Production functions in MIRAGE-BioF and in GLOBIOM

Production in GLOBIOM and MIRAGE-BioF follow two different settings, due to differing theoretical approaches. GLOBIOM, as a bottom-up mathematical programming model, relies on a detailed representation of technology for each sector with different management systems and production locations. Each management option has its own input requirements, production cost, and production efficiency. For instance, in the case of crops, the level of fertilizer and water requirements is precisely known depending on the level of intensity of the management (low, high input, irrigated). The model computes for a given demand, what the most cost-efficient systems are under a constraint of land availability and cost of resources. At the level of a region, the production pattern is then obtained by the sum of all production systems and locations used. This representation provides non-linear supply functions, whose slope patterns directly depend on the distribution of cost-efficiency across management systems and locations. The advantage of this approach is the explicit link between technological options and the production potentials. The shape of the supply function, however, cannot be simply inferred ex-ante and requires simulation experiments to be calculated.

MIRAGE-BioF, as a computable general equilibrium model (CGE), relies on a more aggregated representation of production, directly calculated at the regional level. Input and production factor requirements (land, capital, labour) are set for the base year at regional level, as observed in statistics. When prices of these inputs or factors change, their level of consumption and level of output changes as well, following a simplified formula designed to capture the aggregated effect directly. For this function, MIRAGE-BioF, like many applied CGEs, relies extensively on the Constant Elasticity of Substitution form (CES) that defines the easiness of substitution between all factors (labour, capital, land) from a specific parameter, the elasticity of substitution (see Box 4 for more details on the CES). MIRAGE-BioF uses this design at the regional level for all its sectors, but relies for several levels on CES nesting, with different elasticity values that depend on inputs and factors.[48] Such stylized representations are very convenient for macro-economic approaches (trade policies, budgetary policies, etc.) when estimation of the different level of substitution around an equilibrium point is the main interest. They however lose the link to underlying technological relations, and generally display a smooth supply profile and lower sensitivity to biophysical constraints due to input substitution possibilities.

I.3 Representation of woody biofuel feedstocks and forestry

In addition to crop feedstocks, the GLOBIOM model also provides potential for woody biomass feedstock extraction that can be used for bioelectricity and second generation biofuels. This is based on a detailed representation of plantation deployment potentials, as well as a refined description of the forestry sector. This combination of a detailed agriculture and forestry sector in one modelling framework is a strong asset of GLOBIOM. The description of forestry in MIRAGE-BioF is limited to a single sector, without biofuel feedstocks, whereas GLOBIOM explicitly models extraction of five primary wood products and distinguishes between short rotation plantations and managed forests.

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[48] See Bouet et al. (2010) for a description of most CES nesting in the different production functions.

I.3.1 Short rotation plantations

Besides energy crop, woody biomass can be supplied in GLOBIOM through short-rotation plantations, a sector that covers very short rotation periods (short rotation coppice i. e. 2 to 5 years) but also longer rotation periods (short rotation forestry, closer to 10 years).[49]

Suitable areas for this sector are determined by using a geographic information system (GIS) that analyses temperature, precipitation (rain), altitude, and population density. The productivity of plantations is based on estimates from the Potsdam Net Primary Productivity[50] Model Inter-comparison, and production costs are calculated based on literature sources.[51] Several deployment potentials can be considered depending on the assumption used for plantation type (cropland, grassland, other natural vegetation). These data are also used to update the model with the amount of carbon that is sequestered.

I.3.2 Woody biomass from managed forests

GLOBIOM relies on information from the global forestry model G4M[52] for its representation of forestry productivity. Locations of forests are supplied to GLOBIOM at a half degree resolution (see Figure 22). Harvest potentials of stemwood are determined based on net primary productivity (NPP) maps and combined with maps of forest biomass stock such as the Global Forest Resources Assessment provided by FAO.

The information on forestry harvest potential from G4M allows four main primary woody resources to be represented in GLOBIOM: industrial roundwood, non-commercial roundwood, harvest losses and branches and stumps. Harvesting costs include logging and timber extraction and depend on harvesting equipment, labour costs and terrain conditions. Primary resources, once extracted, are separated into five primary woody products: sawn wood biomass, pulp wood biomass, energy wood biomass (biofuels, heat and electricity), traditional use biomass (fuel, cooking) directly collected in the forest (no processing chain) and other non-energetic use biomass. Primary forest residues are included (branches and stumps) and can be used for second generation biofuels, electricity and heating. All harvested primary woody products are sent to processing activities which can lead to other types of bioenergy feedstocks (secondary residues such as saw dust and cutter shavings, black liquor, bark). MIRAGE-BioF only contains one aggregated forestry sector (see Box 3) which does not supply feedstock for biofuels and contains no specific information on forest biomass productivity.

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[49] Weih (2004)

[50] Net primary productivity is the measure of the net carbon flow from the atmosphere to the terrestrial biomass, ie the amount of biomass that is growing in a given period of time, a year in our approach. See Cramer et al., 1999.

[51] See Havlik et al (2011) for full details.

[52] See Kindermann et al. (2008).

I.4 Overview of feedstock processing and biofuel production

GLOBIOM expands the number of feedstocks and processing pathways that have been explored so far with MIRAGE-BioF. It includes second generation technologies and offers a flexible framework that can be further developed to describe additional biofuel pathways, present or future, with their expected production costs and conversion coefficients.

I.4.1 Sector coverage and role of supply chain

At the level of primary sectors, GLOBIOM represents, in total, 27 crops, 7 animal products and 5 primary wood products (see details in). These products can then be directly sent to markets to satisfy the demand of households and various industries and services (food industry, seeds, cosmetic industry, etc. which are not explicitly represented in the model[53]). Part of the commodities can also be used as animal feed in the livestock sector, which is the case for a significant share of many crops. Some other products are transformed explicitly in the model into intermediate or final products, before being sent to the market. This is the case for oilseeds, wood primary products and products used as bioenergy feedstocks. For these products, all processing industries are explicitly represented in the model, with their transformation coefficients, their co-products and processing costs. The role of processing industries in the supply chain is illustrated in Figure 23.
The representation of market flows in GLOBIOM is based on information from FAOSTAT that provides details on the quantities of biomass which is processed, directly purchased by final consumers, used as animal feed, or allocated to seeds or other industrial users. The accounting of this distribution across potential users is important to assess the competition between food, energy and other uses.

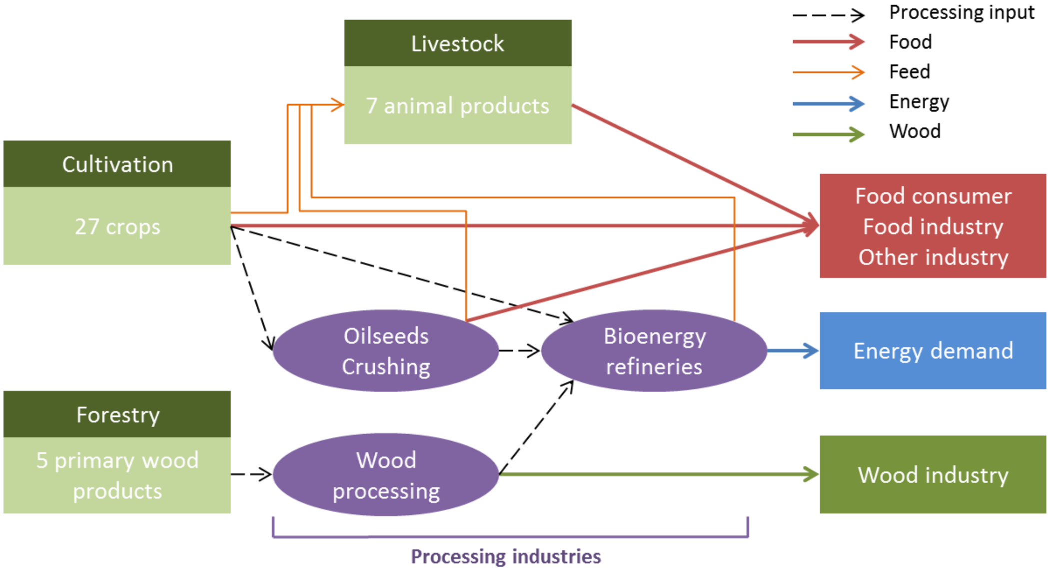

Figure 23: Supply chain in GLOBIOM and role of processing industries

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[53] Industrial uses are captured in the FAOSTAT database in the category "Other uses" of the Supply Utilisation Accounts.

In comparison, MIRAGE-BioF relies on a more comprehensive representation of economic flows, because it contains a complete mapping of all economic sectors with their demand for raw products. For instance, the food industry is represented explicitly in the model, as well as the chemical industry. However, the number of primary sectors is more limited, with only 11 crops, two animal products, and one forestry product. The volume of input in each sectors relies on aggregated regional accounts in monetary units, less precise than in the FAOSTAT utilization accounts expressed in quantities. For crops of interest for biofuels however, some bottom-up data reconstructions were performed in MIRAGE-BioF to refine the initial data and make them more consistent with FAO statistics.

Because the supply chain is long and complex and commodities are aggregated according to their economic value, it is often difficult to trace the flow of the raw commodities 'from field to plate'. For instance, the raw output of an aggregated sector such as fruit and vegetables can be purchased by sectors as diverse as (in decreasing order) food processing (other), vegetable and fruits[54], beverage and tobacco, trade margins, textile, other general services, vegetable oil, chemical rubber plastic, etc.[55] The outputs of these sectors can in turn be purchased by many other sectors.

I.5 Processing activities and bioenergy pathways

The main processing industries currently represented in GLOBIOM are the oilseed crushing industry, forestry industry, and a certain number of bioenergy industries.

Table 14 provides a detailed overview of processing activities and indicates if they are represented in MIRAGE-BioF. Conversion coefficients from input to final products, quantities of co-products generated and processing costs of pathways are currently sourced from literature. They can be updated if better information would become available.

Table 14: List of current processing activities in GLOBIOM and availability in MIRAGE

Processing category	Input product	Output product	GLOBIOM*	IFPRI-MIRAGE*
Oilseed crushing				
Rapeseed crushing	Rapeseed	Rape oil Rape meal	✓	✓
Sunflower crushing	Sunflower	Sunflower oil Sunflower meal	✓	✓
Soybean crushing	Soybeans	Soybean oil Soybean meal	✓	✓
Palm fruit processing	Palm fruit	Palm oil Palm fruit fiber	✓**	✓
Wood processing				

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[54] Auto-consumption in the GTAP database is frequent and is simply the result of aggregation across sectors having input-output flows.

[55] Based on the GTAP8 database for the year 2007 at world level. All sectors listed purchase more than 2% of the output consumed as intermediate consumption (40% of the total production).

Processing category	Input product	Output product	GLOBIOM*	IFPRI-MIRAGE*
Sawmill	Sawn wood biomass	Sawn wood Saw dust Saw chips Bark	✓	
Mechanical pulping	Pulp wood biomass Saw chips	Mechanical pulp Bark	✓	
Chemical pulping	Pulp wood biomass Saw chips	Chemical pulp Black Liquor Bark	✓	
Plywood production	Sawn wood biomass	Plywood Sawdust Saw chips Bark	✓	
Fiberboard production	Pulp wood biomass Saw chips Sawdust	Fiberboards	✓	
Bioenergy				
Combustion	Energy biomass Sawdust Saw chips Black Liquor Bark	Electricity Heat	✓	
Cooking	Traditional biomass	Stove energy	✓	
Biofuel corn based	Corn	Ethanol DDGS	✓	✓
Biofuel wheat based	Wheat	Ethanol DDGS	✓	✓
Biofuel sugar based	Sugar cane	Ethanol	✓	✓
	Sugar beet	Ethanol Sugar pulp	✓	✓
Biofuel FAME	Vegetable oil	Biodiesel (FAME)	✓	✓
Cellulosic ethanol	Woody biomass Grassy crops Cereal straw	Ethanol	✓	
Fischer-Tropsch biodiesel	Woody biomass Grassy crops	Biodiesel (drop-in)	✓	
Biogas fermentation	Corn silage	Biogas	✓	

* GLOBIOM version with disaggregated EU as used for this project. MIRAGE-BioF as in Laborde (2011).

** Palm fruit fibers are not represented in the current version of GLOBIOM.

The flexibility of GLOBIOM with respect to modelling supply chains can be used to improve the processing description at the level of detail deemed relevant for an accurate assessment. It is possible for instance to:

- Disaggregate the pathway to represent more precisely the underlying technologies currently used;
- Refine the type of inputs and co-products associated to a processing pathway (e.g. the use of ethanol or methanol during the transesterification for biodiesel production and production of glycerol);
- Account for the quality of co-products generated depending on the supply chain, for example the protein content of dried distiller grain solubles (DDGS).

In Laborde (2011), the number of bioenergy sectors in MIRAGE-BioF is limited to conventional (first generation) biofuels (see Table 14). Main crushing sectors and bioenergy production sectors have been carved out in the GTAP database and their processing costs and conversion coefficients are derived from literature.

However, this process is time-consuming because any change made to the model database requires a full rebalancing of all economic flows in the model. In a computable general equilibrium model like MIRAGE-BioF, the total country income, households and industry purchases, must remain consistent with the national accounts, also after addition of new sectors. For this reason, the number of sectors that can be added is more limited.

Another issue in MIRAGE-BioF is related to the unit of substitution. A product can only have one rate of substitution with other products within the same nest. By default, the unit of substitution is the economic value in the base year, when the model is calibrated. For instance, one dollar of vegetable and fruit imported in the base year from one region can be replaced by one dollar of vegetable and fruit from a different region. In the case of MIRAGE-BioF, the most important flows of homogenous products (wheat, corn, sugar, ethanol, vegetable oil, biodiesel) were reconstructed with the same prices per tonne to make the substitution equally consistent on a quantity basis. But this remains an imperfect adjustment because some products are substituted differently in reality, depending on their final use (for instance, calories or proteins).

GLOBIOM allows for taking into account quality aspects relevant per type of use (food, feed, bioenergy feedstock). For instance, it is possible to substitute bioenergy feedstock on the basis of their biofuel yield when used in a bio refinery and at the same time express the quantity in kilocalories (or other nutrition metric) for the final consumer. Similarly, in the case of feed, the protein and energy content are both important for the calculation of livestock rations, i.e. the bundle of feed given to the animals, as we will see in the next section.

Another interesting feature of GLOBIOM is its capability to model discontinuities in substitution patterns. For instance, it is possible to represent substitutions between several types of biodiesel sourced from different vegetable oils, but to restrict this substitution to some maximum incorporation constraint (for instance the amount of soybean oil or palm oil, following quality standards). In that case, a competitive price plays a role only when substitution is possible. Once the maximum incorporation level is reached, the more expensive feedstocks have to be used to satisfy the extra demand.

I.5.1 Dealing with co-products

The role of co-products of biofuel feedstocks has been discussed intensively in the ILUC debate. There is consensus about the fact that the cogeneration of products can limit the land footprint of bioenergy production but evaluations find varying estimates for this effect. The assessment of this effect is in particular related to the representation of feed intake by the livestock sector.
The feed representation of GLOBIOM provides detailed information on animal requirements. Rations of animal feed are calculated based on a digestibility model, which ensures consistency between what animals eat and what they produce, and rations are specific to each management system. When the price of a crop changes, the price of the feed ration changes as well, causing a change in profitability of each livestock management system. Switching between management systems allows for representing changes in the feed composition of the livestock sector.

Oilseed meals are explicitly modelled in GLOBIOM as a part of the rations represented in the livestock sector. If availability of one type of meal increase (e.g. rape), it can replace another type of oilseed meal (soybean) or increase the number of animals relying on a higher share of protein complement in their diet. The substitution of feed is handled under a double constraint of constant protein *and* energy requirement. For instance, it is possible to represent the fact that DDGS can be incorporated in high quantities to substitute some oilseed meals on a protein content basis, but that beyond a certain level of incorporation, this generates a deficit in energy needs that requires other feed items to be added in the ration. Other co-products such as corn and wheat DDGS are modelled in a simpler way and are just considered to replace some crop groups with a substitution ratio that is determined exogenously (see Annex II.7). Some constraints on the maximum level of incorporation of co-products in the livestock sector are also represented.

Contrary to GLOBIOM, the representation of feed in MIRAGE-BioF is based on a top-down decomposition of inputs based on economic statistics and FAOSTAT information and not established on the basis of a biophysical model. For that reason, feed quantity and composition are not explicitly linked to production levels for the livestock sectors (and based on aggregated statistics). Grazing input is not determined on the basis of animal feed needs but on the amount of land classified as grassland in the model. Therefore, increasing production requires increasing grassland, independently from the cattle density on land. This can overestimate the response of grassland area to change in livestock production level.

Co-products are well represented in MIRAGE-BioF and they also substitute in the livestock production functions associated to feed. Feed substitution is managed at two levels: the first level deals with substitution of different types of grains and the protein complement aggregate; the second level disaggregates the protein complement category to represent an easier substitution between oilseed meals and DDGS. However, the substitution ratio remains determined by the economic value associated to the different meals, which are highly correlated with protein contents in the case of protein meals. Although these substitution patterns have been compared and found consistent with literature, the flexibility to fit a specific substitution patterns is limited by the model design. In particular, it is not possible to exactly match a substitution ratio to multiple crops, for instance, one tonne of wheat DDGS replacing 0.5 tonne of soybean and 0.66 tonne of wheat.[56]

I.6 Capturing the world markets and the global economy

Both GLOBIOM and MIRAGE-BioF have a full representation of world markets but GLOBIOM trades all single goods as perfect substitute[57] in tonnes, whereas MIRAGE-BioF represents imperfect substitution between trade flows measured in monetary terms. GLOBIOM is therefore more suitable to account for replacements between specific goods on international markets, between the sectors covered. In GLOBIOM the description of the economy is however limited to main land based sectors (it is a partial equilibrium model whereas MIRAGE-BioF is a general equilibrium model).

MIRAGE-BioF has a greater understanding of interactions between all sectors of the economy but is coarser for sectors highly relevant to the ILUC debate such as agriculture and forestry. The GLOBIOM model might miss certain interactions (fuel market feedback, income impact), a caveat that can be addressed by calculating separately the magnitude of these effects.

I.6.1 International markets and trade

Both GLOBIOM and MIRAGE-BioF represent international markets for the various products that are traded between regions. They both rely on international trade statistics for trade flows and tariffs.[58] Their trade specifications however differ, as explained in the section below.

Trade in GLOBIOM follows a representation where products are all expressed in tonnes across the 53 economic regions and are considered as identical goods. Products are always sourced from the region with the least expensive production costs, adjusted by international transportation costs and tariffs. An increasing cost of trade prevents that all exports are provided by the same region. The advantage of such an approach is that it allows to trace precisely all substitutions of traded goods on a quantitative basis. Some patterns of trade creation are also possible, i.e. if increase of population requires or if a change in production costs makes it more profitable, two countries can start to trade in the future even if they were not trading partners before. This is not possible in the MIRAGE-BioF model.

In MIRAGE-BioF, all products are traded based on their economic value in the base year and consequently all substitution relations are by default measured in base year US dollars. To allow the substitution of agricultural goods and biofuel feedstocks to be on a 1 to 1 basis in quantitative terms, trade values are adjusted in the MIRAGE-BioF database. But this rate of substitution is difficult to

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[56] Estimate from CE Delft in the Ghallager review (2008).

[57] A perfect substitution means that an importing country will always decide to import from the country which hasthe lowest cost. This is different from an imperfect substitution representation where some stickiness in trade flows is assumed, meaning that trade patterns are not immediately impacted by small changes in price because it takes some effort to switch to a different supplier. Note that in GLOBIOM, as explained in this section, transportation costs increase with the size of trade flows, which also introduce some stickiness.

[58] GLOBIOM relies for its trade on FAOSTAT net export and reallocates trade bilaterally using COMTRADE. MIRAGE-BioF use data from the GTAP database that is built on COMTRADE statistics. Both models use the tariffs information from the MAcMap-HS6 database (Bouët et al., 2008).

maintain in case of large change in trade flows, due to the function of substitution used (see Box 4 for a detailed discussion). Additionally, trade patterns can only evolve in MIRAGE-BioF around the base year trade flows, and no new trade flow can appear. Products are not necessarily sourced from the cheapest region, because consumers are assumed to differentiate them on other criteria (quality or sanitary measures for instance).

This can help in reproducing some trade patterns in high value products (limited change in meat trade) but is sometimes a constraint to replicate rapid changes in the trade balance of bulk commodities (for instance, the change in rapeseed trade direction in Europe in the 2000s).

I.6.2 Including the economy partly or entirely: PE versus CGE

GLOBIOM is a partial equilibrium (PE) model, this means that the relevant sectors (agriculture, forestry and bioenergy) are represented in detail, which makes it suitable for modelling LUC effects. Other economic sectors however are not included or only included in a very coarse way. GLOBIOM assumes that the economy outside land using sectors evolves independently from the policies assessed in the model, following a *ceteris paribus* approach[59].

In the MIRAGE-BioF model, all sectors of the economy are simultaneously and immediately interconnected, for this reason the model is classified as a computable general equilibrium (CGE) model. It works as a giant water bed – if you press on one side of the economy, it moves everywhere. This is because all relations in the economy are described through equations that take the trickle-down effect to all other sectors already into account. The relation between all sectors is described on the basis of base year economic flows (national accounting perspective).

As stated above, GLOBIOM models only agriculture, forestry and bioenergy and focuses on understanding the land use impact of these activities. The impacts on the rest of the economy are assumed to have a second order effect and are not accounted for the modelling of LUC. Using the GLOBIOM model instead of the MIRAGE-BioF model implies that some sector interactions are missing. These interactions are however predictable in the case of biofuel policies, in which an increase in biofuel demand leads to more demand for biofuel crops. In particular, two interactions with sectors not covered in GLOBIOM can have a feedback effect on the land use 1) the effect biofuel policies have on the fuel market and its feedback on agriculture and forestry via fossil fuel and fertilizer prices and 2) the increased regional income in developing countries associated to the development of bioenergy production, that lead to higher consumption of land based products. These interactions are described in more detail in Box 4. Where necessary, effects not currently covered by GLOBIOM can be calculated ex-ante (before the event) and added to the simulation of the GLOBIOM model. For example, the change in oil price associated to the biofuel policy can be calculated based on a literature review or a simplified model. If required, it is also possible to introduce a simplified representation of the fuel market in GLOBIOM to represent its relation to the bioenergy market.

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[59] *Ceteris paribus* is an assumption widely used in economics where the effect of changing a parameter in the economic system is analysed, while considering that all other parameters influencing the economy are kept unchanged.

Box 4: General equilibrium effect from biofuel policies not captured in GLOBIOM

A certain number of general equilibrium effects are not captured in GLOBIOM, for instance across sectors or economic agents. Depending on additional information coming available during the present study (from literature, from stakeholders), we can decide to improve the description of interaction between the increasing biofuels volume and the feedback effects on other land based sectors.

- *Fuel market leakage*: Biofuels can lead to a decreased demand for fossil fuel and therefore somewhat reduce prices of fossil fuels. In response, cheaper prices can lead to an additional consumption of fossil fuel. This means that the replacement of fossil fuels by biofuels may not be 1 to 1.[60] This leakage is of different nature than the ILUC leakage but is important for the final GHG balance of biofuels.
- *Impact on fuel prices and feedback on agriculture*: Al-Riffai et al. (2010) report (using MIRAGE)-BioF that the EU biofuel mandate will lead to a fall in oil price of about 0.8% and a price reduction in the EU of about 0.3% of conventional petroleum based fuel at the pump. This could have a feedback effect on the input side of the agricultural sector and forestry sector. As this impact is usually small, this feedback effect should remain limited.
- *Impact on fertilizer prices*: fertilizer prices can be influenced by the price of fossil energy as well as by the change in production level required by the expansion of the agricultural sector. Furthermore, changing crop prices change the specific intensity of input use, increasing demand for biofuels thus increases the use of fertilizer on the existing cropland. As mentioned in the previous bullet, oil prices are expected to change in response to biofuel policy shocks, which could impact the price of fertilizer. However, as this effect is expected to remain small, the magnitude of this impact will remain limited, as long as quantities of extra fertilizer are low compared to overall agricultural needs.
- *Change in consumer income.* Impact on food prices is captured by a model like GLOBIOM. But in some developing regions, the development of a biofuel sector can have a significant impact on national income. Additionally, a change in fuel price can also lead to an increase or decrease of purchasing power and consequently a higher or lower consumption of other products.
- *Change in exchange rates, wages, cost of capital, service input prices, etc.*: many other interlinkages are described in a general equilibrium framework such as impacts on the labour market, capital market and currency market. However, as the biofuel sector remains of limited size compared to the rest of the economy, its macroeconomic impact usually remain limited. Bouet et al., 2010 find that the welfare impact of the EU biofuel mandate is close to zero (-0.01%) for the EU and regions in the world that are more notably affected are the least advanced countries, due to change in commodity prices, captured in GLOBIOM.

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[60] Rajagopal et al., 2011; 2013; de Gorter et al., 2011

I.7 Modelling land use change and associated GHG emissions

The modelling of LUC is a strength of GLOBIOM, as land is the starting unit to all production processes. GLOBIOM uses a flexible framework that represents all major land use substitution possibilities and takes into account the heterogeneity of production across locations. This offers a solution to the limitations observed with the simplified representation of land substitution in MIRAGE-BioF. The link between LUC and GHG emissions is more precise in GLOBIOM because it relies on a more refined approach than MIRAGE-BioF, which uses the default IPCC coefficients, and an updated estimate for peatlands. Additionally, GLOBIOM contains sources of non-CO_2 emissions from agriculture that can complement the understanding of the full GHG effect of bioenergy policies. MIRAGE-BioF however can inform policy on the emissions from the rest of the economy (industry and services).

I.7.1 Land allocation for crops

Trade in GLOBIOM is handled at the level of its 57 economic regions (EU28 + 29 world regions). The supply side of the model optimises the location of crop cultivation at a much finer resolution in so-called Supply Units: geographical areas of similar topographic, climatic and soil conditions of which more than 10,000 are distinguished in GLOBIOM. Depending on the potential yield and cost in each Supply Unit the model determines which crops will be allocated in that unit and in what quantity.[61] Each supply unit contains information (derived from the biophysical model EPIC) on the productivity of each crop. Therefore the quality of land is not an absolute characteristic of a Supply Unit, but is crop specific. Additionally for the EU region, more precise data could be fed into the model to represent crop rotations in GLOBIOM and substitutions occurs between these rotations (defined as group of crops including rotations) instead of between single crops.

This representation is more detailed than in MIRAGE-BioF, which relies on an aggregated approach at the level of the region and agro-ecological zone. Land substitution in MIRAGE-BioF is managed through a Constant Elasticity of Substitution (CES) nested structure that allows different levels of substitutability between crop productions to be distinguished (see Box 5). Two elasticities of substitution determine which crops are grown (see Figure 24). For instance, corn and wheat are highly substitutable. If the price of wheat increases, a significant share of corn harvested area is reallocated to wheat. Rice is placed at a lower level of substitution. Therefore, for the same wheat price increase, the increase of rice acreage will be much smaller. This simplified approach has the advantage of representing all the relevant substitution mechanism at the aggregated level. However, it does not use the full biophysical information useful to know the relative crop profitability in each location and may neglect non-linearities in the system. For instance, in the previous example, it is possible that corn remains very profitable in many suitable regions, initially limiting substitutions. When the wheat price hits a record, making it more profitable everywhere, substitutions will occur more massively.

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[61] This process of allocation of land between crops can be assimilated as a perfect substitution. In practice, to avoid the model to reallocate too abruptly across production systems, a flexibility constraint is implemented, often a lower or upper limit to the share of harvested area that the crop can use in the given location. In the EU, crop rotations also play this role of flexibility contraint.

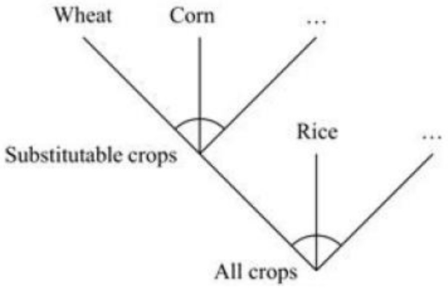

Figure 24: Land substitution nesting structure for crops in MIRAGE-BioF

Box 5: CES and CET functional forms, the bricks of MIRAGE-BioF

The Constant Elasticity of Substitution (CES) function is a production function widely used in applied economics to define how the level of output of one sector depends on a certain number of inputs or production factors (labour, capital, land, etc.). In a CES, when a quantity Q of output is obtained using two inputs in quantity q_1 and q_2, a mathematical relation defines how q_1 and q_2 can substitute each when their relative prices change. The central parameter of the CES is the elasticity of substitution σ that defines the easiness of substitution. For instance, an elasticity of substitution of 0.1 between labour q_1 and capital q_2 means that if price of labour increases by 10% relative to capital, more capital will be used such as capital purchase over labour purchase (q_2/q_1) increases by 1% (10% x 0.1).

The Constant Elasticity of Transformation (CET) function is used to define allocation of production factors (typically land or labour) where the returns are the highest. It works exactly as a CES but in the other direction: quantity is increased for the good that gets a higher relative price. For instance, a land owner puts more land in production in the sector that has higher market prices. Mathematically, the two functional forms are the same but the sign of the elasticity of substitution becomes negative for the CET.

CES and CET are used as elementary bricks in many CGE models and are extensively used in MIRAGE-BioF. One level of substitution (one elasticity only and all products at the same level) is usually too coarse to represent the complex substitution patterns observed at the aggregated level., In an attempt to approach reality and model capacities, modellers usually increase the number of levels (nested CES or CET) to differentiate different levels of substitution.

Although this approach allows for controlling the ease of substitution with different elasticity values for the different nests, three limitations are however to be noted. First the number of degrees of freedom for the calibration is only one per nest. So for instance, using one CET level for land means that forest, crop land and pasture is the same.[62] Moreover, the substitution patterns are by construction symmetrical, i.e. it is possible to reverse the land conversion with the same easiness. In other words, if prices come back to their initial values, land use comes back to its initial distribution.[63] In a conversion cost approach as in GLOBIOM, costs can be different for changing from land type A to B and for the reverse relation.

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[62] This specification is for instance used in GTAP-BIO (Golub and Hertel, 2012). See discussion in CARB (2011) and Laborde and Valin (2012).

[63] In MIRAGE-BioF, this symetry is also observed. However, if natural forest disappears, and is later replaced again by forest, it is assumed that the level of carbon is lower, equivalent to a managed forest.

A second issue is that the substitution around the equilibrium is performed on the basis of input values (one USD versus one USD).

To obtain a substitution in a different metric (for instance, one tonne for one tonne), it is necessary to reconstruct all the input values, using a same price per unit of substitution (in our example, same price per tonne). In MIRAGE-BioF, this was indeed required for a large number of agricultural goods, to ensure consistent substitution patterns.

A last drawback for the CES and CET is that the sum of volumes is not conserved by the substitution. This is a critical issue in the case of land use substitution and in the case of MIRAGE-BioF, it has been corrected for land by applying a correction factor.[64] However, it remains a limitation for the many other CES functional forms in the model, when moving away far from the initial equilibrium point.

I.7.2 Cropland, grassland and agricultural land expansion

Another important difference between GLOBIOM and MIRAGE-BioF is the way in which land use is represented between land cover types.
In MIRAGE-BioF, several representations have been tested. The design used for Laborde (2011) is as represented in Figure 25. Land expansion is managed at two levels:

- First level: Land expansion within agricultural and managed forest area (i.e. economic use area). For these cases, the substitution between cropland, grassland and forest is managed through a CET functional form (see Box 5).
- Second level: Land expansion in other natural area is managed through a separated elasticity of total managed land expansion.

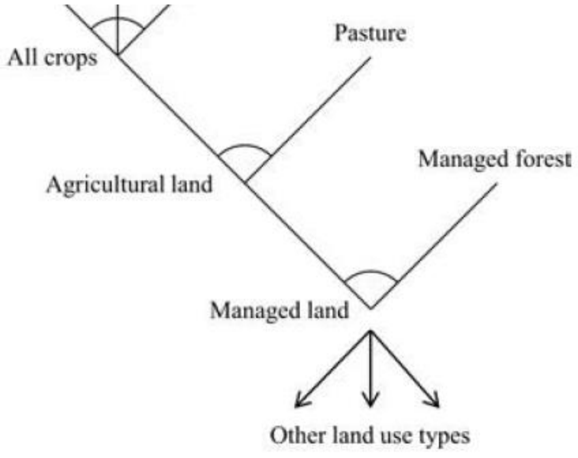

Figure 25: Land use type substitution nesting and expansion in MIRAGE-BioF

The limitation of this approach is the proper evaluation of land rents associated to grassland and managed forest (see

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[64] See Golub and Hertel (2012) for an illustration of how this correction is made. Elasticities of transformation are however no longer constant in that case, which imposes some recalibration when far from the initial point.

Box 6). The aggregated representation of MIRAGE-BioF does not allow for capturing the value of land in the different locations adequately. Moreover, the quality of land is often related to the type of cultivation, livestock activity, or forest plantation that land owners can choose, depending on output and inputs prices.

A very suitable land for wheat is not necessarily as suitable for corn, or for cotton, as illustrated by the regional specialization observed all over the world.

In GLOBIOM, the productivity of land for each type of crop is specific to the grid cell, also for land not currently used as cropland. Therefore, it is possible to consider conversion of other land to cropland on the basis of the expected profitability associated to productivity of new locations. A similar approach is used for grassland and grass productivity. This allows for direct calculation of the value of the marginal productivity of land in the model (a parameter often discussed in the ILUC debate). This value is estimated on the basis of real land use productivity estimates from EPIC (see Section I.2.1) instead of using an ad-hoc coefficient like in MIRAGE-BioF. By default, a yield value equivalent to 75% of average yield in the region was applied in MIRAGE-BioF in case of land expansion (with an interval for sensitivity analysis of 50%-100%).

Land expansion in GLOBIOM is described at the level of each spatial unit. Instead of substituting use with an aggregated function at a regional level, as for crop substitution in MIRAGE-BioF, land conversion is performed at the local level, on a one to one hectare basis, to allocate the new production to the spatial unit. A matrix of land use conversion between land use types defines which land use conversions are possible and what the associated costs are (Figure 26).
The land transition matrix has the great advantage of offering a flexible representation of land conversion patterns that has close resemblance with the real world. Conversion costs are not the same and vary between land types. For instance, it can be less costly to expand into natural vegetation than into forest (although less economically rewarding if the timber can be valued). This conversion cost approach in particular allows for a more flexible representation of the main drivers of LUC and deforestation observed in the different regions of the world.[65]

Peatland is one of the land covers that are under scrutiny in the biofuel debate. No spatially explicit information on peatland is currently available in GLOBIOM. Therefore, as in MIRAGE-BioF, drainage of peatlands drainage is currently accounted ex-post (with hindsight) in the model and based on other indicators, in particular cropland expansion in areas already containing drained peatlands. This representation can be improved if more information becomes available in the course of the project.

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[65] All land use changes in GLOBIOM are driven by expansion of agriculture and forestry. Hosonuma et al. (2012) estimate that 80% of deforestation is driven by agriculture.

Box 6: Land rent and land areas

One of the main challenges of the CGE approach used by MIRAGE-BioF is the mapping between the value of land represented in the production function, and the effective land area observed in the statistics. In the GTAP database, land use is represented as *land rent*, because production functions account for purchases of the different production factors (labour, capital, land). High value products (e.g. vegetables, fruits, cash crops) are therefore allocated a higher land rent, but only for a limited cultivated area. This can become a problem when starting to reallocate land input from one sector to another. For example, in GTAP, cereals have generally lower value added and therefore lower land rent per hectare. Transferring all land rents from vegetable and fruits to the cereal sector provides a lot of *virtual land* because, even though the value of land rent is very high (providing great expansion possibilities for cereals), the real biophysical area transferred is in reality small.

In MIRAGE-BioF, this anomaly has been fixed in the crop sector by reconstructing all land rents and assuming the same rent per hectare for all crops in a given region. However, the issue remains in the mapping of other land use. In particular, it is not possible to assume the same land rent per hectare for grassland, managed forest and cropland, as the areas considered are too vast. Consequently, representation of cropland expansion remains delicate when managed through a CET function (see Box 3). Several modelling options are proposed in Al Riffai et al. (2010) and Laborde and Valin (2012).

The methodological difficulties above are avoided in the bottom-up approach taken with GLOBIOM by relying on an explicit gridded representation of land, based on detailed information from remote sensing and data downscaling. This approach however does not remove the need for specification and calibration efforts when defining land conversion costs associated to the different transitions allowed.

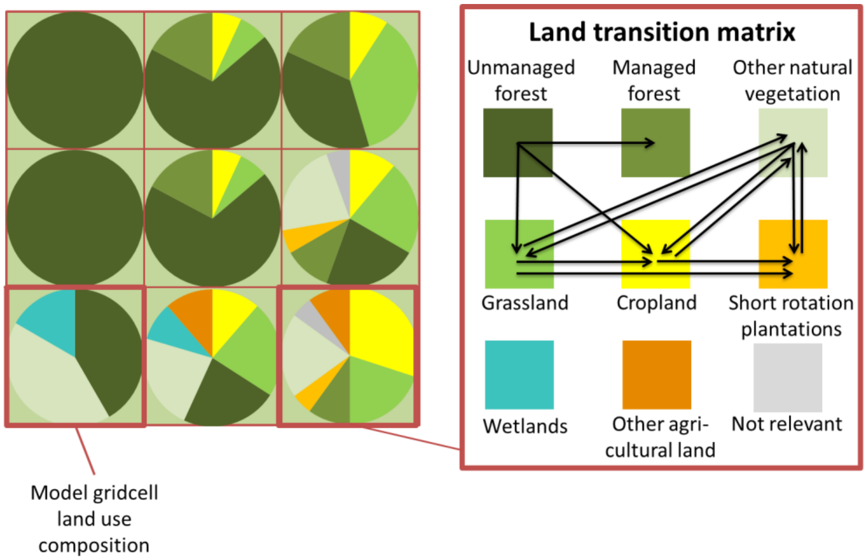

Figure 26: Land cover representation in GLOBIOM with land use distribution in each model gridcell (left hand-side) and land transition matrix defining in each gridcell the conversion allowed (arrows, right hand-side)

I.7.3 GHG emissions of agriculture and land use change

A dozen different GHG emissions sources related to agriculture and LUC are represented in GLOBIOM. Agricultural emission sources covered represent 94% of total agricultural emissions according to FAOSTAT, and LUC emissions are consistent with recent reporting, although slightly lower[66](Valin et al., 2013). All GHG emission calculations in GLOBIOM are based on IPCC guidelines for GHG accounting (IPCC, 2006). These guidelines specify different levels of detail for the calculations. Tier 1 is the standard calculation method with default coefficients, whereas Tier 2 requires local statistics and Tier 3 onsite estimations. Seven out of eleven GHG sources in GLOBIOM are estimated through Tier 2 or Tier 3 approaches.

Table 15: GHG emission sources in GLOBIOM

Sector	Source	GHG	Reference	Tier
Crops	Rice methane	CH_4	Average value per ha from FAO	1
Crops	Synthetic fertilizers	N_2O	EPIC runs output/IFA + IPCC EF	1
Crops	Organic fertilizers	N_2O	RUMINANT model + Livestock systems	2
Crops	Carbon from cultivated organic soil (peatlands)	CO_2	FAOSTAT	1
Livestock	Enteric fermentation	CH_4	RUMINANT model	3
Livestock	Manure management	CH_4	RUMINANT model + Literature review	2
Livestock	Manure management	N_2O	RUMINANT model + Literature review	2
Livestock	Manure grassland	N_2O	RUMINANT model + Literature review	2
Land use change	Deforestation	CO_2	IIASA G4M Model emission factors	2
Land use change	Other natural land conversion	CO_2	Ruesch and Gibbs (2008)	1
Land use change	Soil organic carbon	CO_2	Harmonised World Soil Database JRC for the EU28	1/2

For specific cases of LUC emissions, four different sources are particularly relevant:

- Deforestation: only changes in above and below ground living biomass are accounted for. G4M provides estimates that are consistent with Forest Resource Assessment (FAO, 2010). When forest is converted to a non-forest land cover, forest C stock is lost and replaced by the carbon stock from the new land cover (see next bullet);
- Natural land conversion: for other land cover than forest, above and below living biomass is accounted for based on the Ruesch and Gibbs (2008) database. This applies to grassland, other natural land and short rotation plantations;

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[66] This is due to the fact that the model only represents land use change emissions from agricultural activities and not from other activities such as illegal logging, mining, etc. Current observations however show decreasing patterns of deforestation in some regions with significant deforestation in the past, in particular Brazil.

- Soil organic carbon: following improvement performed in this project, soil organic carbon (SOC) is accounted for the world using information from the Harmonised World Soil Database. In Europe more precise data from JRC are used. SOC is influenced by crop management practices, in particular tillage. See Annex II.5 for more details;
- Organic soil cultivation: this concerns peatlands that are taken into cultivation and emit GHG emissions over multiple years. The associated emissions have been precisely studies in this study, as described in Annex II.3.

In comparison to GLOBIOM, MIRAGE-BioF LUC GHG accounts are based on more generic calculations as they often rely on Tier 1 approach from IPCC. Non-CO_2 emissions from agriculture were not used to avoid some double counting with the direct emissions coefficients from biofuel life cycle analyses.

From the four types of emission sources listed above, only three sources are represented in MIRAGE-BioF, natural land carbon stocks in living biomass are not represented. MIRAGE-BioF models the other three as follows:

- Carbon stock in forests is based on IPCC Tier 1 emission factors applied to the different AEZ in the 15 regions (Laborde and Valin, 2012). Forest coefficients correspond to above and below ground living biomass and a distinction is made between primary forest, managed forest, and in the case of EU, afforested areas. However, the carbon stocks are not spatially allocated like in G4M;
- Soil organic carbon is estimated for all regions in the world using IPCC Tier 1 emission factors;
- IPCC coefficients are not applied for peatland, but instead a higher value of 55 tCO_2 ha^{-1} yr^{-1} is used, sourced from more recent literature estimates. Based on historical observations, a share of 33% of oil plantations is assumed to expand into peatland (based on Edwards et al., 2010).

I.8 Modelling changes in food consumption

Both GLOBIOM and MIRAGE-BioF represent a response of food demand that increases the price of agricultural products. MIRAGE-BioF features the most sophisticated approach to modelling food demand having a full representation of household substitution patterns. Consumers in GLOBIOM do not substitute across products, but the impact of their change in food intake can be estimated in a more tangible way, using statistics on kcal per capita per day provided by FAO.

Food demand is endogenous in GLOBIOM and depends on population size, gross domestic product (GDP) and product prices. When population and GDP increase over time, food demand also increases, putting pressure on the agricultural system. Change in income per capita in the baseline drives a change in the food diet, associated to changing preferences. Current trends in China for example show that per capita rice consumption decreases, whereas pig consumption increases and milk consumption grows even faster. Food prices are another driver for a change in food consumption patterns. When the price of a product increases in GLOBIOM, the level of consumption of this product decreases by a value determined by the price elasticity associated to this product in the region considered. The price elasticity indicates by how much the relative change in consumption is affected with respect to relative change in price.

For instance, an elasticity of -0.1 means that if the price of the product increases by 10%, the consumption of this product decreases by 1% (10x-0.1). The values of these elasticities in GLOBIOM are sourced from the USDA demand elasticity database[67]. In this database, price elasticities of demand are lower for developing countries than for developed countries and lower for cereals than for meat products. This is consistent with observations.

The representation of demand in MIRAGE-BioF is more comprehensive because the model incorporates a full representation of the consumer budget covering consumption responses to changes in household income and to the different product prices at the same time.
In particular MIRAGE-BioF allows for representation of cross-price effects. This means that when the price of wheat increases the consumption of wheat decreases (own-price effect) whereas the consumption of corn increases to compensate for wheat loss (cross-price effect). GLOBIOM models the own-price effect but does not account for the cross-price effect. Therefore its assessment of food demand change cannot account for substitution, which may underestimate the transmission of effects across agricultural markets.[68] An additional feature of GLOBIOM compared to MIRAGE-BioF is that it accounts for kcal per capita supplied per day by using FAOSTAT data. The impact of food prices on food demand can therefore be assessed as a change in kcal per capita per day for each of the products.

I.9 GLOBIOM and MIRAGE-BioF characteristics – technical summary

GLOBIOM and MIRAGE-BioF are two very different types of economic models: GLOBIOM is a detailed multi-sector multi-region mathematical programming model focused on agriculture and forest activities, and therefore follows a partial equilibrium approach; MIRAGE-BioF is a multi-sector multi-region computable general equilibrium model (CGE), based primarily on the Global Trade Analysis Project database (GTAP). Although these approaches differ in several important points, they are both grounded in microeconomic traditions and based on the same assumptions of optimizing behaviours of the agents they focus on, producers for GLOBIOM, and producers and consumers for MIRAGE-BioF. Prices play a central role in these models to shape decisions of agents.

I.9.1 GLOBIOM, a partial equilibrium mathematical programming model

GLOBIOM is a multi-sectoral model developed at the International Institute for Applied Systems Analysis (IIASA) since 2007. The model is grounded in the mathematical programming tradition (McCarl and Spreen, 1980). This type of model is derived from aggregation of more simplified linear programming models of production used in microeconomics (Day, 1963). This type of approach has been long used in economics for many sectoral problems, in particular in agricultural economics (Takayama and Judge, 1964; 1971).

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[67] This database provides demand elasticities for 144 regions and eight food product groups. See Muhammad et al. (2011).

[68] Market interactions however also occur through the supply side with land use competition.

Development of recent computation capacities allowed application of this framework to large scale problems with a high level of details, for example to US policies affecting agriculture and forestry sectors (Schneider et al., 2007; US EPA, 2010) and GLOBIOM has common roots with the US-FASOM[69] model. Sectors covered by GLOBIOM are currently agriculture, forestry and bioenergy, with their supply side production functions, their markets and the demand side. The model is therefore a partial equilibrium model, because not all goods, factors or agents are represented in this approach. It is therefore designed to address issues affecting land use based sectors, and consider that situation in the rest of the economy is unchanged (ceteris paribus).

The economic formulation problem in GLOBIOM is expressed as follows: the model optimises an objective function defined as the sum of producer and consumer surplus associated to the sector represented, under a certain number of constraints. Producer surplus is determined by the difference between market prices and the cost of the different production factors (labour, land, capital) and purchased inputs. International transportation costs are also taken into account in the producer costs. On the consumer side, surplus is determined by the level of consumption on each market: the lower a price is, and the higher this consumption level can be, as well as the consumer surplus. Technically, this is achieved by integrating the difference between the demand function of the good on its market and the market price level. Constraints in the model are related to various dimensions: technologies available, biophysical resources availability (land, water), capacity constraints, etc.
In this type of approach, the supply side can be very detailed, in particular benefiting from the possibility of linearizing the non-linear elements of the objective function, the model can be solved as a linear programming (LP) model, allowing a large quantity of data to be used for production characteristics. The GLOBIOM model for instance can optimize the production for each sector on a large number of geographic units (maximum resolution is 212,000 units but typically the model is run at a more aggregated level of around 10,000 units). Additionally, many technologies and transformation pathways can be defined for the different sectors. This detailed representation on the production side however induces a trade-off on the demand side. Because of the linear optimization structure, demand is represented through separated demand functions, without a representation of total households budget and the associated substitution effects (McCarl and Spreen, 1980).

I.9.2 MIRAGE-BioF, a computable general equilibrium based on the GTAP framework

MIRAGE-BioF is a computable general equilibrium model (CGE) dedicated to biofuel impact analysis, derived from the trade policy analysis model MIRAGE developed at CEPII (Bchir et al, 2002; Decreux and Valin, 2007) and based on the GTAP database (Narayanan et al., 2012).
CGE models have their basis grounded in microeconomic theory, but operate in a macroeconomic framework, with a complete coverage of economic flows circulating in the economy for purchase of goods, remuneration of production factors. The father of the general equilibrium theory is Leon Walras who defined this framework in 1871, emphasizing the importance of interactions across the different component of the economy, ie sectors and regions, but also factor market, government expenditure, households savings and investment, current accounts disbalances, etc.

Kennet Arrow and Gérard Debreu implemented these principles in the 1950s in a more systematic formalized framework. To the difference of partial equilibrium models, all prices in CGEs are endogenous determined through equations to other economic trade flows, including real wages, return on capital, or exchanges rates (only one single price needs to be fixed to serve as a reference, called *numeraire*). These models are calibrated to a pre-existent state of the economy, considered in equilibrium. Prices all vary around this initial equilibrium in response to a shock (change in tax level, tariff, level of quota). Data on the pre-existing state is supplied by extensive datasets, called Social Accounting Matrices (SAM), usually produced by national statistical agencies.

The big advantage of CGEs is their full theoretical consistency as no ceteris paribus assumption is necessary with all sectors of the economy simultaneously interconnected. This however comes at the expense of details because SAMs are often more limited in their sectoral representations, due to their macroeconomic perspective and they only provide economic flows in monetary terms.
Even if some countries produce precise datasets tracking all economic interdependencies, with high level of representation of sectors, households and factor markets, many others rely on coarser information, and must rely on construction assumption and allocation rules to build up a complete and consistent SAM. These models were used until the end of the 80s mainly to assess the effect of taxation policies and trade policies (Shoven and Whaley, 1984), but they have been progressively extended to other applications such a climate change impact, carbon trading policies or bioenergy policies.

In the case of global CGEs, the GTAP database is very often used as the source of data, as it represents a unique effort of reconciling information from the SAMs of the different countries around the world. The process is however delicate as SAMs from various countries are usually not consistent with each another, due to differences in accounting method but also to the year in which the SAM has been constructed (SAMs are rarely available for every year). The GTAP consortium performs this reconciliation process and succeeded to put together an increasing number of SAMs over the years (96 for GTAP6 with base year 2001, 112 for GTAP7 with base year 2004, 134 for GTAP8 with base year 2007).

The GTAP database currently uses a nomenclature of 57 sectors, including 12 for raw agricultural products, and 1 for forestry. This often makes the data too coarse for a precise assessment of bioenergy. For instance, ethanol and biodiesel are missing but also fossil fuel. Oilseeds are aggregated and vegetable oil and their co-products are in the same sectors. For that reason, IFPRI has developed an extended database used with the MIRAGE-BioF model (82 sectors) for the different biofuels assessments, in which the most important missing sectors have been singled out.

I.10 Technical comparison table GLOBIOM versus MIRAGE-BioF

GLOBIOM	MIRAGE-BioF
Land use resolution	
Simulation units (SimU) architecture (Skalsky et al., 2008) • Global-SimU = Countries boundaries x HRU* at 5' resolution x Grid layer with 30' resolution Total number of Global-SimU (incl. EU): 212,707 Usual aggregation for global runs (2°x2°): 10,893 Max number of Global-SimU for Brazil: 11,003 Usual aggregation for global runs, Brazil: 443 • EU-SimU = NUTS2 spatial unit x HRU at 1 km resolution Max number of EU SimU: 379,220 Usual aggregation: 648 (NUTS2 x AEZ regions) *HRU = Region of same altitude, soil type, slope and other characteristics (Balkovic et al., 2010)	GTAP Land database (GTAP-AEZ) 1 spatial unit = 18 agro-ecological zones x GTAP7 countries (112) Typical aggregation, world: 155 units but of unequal importance (Laborde and Valin, 2012) Typical aggregation, EU27: 10 units (87% of rent in 2 AEZ) Typical aggregation, Brazil: 9 units (98% of rent in 4 AEZ)
Land cover types	
World: Global Land Cover 2000 (JRC, 5'x5') EU: CORINE Land Cover 2000 (EEA, 1 x 1 km) Land cover types imported into GLOBIOM: • Cropland • Other agricultural land • Grassland • Forest • Wetlands • Other natural land • Not relevant Improvements performed in the model • Split managed/unmanaged forest (G4M data) • Grassland match to grazing requirements • Short rotation plantation land cover	FAOSTAT database Land cover types imported into MIRAGE: • Arable land • Meadows and permanent pasture • Permanent crops • Forest • Other Land available for expansion: GAEZ (IIASA and FAO, 2002) Improvements performed in the model: • Split managed/unmanaged forest (GTAP-AEZ data)
Crop production	
World: 18 crops: • cereals: barley, corn, millet, rice, sorghum, wheat, • oilseeds: groundnut, rapeseed, soybeans, sunflower, palm • sugar cane • roots/tubers/vegetables: cassava, chick peas, dry beans, potatoes, sweet potatoes	World: 11 crops aggregates from an extended GTAP database: (Laborde and Valin, 2012) • Wheat • Maize (built by IFPRI)

GLOBIOM	MIRAGE-BioF
- cotton EU: 9 additional crops: - cereals: soft wheat, durum wheat, rye, oat - sugar beet - peas - green fodder: corn silage, other green fodder - fallow	- Sugar crops - Soybeans (built by IFPRI) - Sunflower (built by IFPRI) - Rapeseed (built by IFPRI) - PalmFruit (built by IFPRI) - Rice - OthCrop (aggregates of GTAP other crops, plant fibers and other coarse grains) - Other oil seeds - Vegetable and fruits
Harvested area: World: FAOSTAT with spatial allocation from Spatial Production Allocation Model (IFPRI) EU28: EUROSTAT NUTS2 statistics	**Harvested area:** FAOSTAT distributed by AEZ according to the M3 database (Ramankutty et al., 2008)
Yield: World: EPIC model on SimU grid for the 18 crops. Yield values adjusted to fit FAOSTAT country level Spatial and management system differentiation. EU28: EPIC run for combination of different rotation systems for all NUTS2 regions.	**Yield:** FAOSTAT, only at regional level.
Production: At SimU level. Consistent with FAOSTAT & EUROSTAT aggregates.	**Production:** FAOSTAT, only at the regional level.
Production costs: FAOSTAT producer prices.	**Production cost:** GTAP database
Technology: Substitution between Leontieff technologies World : 4 technologies estimated by EPIC - Subsistence - Low input, rainfed - High input, rainfed - High input, irritaged EU28: large set of technologies - 2 different levels of fertilizer x 2 different levels of irrigation x 3 different level of tillage	**Technology:** 1 aggregated nested CES function
Livestock sector	
Eight Animal types (and seven associated products): - Bovine dairy (bovine milk and meat) - Bovine other (bovine meat)	Two livestock sectors: - cattle - other animals

GLOBIOM	MIRAGE-BioF
• Sheep and goat dairy (small ruminant milk and meat) • Sheep and goat other (small ruminant meat) • Pigs (pig meat) • Poultry hens (eggs) • Poultry broilers (poultry meat) • Poultry mixed (poultry meat and eggs)	(three sectors in GTAP: cattle dairy, cattle other, other animals)
Animal number: ILRI/FAO Gridded Livestock of the World (GLW) animal number and distribution at the 3’x3’ resolution.	**Animal number:** Not available in GTAP or MIRAGE-BioF. (Assimilated to capital)
Yield: Estimated using RUMINANT, a digestibility model. Ensures perfect consistency between feed input (grass, grains, stover…) and output. For monogastric, based on a literature review.	**Yield:** Input/Output coefficient from the SAM
Production: Seven products: • Bovine meat (from bovine dairy and bovine other) • Bovine milk • Sheep and goat meat (from sheep and goat dairy and sheep and goat other) • Sheep and goat milk • Pig meat • Poultry meat (from broiler and poultry mixed) • Poultry eggs (from hens and poultry mixed)	**Production:** GTAP production value. Can be matched ex post with FAO quantities.
Production cost: FAOSTAT producer prices and grains input.	**Production cost:** GTAP database
Technology: Substitution between Leontieff technologies Ten systems (Seré and Steifeld classifications) 8 systems for ruminant: • Grassfed arid • Grassfed humid • Grassfed temperate • Urban • Mixed arid • Mixed humid • Mixed temp. • Other 2 systems for monogastrics • Industrial • Smallholders	**Technology:** 1 aggregated nested CES function
Forestry sector	
Forest area: based on G4M model (0.5°x0.5°) **Harvest yield:** Stemwood harvest potential determined from net primary productivity (NPP) maps, combined with maps on forest biomass stock (Global Forest Resources Assessment, FAO)	Forestry as one single sector.

GLOBIOM	MIRAGE-BioF
Forest primary products: 4 forest resources. • Industrial roundwood • Non-commercial roundwood • Harvest losses • Branches and stumps Separated into 5 primary woody products: • Sawn wood biomass • Pulp wood biomass • Energy wood biomass (biofuels, heat and electricity) • Traditional use biomass (fuel, cooking) • Other use biomass **Forest secondary products:** Secondary forestry residues from forest industries and milling activities: • Saw chips • Sawdust • Bark • Black liquor **Production costs:** Harvesting costs including logging and timber extraction account for: • Unit cost of harvesting equipment and labour • A slope factor accounting for terrain conditions • A regional adjustment of labour cost by the ratio of mean PPP (purchasing power parity over GDP). **Technology:** Substitution between Leontieff technologies Technologies with yield estimated for: • Sawmills • Mechanical pulp mills • Chemical pulp mills • Fiberboard production • Plywood production	**Production cost:** GTAP database **Technology:** 1 aggregated nested CES function
Conversion technologies in agriculture, forestry and bioenergy	
List of sectors/processes: • Agriculture ○ Rapeseed crushing ○ Sunflower crushing ○ Soybean crushing • Forestry ○ Sawmill ○ Mechanical pulping ○ Chemical pulping ○ Plywood production ○ Fiberboard production • Bioenergy ○ Combustion ○ Cooking ○ 1st gen biofuel corn ○ 1st gen biofuel wheat	List of sectors/processes: • Agriculture ○ Rapeseed crushing ○ Sunflower crushing ○ Soybean crushing ○ Palm fruit processing • Bioenergy ○ 1st gen biofuel corn ○ 1st gen biofuel wheat ○ 1st gen biofuel sugar cane ○ 1st gen biofuel sugar beet ○ 1st gen biofuel FAME

GLOBIOM	MIRAGE-BioF
○ 1st gen biofuel sugar ○ 1st gen biofuel FAME ○ 2nd gen biofuel fermentation ○ 2nd gen biofuel gasification **Conversion coefficients and costs:** Based on FAOSTAT and literature reviews. Can be expanded or updated more easily as a CGE.	**Conversion coefficients and costs:** Based on the GTAP modified database. Changing in technology representation technical due to modification to report in the SAMs
GHG Emission sources	
Eleven emission sources from agriculture and land use change: • Rice methane CH_4 • Synthetic fertilizers N_2O • Organic fertilizers N_2O • Enteric fermentation CH_4 • Manure management CH_4 • Manure management N_2O • Manure grassland N_2O • Deforestation CO_2 • Other natural land conversion CO_2 • Soil organic carbon CO_2 • Cultivated organic soil CO_2	CO_2 Industrial and service emissions + Three emission sources from land use change • Deforestation CO_2 • Soil organic carbon CO_2 • Cultivated organic soil CO_2

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Annex II Building an improved version of GLOBIOM

The GLOBIOM model is well suited for the purpose of modeling LUC. During the projest the consortium worked to further improve the model for this specific purpose. The consortium invited stakeholders to provide input on possible improvements. This Annex describes the improvements which the consortium implemented during the study. Selected Improvements are taken from a longer list of improvements based on stakeholder recommendations received during the first stakeholder consultation in November-December 2013. The consortium selected in co-operation with the project Advisory Committee the most important improvements, which were discussed with the European Commission in January 2014, with stakeholders during the second stakeholder consultation in February and again with the Commission in March 2014.

Nr	Improvement
1.	Improve the representation of cereal straw to enable the modelling of possible LUC effects of removing cereal straw from fields in 3 selected EU Member States
2.	Include carbon sequestered in annual and perennial crops as this carbon influences the carbon flows (emissions and sequestration) due to land use change.
3.	Update peat land emission factors based on best available literature.
4.	represent the expansion of plantations into peat land based on literature review.
5.	Inclusion of soil organic carbon (SOC) to rest of the world as currently only included for the EU. Tillage data are included at regional level where available.
6.	Include forest regrowth and reversion time on unmanaged land based on IPPC estimates. These effects increase the opportunity costs of using abandoned farmland in areas where forest regrowth is likely to occur.
7.	Improve protein and energy content representation to refine co-product substitution. Co-product substitution was already represented in GLOBIOM, accounting for both protein and energy content. Substitution patterns are a highly debated topic, therefore, fine-tuning of this mechanism is important to produce reliable substitution effects.
8.	Represent multi-cropping. Multi-cropping increases production per hectare and reduces agricultural land expansion. It can therefore influence the LUC response. As it is challenging to model multi-cropping response to price, multi-cropping will be included in the modelling baseline (with yield projections) rather than in the model itself.
9.	Represent imperfect substitution of vegetable oils. Previously, GLOBIOM could only represent perfect substitution or fixed composition of vegetable oils. Market leakage across vegetable oil markets is crucial to the LUC impact of biodiesel but is characterised by imperfect substitution. Hence, it was important to introduce this in GLOBIOM. Substitution elasticities are based on previous modelling exercises
10.	Separate representation of Argentina, Indonesia, Malaysia and Ukraine. The first three are important players in the production of biofuels and Ukraine has the potential to become an important supplier of agricultural products to Europe in the future. Previously, the countries were not represented separately in GLOBIOM but were represented as part of larger regional areas.

Nr	Improvement
11.	Represent unused agricultural land in Europe. Large amounts of unused land, mostly abandoned farmland, exist in Europe that could be potentially be used to produce additional quantities of biofuel feedstock. Using this land would limit expansion in other regions of the world and thus reduce LUC. Biofuels produced on this land would be low ILUC risk.
12.	Refine biofuel feedstock processing coefficients (oilseed crushing, ethanol production coefficients). Crushing rates are important to determine the final land use impact of biofuels. Coefficients used in GLOBIOM are fine-tuned.

II.1 Improve the representation of cereal straw

Motivation for improvements

Agricultural residues were so far represented in GLOBIOM only on the supply side, without consideration of competitive uses and sustainability removal threshold. As agricultural residues constitute one of the feedstocks studied in this assessment, it was decided to improve their representation on the supply and demand side to overcome the current loopholes. The representation of agricultural residues focuses in this study on wheat and other cereals straw.[70] Three regions were selected as illustrative case studies. They were chosen taking into account data availability on straw production and uses, a geographic coverage consistent with straw market size,[71] but also contrasting situations with respect to sustainability of additional residue removals, if a 1% biofuels shock from residues is implemented at the national level. The three selected regions are : i) Hungary, as an example of limited availability of straw, as more than half of cereal straw potential is currently being used for feed and animal bedding, which is considered beyond the sustainability removal level, ii) Great Britain as a region with greater availability,[72] but where sustainable potential would be hit if 1% of transportation fuel was supplied from straw biofuels, and iii) Center of France[73] where supply is relatively larger and sustainable potential should not be fully exhausted if 1% of French transportation fuel was supplied from straw biofuels. Statistics on characteristics of the different countries are summarized in Table 16 and the contrasting situations of these three regions detailed in Table 17.

Methodological approach

Supply of residues: Three different management systems were distinguished to reflect different levels of residue removal: i) no residue removal; ii) sustainable residue removal (around 33-50% depending on the region); iii) high residue removal (greater than sustainable removal). The first and second systems are assumed to have the same biophysical characteristics in terms of crop production (yields, soil organic carbon stocks), but production costs in the second system are higher due to collection of residues.[74]

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[70] We will represent cereal straw market in GLOBIOM with straw from wheat, barley, oat and rye, which are found to supply most of straw in Europe (Ecofys, 2013).

[71] Typical transportation distances are reported to be below 500 km.

[72] Excluding Northern Ireland

[73] Defined as NUTS1 regions FR1 (Ile de France) and FR2 (Bassin parisien).

[74] The cost for residue removal or residue incorporation is based on the data Standarddeckungsbeitragskatalog 2008, from the Austrian Ministry of Agriculture. We follow an assumption of 74 EUR/ha for full residues collection with balling.

The third management system also has a different collection cost, and modified characteristics for yield and soil organic carbon (SOC). Depending on the management, in particular the degree of fertiliser application that can compensate the yield losses, these effects can have more or less impact.

Impact of residue removal on yield is occurring through multiple channels, such as change in soil temperature and moisture, nutrient content, soil texture and sensitivity to water and wind erosion (Blanco-Canqui & Lal, 2007; Johnson & Barbour, 2010). To assess its impact, we EPIC simulations on EU data assuming a linear decrease of yield between sustainable removal rate and yield loss observed when 90% of residues are removed. EPIC simulations only capture a part of the drivers cited above and provide effects on yield of around -2% for median value after 20 years, with first quartile at -4.8% and third quartile at 0% (see Figure 27). Some other authors find greater impacts on some crops but this is highly dependent on soil type (no impact in two types of soil or up to -15% one type for corn stover in Blanco-Canqui & Lal, 2007; around -10% in Wilhelm, Doran & Power, 1986). Our simulations lead in particular to some positive feedback in case of low input system when residues are removed.[75] We also analyzed with the EPIC model the relative change of soil organic carbon associated with straw removal of 90% (Figure 28). At such rate of removal, under full tillage, SOC decreases after 20 years by 8 ± 3% with some significant differences across locations. For our sensitivity analysis in the Monte-Carlo simulation, we vary the full range of possible value of impact around representative values based on these findings. Our range of value acknowledges the uncertainty related to the farmer management response and soil quality implications. For yield impact, we assume an impact ranging from no impact (0%) to high impact (-4%) with a median value at -2%. For soil organic carbon impact, we assume an impact ranging from no impact (0%) to full impact (-10%) with a median value at -5%. The two ranges of impact are considered correlated.

Demand for residues: Several sectors are represented in the model that can compete for residues. First, the livestock sector uses straw as bedding, and to a lesser extent as feed. A generic substitute to straw has been represented in the model for bedding, which allows straw to be replaced by some other materials above a certain price.[76] Animal needs are implemented, with requirements based on Scarlat, Martinov & Dallemand (2010): straw use for cattle is 1.5 kg/day/head for 25% of population, sheep is 0.1 kg/day/head, pigs is 0.5 kg/day/head for 12.5% of population adjusted to (Ecofys, 2013) data when available. Straw used as feed can also substitute with other feedstuff in the livestock sector, with some implications on land use. Additional uses are also considered for energy and horticulture (mushrooms, strawberry, vegetables etc.) as well as industry (material use, pulp and paper).

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[75] Producing sufficient and timely quantities of crop residues is expected to increase soil organic carbon and overall soil quality. Incorporated crop residues also support recycling of essential nutrients in the soil and, from long-term perspective, improve soil fertility and have positive impact on yields. However, mineralization is a complex process driven by weather, soil mixing efficiency, soil moisture and nutrients available for microorganisms, and also by the ratio of C (mostly lignin) to N and P in incoming litter. Therefore, EPIC provides quite variable results as these major drivers vary in time and space. Most importantly, high quantities of soil-available N and P are used by microorganisms during plant residue decay (immobilization) which may also negatively impact yields in the following year as nutrients are then lacking for plants. These processes are explicitly included in C, N and P routines in EPIC. Repeated and intensive straw ploughing may therefore have negative effects on yields under management with generally low nutrient inputs. Moreover, other processes including leaching, erosion, runoff, or nitrification/denitrification determine fate of crop residue nutrients and introduce variability into our results.

[76] We currently assume substitute material for bedding available at 22-32 Euro per m^3 of wood chips (0.42 m^3/t wood chips) depending on country according to the Finnish Forest Research Institute (Asikainen, Liiri, Peltola, Karjalainen & Laitila, 2008). One ton of straw requires 1.5 tonne of wood chip in the substitution due to different absorption rate.

These latter uses are rather small at the EU level (5.5%, 4.8% and 1.5%, respectively, of total residue demand) and are considered as fixed in the model. In total cereal straw uses amounts in the EU28 to 63 Mt per year.

Sustainable straw potentials after removal of other uses (Table 16 and Table 17) are consistent with estimates from the Biomass Futures project (BIOMASS FUTURES, 2012), as illustrated in Figure 29 below. The few available sources disagree however on the straw collection potential and the amount of residues already used. For instance, for the three regions of interest here, HGCA (2014) reports significantly lower availability of residues for the UK (9.5 Mt) than the estimate we rely on. LUC value associated with 1% extra demand could then be underestimated for this region. For France, ADEME (2002) also reports smaller residue potential (25 Mt) and higher uses (17 Mt) compared to ECOFYS (2013). However, for the latter, a sufficiently large potential remains, and results would not be expected to change in France would the potential be reduced accordingly.

Regional markets: Straw is usually not being traded on long distance (usually transported within 500 km maximum). Therefore, we base our representation of local markets on NUTS1 region supply as a general rule, because their size corresponds approximately to this order of magnitude. However, for regions where NUTS1 are of relatively smaller size (Germany, UK, the Netherlands), larger units were considered (for instance Great Britain as a whole for the UK). For regions with straw deficit (Netherlands), import needs were added to the demand of neighbour countries.

Implications for model results

With this representation of cereals residues, it will be possible to look at land use implications of increasing straw removal. A shock in straw demand at the NUTS1 level will lead to cereal production cost increase in each of the three countries of focus. Residue prices will increase, but will be capped by the price of the substitution materials. Grains, as a joint product with straw, will be affected by the extra demand for residues. Primarily on its price, related to the change in price of residues. But also in production level, as food and feed demand reacts to prices. Beyond the sustainability threshold, soil organic carbon stock will also be impacted. Effect on cereal yields will also be looked at in the case of a sensitivity analysis, for cases where the suitability threshold is reached. The focus on different regions will help to understand the regional nature of results for straw removal due to the limited extent of trade for this material.

Table 16: Cereals straw balance in 2000 for EU Member States, and impact of a 1% demand shock of bioenergy from straw (1000 tonnes)

Country	Demand	Technical Potential	Sustainable Potential (40%)	Supply - demand	Gap compared to sustainable straw available	Gap after 1% national supply	1% national demand straw req	Share wheat
AT	382	2,535	1,126	744	66%	25%	461	50%
BE	556	1,476	656	100	15%	-73%	577	78%
BG	289	4,741	2,107	1,818	86%	79%	148	82%
CZ	228	5,158	2,292	2,064	90%	73%	399	64%
DE	6,010	32,718	12,360	6,350	51%	23%	3,489	51%
DK	3,635	4,799	2,133	-1,502	-70%	-85%	305	47%
EE	46	638	284	238	84%	65%	54	24%
ES	2,949	16,823	7,477	4,528	61%	28%	2,413	41%
FI	179	3,818	1,697	1,518	89%	72%	298	13%
FR	11,382	36,756	20,420	9,038	44%	30%	2,945	76%
GR	795	2,617	1,163	368	32%	-9%	476	84%
HU	3,522	5,201	1,907	-1,615	-85%	-100%	300	74%
IE	1,191	1,702	756	-435	-58%	-99%	314	31%
IT	1,664	9,094	4,042	2,378	59%	-7%	2,653	83%
LT	148	1,952	868	720	83%	73%	84	49%
LU	30	77	34	4	12%	-446%	156	26%
LV	64	958	426	362	85%	67%	75	46%
NL	1,311	1,087	483	-828	-171%	-336%	797	71%
PL	18,427	24,179	10,746	-7,681	-71%	-79%	758	40%
PT	396	563	250	-146	-58%	-229%	427	66%
RO	1,240	7,595	3,376	2,136	63%	55%	287	79%
SE	289	4,699	2,089	1,800	86%	62%	505	40%
SI	77	198	88	11	13%	-108%	106	76%
SK	112	2,138	950	838	88%	76%	119	65%
UK	7,740	17,698	7,866	1,230	16%	-21%	2,917	66%

Not reported: Malta, Cyprus, Croatia. Demand data for year 2000 were used applying Scarlat et al. (2010) coefficients on livestock number, or when Ecofys data for recent years were available.

Table 17: Selected three case studies for the marginal 1% shock at national level (1000 tonnes)

Country	Demand	Technical Potential	Sustainable Potential (40%)	Sust. Supply - demand	Remaining sustainable straw available	Remaing sustainable straw after 1% biofuel demand	Straw required for 1% biofuel	Share wheat
Centre France*	3,103	20,253	11,252	8,149	72%	50%	2,509	80%
Great Britain	7,034	17,210	7,649	615	8%	-24%	2,485	66%
Hungary	3,522	5,201	1,907	-1,615	-85%	-98%	255	74%

* This value excludes imports demand from the Benelux.

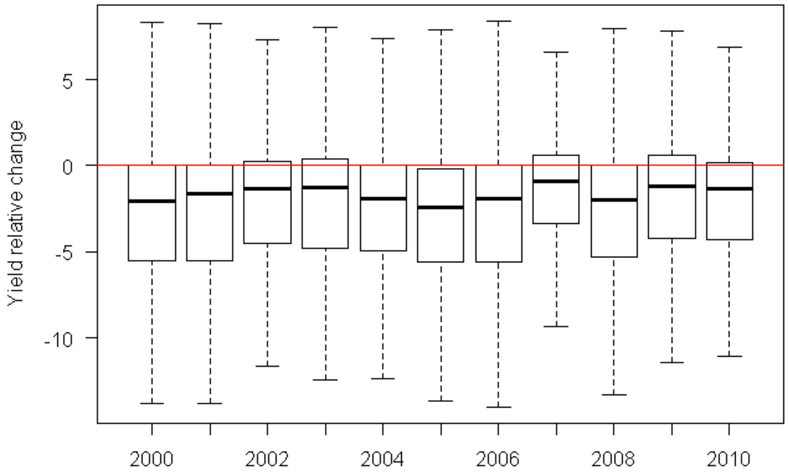

Figure 27: Crop yield relative change (%) in the EU when removing 90% of residues compared to 40%. Ten representative years are shown with their representative climate, after 20 years of removal. Estimates are sourced from the EPIC crop model simulations in all cropland location in the EU. Boxes indicate the first and third quartile of values and whiskers the 5%-95% range

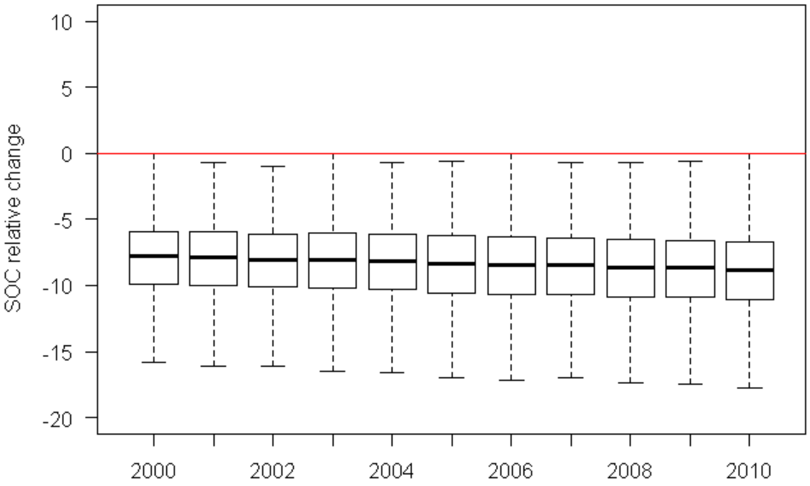

Figure 28: Soil organic carbon (SOC) relative change (%)in the EU when removing 90% of residues compared to 40%. Ten representative years are shown with their representative climate, after 20 years of removal. Estimates are sourced from the EPIC crop model simulations in all cropland location in the EU. Boxes indicate the first and third quartile of values and whiskers the 5%-95% range

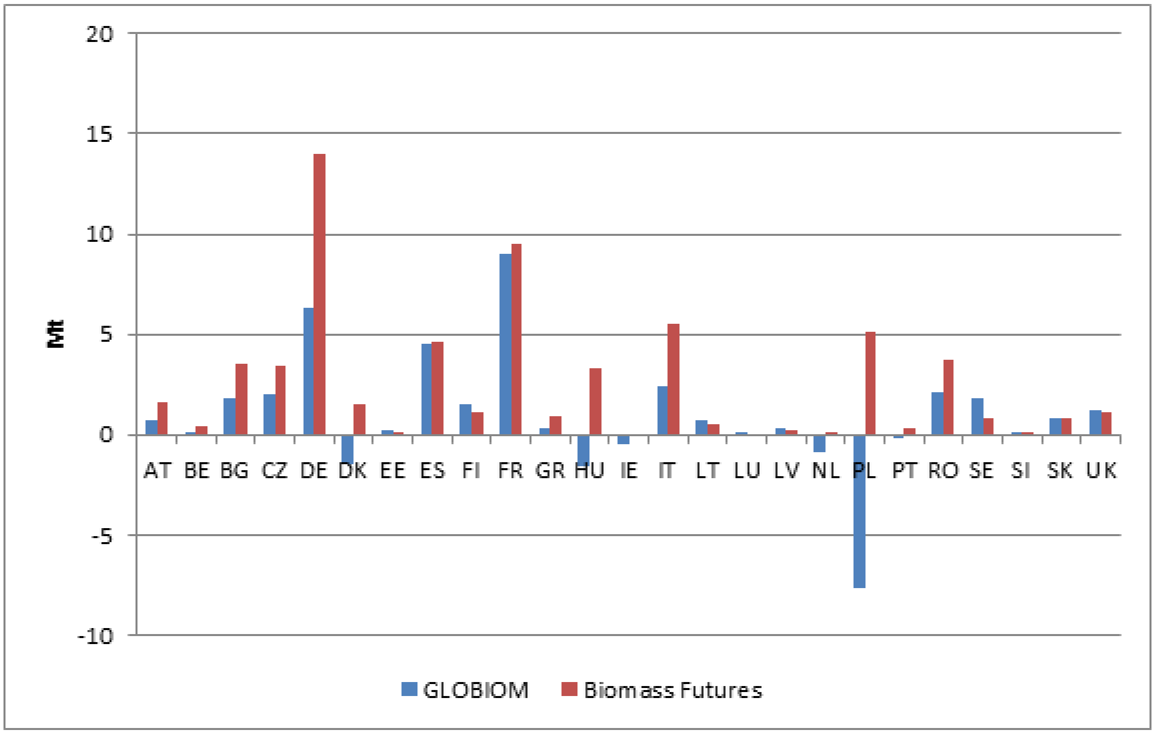

Figure 29: Comparison of straw potential for bioenergy use with data from BIOMASS FUTURES (2012). BIOMASS FUTURES data has been converted from ktoe to Mt wet matter using a LHV of 18 GJ/t and a dry matter content of 85%. IIASA data corresponds to the year 2000 while BIOMASS FUTURES refers to 2004

II.2 Include carbon sequestered in annual and perennial crops

Motivation for improvements

LUC drives GHG emissions in particular due to changes in carbon stocks from different biomes. So far, in GLOBIOM, carbon stocks were represented for forest, following statistics from the Forest Resource Assessment 2010 (FAO, 2010) and for grassland, and other natural vegetation, based on the Ruesch & Gibbs (2008) database. However, cropland was not covered. This could lead to some bias in the emissions associated with cropland expansion because some carbon can be sequestered in crops during the harvest cycle, and this for several years in the case of perennial crops.

Methodological approach

Different sources were applied to collect carbon stock values associated to each crops. In the case of annual crops, we used the EPIC crop model information, directly related to the management of crop in each simulation unit. EPIC provides crop yield but also dry matter living biomass produced per ha. The IPCC (2006) default value of 0.47 tonne C per tonne dry matter biomass recommended for herbaceous biomass was applied. The carbon stock of annual crops was then multiplied by the fraction of the year during which crops are grown and divided by 2 on the basis of the assumption of a linear growth.

In the case of semi-perennials or perennial crops (sugar cane, miscanthus), the crop calendar was applied over the number of years of the plantation cycle. Results for EU crops are provided in Table 18.

A particular case is palm plantations that is modelled as a crop activity in the model but contains carbon stocks that are those of tree plantations. Carbon stock default value for palm oil tree from IPCC (2006) is 68 tonnes C per ha for a mature plantation (136 tonnes dry matter above ground biomass x 0.5 tonne carbon per dry matter tonne as for woody biomass; see IPCC AFOLU Guidelines Chap 5, Table 5.3). However, a typical rotation period for palm oil is 25 years and palm trees are continuously growing on this time period. Therefore, the IPCC value needs to be corrected to account for the growing stock. Khasanah et al. (2012) consider based on several site studies an average of 40 tC/ha on the life-cycle on a plantation, using growth profiles that are consistent with IPCC values for a mature plantation. Therefore, the estimate of 40 tC/ha appears appropriate for above biomass of palm plantations in GLOBIOM. For calculation of below-ground biomass, we also rely on IPCC below to above biomass ration of 0.2 (subtropical humid forest; above biomass lower to 125 t dry matter per ha).

Implications for model results

Accounting for cropland carbon stocks should lead to a more comprehensive calculation of CO_2 emissions resulting for LUC, when cropland expands in another land use type or is converted to another use.

Table 18: Above- and below-ground average carbon stock in living biomass for GLOBIOM crops, and annualized stock values. Crops stocks are aggregated at the global level based on their location in 2000

Crop	Carbon stock at harvest (tC/ha)	Annualized carbon stock in living biomass (tC/ha)
Barley	5.8	1.5
Dry beans	3.4	0.9
Cassava	2.4	0.6
Chick peas	2.5	0.6
Maize	9.6	2.4
Cotton	6.3	1.6
Groundnuts	8.6	2.2
Millet	4.2	1.1
Potato	3.3	0.8
Rapeseed	2.5	0.6
Rice	8.3	2.1
Soybean	6.3	1.6
Sorghum	3.5	0.9
Sunflower	6.4	1.6
Sweet potato	3.1	0.8
Wheat	5.6	1.4
Flax*	3.0	0.8
Peas*	3.2	0.8

Crop	Carbon stock at harvest (tC/ha)	Annualized carbon stock in living biomass (tC/ha)
Sugar beet*	5.5	1.4
Fallow*	4.2	1.1
Fodder*	3.8	1.0
Maize silage*	2.4	0.6
Oats*	8.5	2.1
Rye*	4.1	1.0
Grassy crop**	6.2	6.2
Sugar cane***	13.4	13.4
Oil palm	--	48.0

* for EU only, ** On the basis of miscanthus annual stocking rate for a yield of 10 dry matter ton per year *** Carbon stock after one year, harvest after two years

II.3 Update peat land emission factors

Motivation for improvement

Past studies on LUC have found biodiesel consumption to impact palm oil production, directly or indirectly. Expansion of palm plantations in Indonesia and Malaysia, which represents 80% of global production (FAO, 2014), has occurred for a significant share on tropical peat soils (Gunarso, Hartoyo, Agus, & Killeen, 2013). As a consequence of soil being drained, the peat starts to slowly decompose and can emit greenhouse gas (GHG) for several decades.[77] Although the number of studies that estimate these peat emissions has increased tremendously during the last decade, the scientific community has not yet reached a consensus on an appropriate range of emission factors. For instance, revision of IPCC guidelines for wetlands has been hotly debated (IPCC, 2013).

So far, GLOBIOM could only take into account this type of emissions by mapping cropland area to the organic soil emissions reported in FAOSTAT at the national level. The objective of this improvement is to define, on the basis of the existing literature, a more specific range of emission factors for peat drainage[78] for the LUC simulations. This range of values will then be used in the Monte-Carlo simulation, i.e. an iterative approach to take account of a range of plausible emission values. Moreover, this section also aims at providing an overview of the most prominent drivers of GHG emissions from peat and explains the most critical methodological issues that may explain the scientific disagreement observed between the various author groups.

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[77] CO_2 is by far the most prominent GHG, accounting for about 98% of all peat-related GHG's (Hergoualc'h and Verchot 2013; Schrier-Uijl et al. 2013). CH_4 and N_2O, the later mainly upon application of mineral fertilizers, constitute the remainder of the total GHG emissions. In the present literature review we thus focus on the role of CO_2.

[78] Due to methodological uncertainties, immediate emissions from peat fires and emissions from peat drainage in forests adjacent to plantations will not be considered in the LUC assessment.

Methodological approach

Our analysis of potential emission factors builds here upon a wide examination of past literature. A number of determinants were identified that drive the pace and the magnitude of GHG emissions from peat:

- The **level of the water table (drainage depth)** directly determines peat decomposition rate. Several scholars provide estimates of GHG emissions per additional centimeter of drained soil (Hirano et al. 2012; Hooijer et al. 2006; Wösten et al. 1997).
- **Natural respiration variability and timing of measurement:** Both intra-annual changes (e.g. temperature and rainfall distribution over the year) and inter-annual changes, such as the el Niño phenomenon can explain a significant part of the variability observed in measurement. Additionally, peat respiration curves show a tendency to peak over the 5-10 years after drainage followed by a flattening of the emission curve (Page et al., 2011), which needs to be taken into account to provide reasonable emission factors.
- **Current and past land use and management:** land use and land management affect the level of peat oxidation and thus the measured emission flow. For instance, fertilization practices stimulates microbial soil activity and can increase peat emissions; furthermore, different types of land use imply different drainage depths (Dariah et al., 2013).
- **Peat bulk density (BD) and the fraction of carbon in soil** influence peat decomposition rates. BD values vary throughout the soil profile and need to be sampled with care as they feed directly in the formula for emissions in the case of studies based on measurement of the soil subsidence (Melling and Henson 2011; see Box 1).
- The **measurement method** used to estimate fluxes of GHG from peat to the atmosphere, namely measurements of soil subsidence, of direct flux measurement through closed chambers, and measurements by Eddy Covariance techniques (see Box 7).

Table 19 and Table 20 provide an overview of 12 studies based on subsidence and closed chambers, respectively, and lists some of the determinants mentioned above. No Eddy covariance studies were found for oil palm plantations.

Subsidence studies find the highest potential emissions, due to the full accounting of the emission cycle along the exploitation process of plantation. The method strength relies on the explicit representation of peat oxidation process but due to the long period of study required, only a few estimates are available. Estimates critically depend on the subsidence rate. Hooijer et al. (2012) find the highest estimates as they also account for the initial subsidence in the few years following the drainage, whereas other studies look at emission fluxes for a period after 5 years of drainage.

Close chambers studies are more numerous but the range of their results is highly variables. Earlier studies were flawed by methodological problems, such as interference of root respiration,[79] too short periods of measurements and bias due to the time of measurement in the day. Figure 30 shows that closed chamber estimates tend to increase over the past recent years and the most extreme points corresponds to non-peer-reviewed results (Melling et al., 2007; Agus et al., 2010; Comeau et al. 2013). The lowest published value is from Dariah et al. (2013) with measurements at 34.1 and 38.2 $MtCO_2$-eq ha^{-1} yr^{-1} and the highest to Husnain et al. (2014) with 66 $MtCO_2$-eq ha^{-1} yr^{-1} and Jauhiainen et al. (2012) with 80 $MtCO_2$-eq ha^{-1} yr^{-1}.

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[79] Trees on the plantation site emits CO_2 through root respiration (autotrophic respiration) which is also captured by closed chambers

This last estimate is however sourced from several acacia sites, and authors disagree on whether such flux chamber measurements are directly transposable to the case of palm oil plantations.[80]
The three to four research groups publishing actively on peat land emissions also authored a number of literature reviews (Table 21). Their usually reported estimates and recommendations vary. Page et al. (2011) repeatedly find high emission rates and recommended a value of 95 t CO_2-eq ha^{-1} yr^{-1} (based on Hooijer et al. 2012) while the group around Agus usually reports emissions of 43 t CO_2-eq ha^{-1} yr^{-1} (Agus et al., 2013; A. Hooijer et al., 2010, 2012). IPCC (2013) chose a Tier 1 emission factor of 40 tCO_2-eq ha^{-1} yr^{-1}.

Sources of uncertainty are too large to lead to a narrow estimate of peat emissions in South-East Asia given these emission estimates. To derive our final range of values, we proceed in two steps:

- **Filtering of studies:** all studies analysed in this review are not equal in terms of level of details, robustness of the methodology and validation of the results. To improve the quality of our reference values, we consider here as relevant only the values produced by studies respecting two criterias: i) peer-reviewed and ii) in the case of closed chambers, we only consider studies separating autotrophic (root respiration) and heterotrophic (peat oxidation) calculations, a bias that can play a significant role around trees (Dariah et al., 2013). As a consequence, three field studies are removed from our sample: Melling et al. (2007), Agus et al. (2010), Comeau et al. (2013).[81] This particularly leads to removal of the lowest and highest values in our closed chamber range for palm oil. In addition, although we kept in the sample the measurements on acacia, we displayed them separately due to the on-going debate about differentiated impact of peat drainage for palm oil and for acacia.[82]
- **Distribution of emissions:** if we follow the subsidence method, emissions depends on different uncertain multiplicative drivers, among which oxidation rate, peat bulk density and subsidence rate (related to water table level). There is no large scale dataset on the distribution of these factors over the regions of interest for our study. If we assume such values are symmetrically distributed and independent, the resulting distribution should be log-normal shaped.[83] This profile is confirmed by observation with flux chambers (see for instance records from Dariah et al. (2013). Based on some distribution of oxidation rates in the range 40-92% (Page et al., 2011; Hooijer et al., 2012), 0.06-0.12 g $cm^{-3}$for peat bulk density at 55% C (Jauhiainen et al., 2012) and a water table of 0.6-0.85 m (Page et al., 2011), we can reproduce a distribution profile consistent with the literature. The mean of the distribution is 61 ± 22 tCO_2 ha^{-1} yr^{-1}.

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[80] The question whether acacia and palm oil should be considered similar is still unresolved. IPCC (2013) rejected comments from the US government to consider acacia and palm oil plantations equivalent pointing four reasons that could justify differences: i) shorter rotation time of 6 years versus 25 years leading to higher soil disturbance, ii) difference in fertilization and nitrogen cycle, iii) larger depth of drainage for acacia iv) different regions of plantations. However, they also acknowledge that studies could have reported different values for the two types of plantations due to some different sites being looked at. Some more recent studies (Couwenberg and Hooijer, 2013 on subsidence; Husnain et al., 2014 on closed chambers) suggest that differences might not be as high as for the currently proposed Tier 1 emission factor from IPCC (11 tC ha^{-1} yr^{-1} for palm oil and 20 tC ha^{-1} yr^{-1} for acacia) and can be of similar magnitude for a same site (Husnain et al., 2014).

[81] Some of the sources above appear in particular very little documented. Melling et al. (2007) is only three pages of explanations, not peer-reviewed; Agus et al. (2010) is the same level of details, with a very succinct results section and no peer-review. Comeau et al. (2013) is more developed, but do not distinguish the effect of root respiration (autotrophic respiration).

[82] See footnote 4 above.

[83] A log normal distribution is the distribution of a random variable whose log value is normally distributed. It is typically characterized by a longer right tail and a mean value higher than the median value. Log-normal distributions are usually observed when evenly distributed random variables are multiplied together. For illustration of the role of log-normal distribution in science, see (Limpert, Stahel, & Abbt, 2001)

The median value is 58 tCO_2 ha^{-1} yr^{-1} and the confidence interval at 95% in the range 27--112 tCO_2 ha^{-1} yr^{-1}.

The first quartile of the distribution is at 44 tCO_2 ha^{-1} yr^{-1}, which is in the magnitude of the Tier 1 value of IPCC (2013). The third quartile is 74 tCO_2 ha^{-1} yr^{-1}, which is above most closed chamber measurements, but below measurements on acacia plantations (Jauhiainen et al., 2012).

Limitations to this approach: Average range of subsidence assumed here is 5cm/yr, with a confidence interval of 3.4cm yr^{-1} to 7 cm yr^{-1}. This is in line with most records from subsidence at steady state, but this does not account for the emission peak of the first five years described by Hooijer et al. (2012) on the observation of an acacia plantation. However, we did not find any study quantifying the effect of such a peak on a palm plantation. The peak effect can be partly represented through high bounds of peat bulk density, typical of higher layer of peat, and the higher values of our subsidence rate, but might be underestimated compared to Page et al. (2011) for instance. More comprehensive information on subsidence rate distribution could help overcome this caveat but is not yet available. Another limitation comes from the assumption that some variables are independent, such as oxidation rate and age of the plantation (reflected through subsidence rate). The most recent publications suggest that the oxidation rate should increase with the age of plantation and compensate the decrease of subsidence rate with the plantation aging (Hooijer et al. (2012), Couwenberg & Hooijer (2013)). However, information to properly quantify this relation on a systematic basis is not yet available.

As more sites will be monitored over time, we can progressively expect better information on key drivers distributions on oxidation rates, subsidence rate and peat bulk densities. For the time being, **we base our final range on the simple subsidence relation above, which covers the current observations for an average water table level of 0.6-0.85 m with a mean value of 61 ± 22 tCO_2 ha^{-1} yr^{-1} and a 95% confidence interval of 27--112 tCO_2 ha^{-1} yr^{-1}.** As a more comprehensive set of records from the literature will be recorded, this method will be able to evolve and the range be refined.

Implications for model results

This range of peatland emission factors will be used with the expansion pattern of improvement 29 to account for impact of palm plantation expansion. These emissions being highly uncertain, they will be clearly identified in the total accounting of LUC emissions.

Box 7: Measurement methods used for peatland emissions

Subsidence: Drainage of peat results in the increase in the oxidation of carbon and the transfer of carbon to the atmosphere. The removal of carbon from peat results in its shrinkage and the increase in its bulk density, thereby resulting in peat subsidence. CO_2 emission estimates may be based on peat subsidence as they are related to one another. Carbon loss is calculated using the formula:

$$C_{loss} = S_t \times DBD_l \times C_{dw}$$

Where S_t is the surface height loss, DBD_1 is the dry peat bulk density and C_{dw} is the volumetric carbon density of peat below the water table (the product of carbon bulk density and carbon concentration in the peat). Estimation of the contribution of the oxidative component to overall subsidence is critical in order to infer soil CO_2 emissions. Assumed or calculated oxidation rate is a source of uncertainty across studies with values in the range 40-90% (Wösten et al. 1997; Hooijer et al. 2012; Couwenberg et al. 2009). The subsidence-based CO_2 estimates are cost-efficient, allow for high spatial resolution in the sampling process, and emissions from peat (heterotrophic emissions) can clearly be distinguished through this method from vegetation emissions (autotrophic emissions). The technique yields results which are comparable to techniques that measure emissions directly (Page et al., 2011). Yet, emission estimates are limited to CO_2 (no CH_4 or N_2O) and they critically depend on the estimation of the oxidative fraction of peat subsidence which is subject to a high uncertainty (Dariah et al. 2013).

Closed chambers: they provide direct measurements of gas fluxes from the soil at discretionary spatial and temporal resolution, the results of which can be up-scaled to obtain emission factors for given site conditions. Rigorous measurement scheme allows for reliable measurements of heterotrophic soil emissions. Homogenous experiment set-up (e.g. chamber location in the micro-relieve and varying chamber sizes) is imperative in order to obtain reliable results. The advantage of this method is the direct measurement of emissions, and the number of samples collected so far. However, a certain number of technical challenge weaken the reliability of measurements, due to the high variability of results, depending on the location and the moment in the year or in the day where experiment are conducted, and the risk of measurement bias related to the distance to root of planted trees that can create interference between heterotrophic respiration from peat oxidation and autotrophic respiration from roots (Page et al., 2011).

Eddy Covariance (EC): method to measure gas fluxes on towers reaching above the top of the vegetation cover. It is suitable to capture the total GHG balance of larger sites with trees, but it is limited by high costs, low portability and low spatial resolution. EC studies on peat were presented by Hirano et al. (2007; 2012) but not for oil palm, thus we did not consider them further in this review[84].

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[84] Similar observations were made on EC by IPCC (2013).

Table 19: Summary of available data from studies based on the subsidence method on plantations on peat (Source: authors' compilation)

Number	Study (year)	Study peer reviewed	Affiliation / funder	Location		Average observed subsidence [cm/year]	Determinants					Mean estimated emission factor [t $CO_{2\text{-}eq}$ ha^{-1} yr^{-1}]	Associated range[85] [t CO_{2}- ha^{-1} yr^{-1}]
				Land use	Location		Drainage depth [m below ground surface]	Time after drainage [years]	Duration of estimation [months]	Observed peat bulk density [g cm^3]	Oxidation rate observed or applied		
1	Wösten et al. (1997)	Yes	Wageningen / Malaysian Ministry of Agriculture	Oil palm	Sarawak, Malaysia	4.6[86]	0.7	14-28	275	0.1	60%	**61[87]**	30-91[88]
2	Hooijer et al. (2012)	Yes	Singapore-Delft Water Alliance	Oil palm	Sumatra, Indonesia	4.3-6.5[89]	0.5 – 1.06[90]	14 - 19[91]	24	0.07–0.09[92]	92%[93]	**109[94]**	47-119[95]
3	Couwenberg & Hooijer (2013)[96]	Yes	Singapore-Delft Water Alliance	Oil palm	Sumatra, Indonesia	3.2-4.4[97]	0.4 – 0.9	5 – 20	36	0.08 – 0.13[98]	~80%[99]	**62.4**	51-75[100]

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[85] Information based on interpretation by authors of this note under assumptions below. Not provided by authors of the studies.

[86] The study reports the profile of subsidence for a long period with 4.6 cm/year for 14 to 28 years of age and 2 cm/year beyond. We apply here the subsidence rate of the earlier period.

[87] Assume 60% decomposition rate and subsidence rate of 4.6 cm/year. The initial published value in Wösten et al. (1997) is 26.5 tons CO_2-eq ha^{-1} yr^{-1}, on the basis of subsidence of 2 cm/year but correspond to a more aged plantation (>28 years).

[88] Replicating the sensitivity analysis of the authors on peat bulk density.

[89] Value observed for plantation older than 5 years old: 5.4 cm/yr on average with standard deviation of 1.1 cm/yr. Very large subsidence rate was observed in the case of acacia in the 5 years after drainage and used for the calculation on palm oil (142 cm in 5 years).

[90] 73 cm drainage measured in particularly wet year – usually WT is lower

[91] Emissions from first years of plantation are also accounted for on the basis of acacia measurements.

[92] Assumption of homogenous BD and carbon content over soil profile

[93] Oxidation rate is here directly inferred from bulk density measurements and subsidence rate, assuming steady state in the subsidence process.

[94] Estimate is an annualized value over 25 years rotation time – taking into account the first five years of a very high emission level (178 tCO_2-eq/yr) and then 73 tCO_2-eq/yr. The high initial subsidence rate was measured on acacia plantation. Assume 70 – 92% decomposition rate.

[95] Using the subsidence range on a period of 25 years, with the 5 first year collapse of peat observed in acacia plantation and without it.

[96] The study looks at three sites, in same provinces as in Hooijer et al. (2012). Calculation methods differ and the study only looks here at emissions after peat consolidation (over 5 years).

[97] Site of young plantation showed subsidence of 3.7 ± 0.5 cm/yr and old plantation 3.9 ± 0.5 cm/yr.

[98] Only lower layer value is used in the steady state calculation.

[99] Due to the carbon loss difference method chosen, oxidation rate is directly derived from peat density and subsidence measurements.

Table 20: Summary of available data from peat carbon emission studies on plantations on peat

Study number	Study (year)	Study peer review-ed	Affiliation / funder	Contextual information			Determinants				Mean estimated emission [t CO_2-eq ha^{-1} yr^{-1}]	Stdev. or range of estimated emission [t CO_2-eq ha^{-1} yr^{-1}]
				Land use	Location	Number of sites	Drainage depth [m below ground surface]	Time after drainage [years]	Duration of estimation [months]	Separation auto- and hetero-trophic respiration		
1	Melling et al. (2005)	Yes	Tropical Peat Research Lab. / Malaysian ministry of Science	Oil palm	Sarawak, Malaysia	1	0.6 (variable)	7	12[101]	No	**60.6**	**15-107**
2	Melling et al. (2007)	No	Tropical Peat Research Lab. / Malaysian ministry of Science	Oil palm	Sarawak, Malaysia	1	NA	5	12	Yes	**33.6/40.1[102]**	**NA**
3	Agus et al. (2010)	No	Indonesian Soil Research Institute	Oil palm	Sumatra, Indonesia	3	0.7 – 1.5	1-10	2[103]	Yes	**19.5**	**±13.2**
4	Jauhiainen et al. (2012)	Yes	SDWA / Grant of Academy of Finland	Acacia[104]	Sumatra, Indonesia	8	0.45 – 1.39	7	24	Yes	**80[105]**	**±15[106]**
5	Dariah et al. (2013)	Yes	Indonesian Soil Research Institute / EU FP7 program	Oil palm	Sumatra, Indonesia	2	0.52 – 0.58	8	10	Yes	**34.1/38.2[107]**	**±9.5/15.9**

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[100] Using the confidence interval on subsidence rate.

[101] Short daily measurement period (two hours) – unclear if measurements are representative

[102] Melling and Henson (2011) report 33.6 $MtCO_2$ which corresponds to microbial respiration, Marwanto & Agus (2013) also report other soil emissions not associated to roots.

[103] Measurement period of 2 months only.

[104] This study is looking at acacia palm but is retained here because it has been largely cited and also discusses application of findings to palm oil plantations.

[105] The authors of the study reduce the daytime measurement of 94 tCO_2-eq ha^{-1} yr^{-1} by 14.5% to account for night temperature correction.

[106] After applying the same correction same correction on standard deviation as for the mean.

[107] Lower value for a plantation aged of 15 years, higher value for a six-year-old plantation.

6	Marwanto & Agus (2013)	Yes	Indonesian Soil Research Institute / EU FP7 program	Oil palm	Sumatra, Indonesia	1	0.59 – 1.27	15	12	Yes[108]	**46**	**±30**
7	Comeau et al. (2013)	No	CIFOR / Australia, Norway and EU FP7 program	Oil palm	Sumatra, Indonesia	1	0.65 – 1.05	10	9	No	**104**	**±4**
8	Melling et al. (2014)	Yes	Tropical Peat Research Lab. / Malaysian ministry of Science	Oil palm	Sarawak, Malaysia	3[109]	0.56 – 0.66	1-7	24	Yes	**60.1[110]**	**±3**
9	Husnain et al. (2014)[111]	Yes	Indonesian Soil Research Institute / EU FP7 program	Oil palm	Sumatra, Indonesia	1	0.2 – 1.4	7	7 - 13	Yes	**66**	**±25**

Source: authors' compilation

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[108] No explicit distinction is performed but measurements were performed sufficiently far from the palm tree according to authors.

[109] No separation of auto- and heterotrophic emissions

[110] Median value for a 5 year-old palm plantation. Authors report 54 and 68 tCO_2-eq ha^{-1} yr^{-1} for a one year and seven-year old plantation, respectively.

[111] The study uses results from two other studies already listed here: Marwanto & Agus (2013) and Dariah et al. (2013). To avoid double-counting we only report here the specific site added by the paper in the Riau province.

Table 21: Overview of reviews and meta-studies on peatland emissions (Source: authors' compilation)

Study (year)	Peer-reviewed study	Affiliation / funder	Number of studies	Common assumption	Final range of estimates [t CO_2-eq ha^{-1} yr^{-1}]	Recommended emission factor [t CO_2-eq ha^{-1} yr^{-1}]	Comment
Verwer, Meer, and Nabuurs (2008)		Alterra, Wageningen	--	• Take 60-80 cm drainage		10 per 10cm drainage depth	• Quantitative estimates based mostly on Hooijer et al. (2006)
Uryu et al. (2008)		WWF Indonesia	2	• Average drainage depth of 53 cm	5 - 165	85	• Estimated values (drainage depth, emission factors) based on studies of Melling and the Hokkaido University • Point out the large variations of drainage depth as a function of the weather (e.g. El Niño)
Couwenberg (2009b)	x	Univ. Greifswald / Wetlands International	--	• Per 10cm of drainage depth • For 50 – 100cm drainage depth, 40% of subsidence caused by oxidation	--	≥ 9 per 10cm drainage depth	• Based on Couwenberg et al. (2009a)
Hooijer et al. (2010)	x	Deltares, SDWA	7 studies reporting water table depth	• Drainage depth • 0.95 m (0.80 – 1.10 m) • 0.91 t CO_2-eq ha^{-1} yr^{-1} per cm of drainage	73 - 100	86	• Relation of WT-depth and emissions based on Hooijer et al. (2006)
Page et al. (2011)		Univ. Leicester / International council of Clean Transportation (ICCT)	12	• Drainage depth • 0.6 – 0.85 m	54 - 115	95	• Recommended value based on Hooijer et al. (2012) • Exclusion of some studies for methodological flaws • Annualized value over 30 years rotation time
Hergoualc'h and Verchot (2011)	x	CIFOR/ Grants from Australia and Finland	11 (2 for oil palm)	• Drainage depth 0.60 m (0.55 – 0.65)	24.1 – 44.1	34.1	• Meta-model based on sample of studies (input-output method) • Includes CH4 and N2O (ca. 2% of total emissions)
Melling and Henson (2011)	x	Tropical Peat Research Laboratory Unit, Malaysia	19 (8)	--	33.6—89.8	--	• Review also CH_4 and N_2O

Study (year)	Peer-reviewed study	Affiliation / funder	Number of studies	Common assumption	Final range of estimates [t CO_2-eq ha^{-1} yr^{-1}]	Recommended emission factor [t CO_2-eq ha^{-1} yr^{-1}]	Comment
Agus et al. (2013)		Indonesian Soil Research Institute / Round Table on Sustainable Palm Oil (RSPO)	14	• Drainage depth 0.5 – 0.7 m	20--95	43	• Recommended value based on recalculation by Agus et al. (2013) of results by Hooijer et al., (2010) and proposed correction factor for root-related respiration by Jauhiainen et al. (2012).--> Approach challenged by Schrier-Uijl and Anshari (2013)
Hergoualc'h and Verchot (2013)	x	CIFOR / Grants from Australia, Norway and EU FP7 program	28	0.65 +/- 0.05 m	35.2-50	45.1	• Meta-model based on sample of studies • Includes CH4 and N2O (ca. 2% of total emissions)

Table 22: Subsidence parameters selected for our distribution of peatland emission factors and results (Source: authors' calculations)

Parameter	Notation	Unit	Range		Distri-bution	Source		Comment
			Min	Max		Min	Max	
Water table	WT	cm	60	85	Uniform	Hergoualc'h and Verchot (2013); Page et al. (2011)	Page et al. (2011); Hooijer et al. (2010)	Typical drainage for oil palm cultivation is supposed to be 0.7 m for oil palm and recommended depth is 60-80 cm (Verwer et al. 2008a; Mutert et al. 1999). Lower depth can be observed (Agus et al., 2013 report low bound at 0.5 m) but can also be much higher in industrial plantations (Hooijer et al., 2010). We follow Page et al. (2011) that cover the most common values also found in Table 1-3.
Subsidence / Drainage depth	r	cm yr^{-1} cm^{-1}	0.05	0.09	Uniform	Wösten et al., (1997)	Wösten et al. (1997); Couwenberg et al. (2010)	Wösten et al. (1997) were the first to propose an average coefficient of 0.07 to link water table and subsidence rate. His proposed range is 0.04-0.09, however, his measurement for the low bound correspond to a plantation more than 30 years old. We therefore conserve the symmetry around 0.07. Couwenberg et al. (2010) find a coefficient of 0.09 for the first 50 cm but suggest the correlation could be not applying beyond this depth. Hooijer et al., (2012) examine the relation for an acacia plantation and find a slope of 0.0498 with however an intercept value of 1.5 cm yr^{-1}. For 0.7m drainage, this regression is consistent with the linear relation from Wösten et al. (1997). They note that they could not find a clear relation on the palm plantation with more homogenous subsidence rates.
Peat bulk density	BD	g cm^{-3}	0.06	0.12	Uniform	Jauhiainen et al. (2012); Couwenberg et al. (2010) ; Couwenberg & Hooijer (2013)	Jauhiainen et al. (2012) ; Hooijer et al. (2010) ; Couwenberg & Hooijer (2013)	Peat bulk density profiles are reported in Hooijer et al. (2012), Couwenberg and Hooijer (2013), decreases significantly along the peat profile, that vary between 0.06 to values up to 0.15 g cm^{-3} for the top 10 cm. Couwenberg et al. (2010) used a density of 0.068 g cm^{-3} for lower peat layers and Jauhiainen et al. (2012) values in the range 0.06-0.12 g cm^{-3}. Couwenberg and Hooijer (2013) observe values around 0.12 g cm^{-3} for the upper 0.5m peat layer and around 0.08 g cm^{-3} for lower layer.

Oxidation rate	Ox	%	40	92	Uniform	Couwenberg et al. (2010) ; Page et al. (2011)	Jauhiainen et al. (2012) ; Hooijer et al. (2012)	Couwenberg et al. (2010) report range in the literature of 35-100% but applies in his calculation a range of 40-60%. Page et al (2011) performs various analysis using 40% and 60% oxidation rate. Jauhiainien et al. (2012) find higher oxidation rate of 80% and Hooijer et al. (2012) report a measure oxidation rate of 92%.
Carbon fraction	Fc	%	50	60	Uniform	Couwenberg et al. (2010) ; Agus et al. (2013)	Page et al. (2011)	Jauhiainen et al. (2012), Hooijer et al. (2012), Couwenberg & Hooijer (2013), Couwenberg et al. (2010) all use a carbon fraction of 55%. Page et al. (2011) use 60%, whereas Agus et al. (2013) note that variation of carbon fraction over the peat profile must be better taken into account. Couwenberg et al. (2010) report some possible slightly lower carbon fraction on peat with average in some samples at 50%.

RESULTS									
Parameter	**Notation**	**Unit**	**Range (95%)**		**Mean**	**Distribution**			**Comment**
			Min	**Max**		**25%**	**50%**	**75%**	
Subsidence rate (=r · WT)	S	cm yr^{-1}	**3.4**	**7.0**	**5.1**	4.3	5.0	5.8	The range of subsidence obtained covers well values reported by the subsidence literature (see e.g. discussion in Hooijer et al. (2012))
Emission per cm drainage (=100 · r · BD · Ox · Fc · 44/12)	e	tCO$_2$ yr^{-1} ha^{-1} cm^{-1}	**0.39**	**1.52**	**0.84**	0.62	0.8	1.02	Emission per cm drainage range encompasses here values from Agus et al. (2013): 0.72, Hooijer et al. (2010): 0.91 and Jauhiainen et al. (2012): 0.71 with an intercept.
Emission factor (= e · WT)	EF	tCO$_2$ yr^{-1} ha^{-1}	**27**	**113**	**61**	44	57	74	Emission factor obtained match well the range from filtered literature as shown in Figure 31.

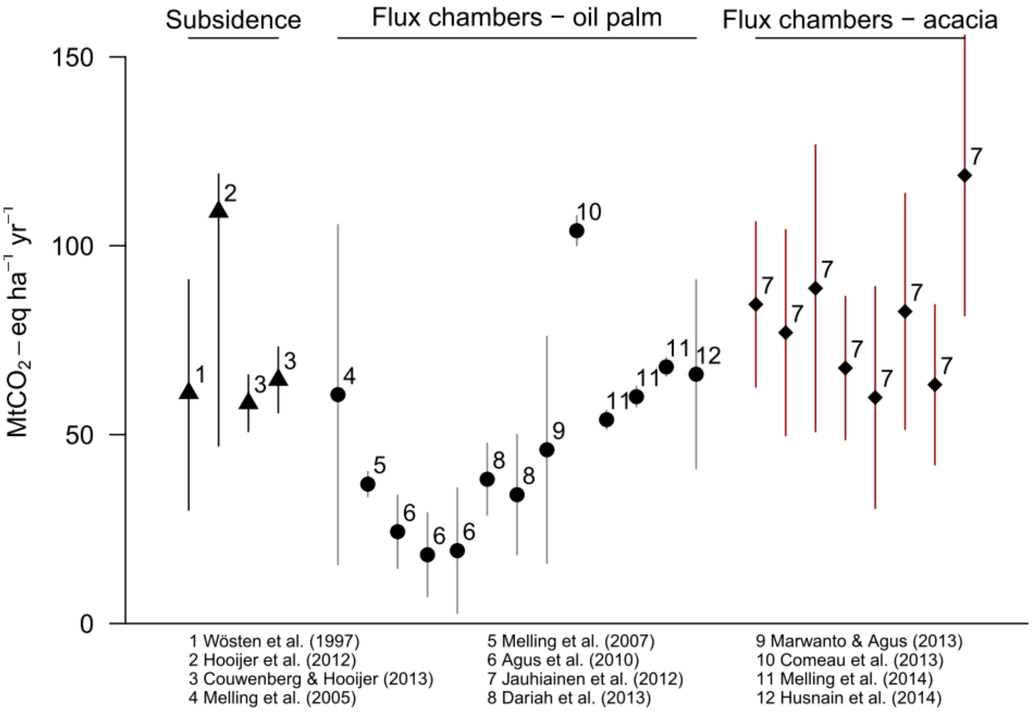

Figure 30: Distribution of central estimates of studies and range of uncertainty. Values are reported according to Table 19 & Table 20 statistics. For papers analyzing different sites, the different findings were reported separately. For subsidence, the range of uncertainty corresponds to sensitivity analysis on subsidence rate or peat bulk density. For Flux chamber studies, the standard deviation is reported, except for Marwanto & Agus (2013) where only the min and max were available. In each group, results are ordered by year of publication. Acacia values are displayed separately

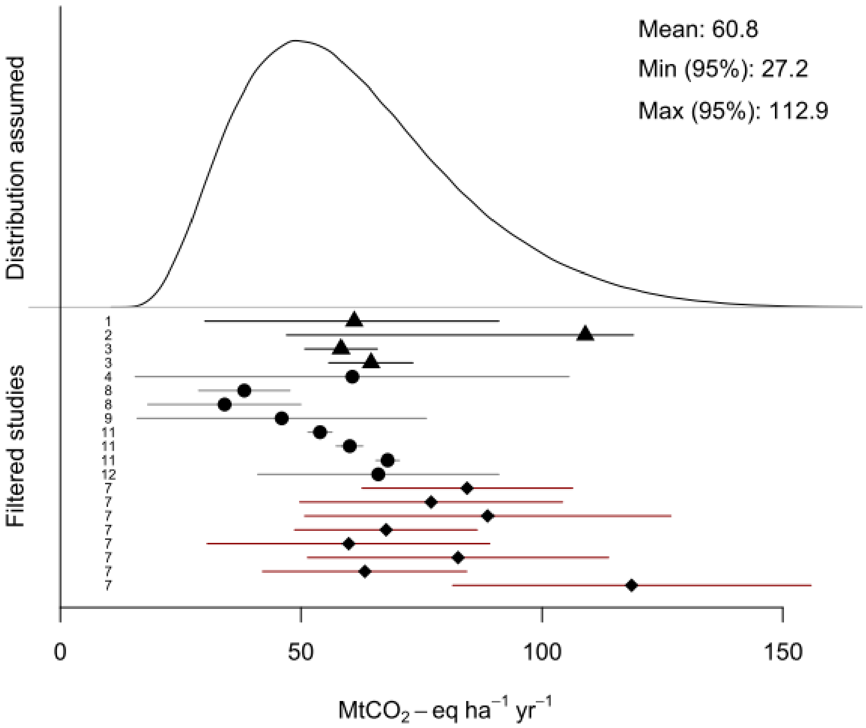

Figure 31: Distribution used for the distribution of emission factors based on simplified subsidence assumptions and comparison with literature values. The upper part of the graph shows the distribution assumed. The lower part features the articles used in Figure 30, after a filtering process. Numbers in the lower part refer to the study names in Figure 30

II.4 Represent expansion of oil palm plantations into peat land

Motivation for Improvement

Palm oil production is a significant source of GHG emissions when new plantations are developed on peat land. Until recently, spatially explicit data on recent development of plantations in Southeast Asia was scarce. As a consequence, future expansion patterns are difficult to predict, and the number of local drivers and extent of policy-driven uncertainty make this dynamics difficult to model. Currently, GLOBIOM does not represent in Indonesia and Malaysia internal transportation costs, which means plantation expansion is only allocated on a crop suitability basis. Therefore, it was decided in the context of this project to ground assumptions on location of palm plantation expansion on the basis of current literature findings. The model will then use different possible allocation within a plausible range as an input in the Monte-Carlo sensitivity runs. Expansion into peat land will then be associated emission factors derived from Section II.3.

Methodological approach

We look at the literature findings on two different aspects: first, the estimation of current peat land occupied by palm oil plantation, to get insight into the average share of plantations that expanded into peat land in the past, and the trend of expansion; second, the projection patterns assumed for future expansion of plantations into peat land, also a topic of exploration of some papers.
Historical expansion: We reviewed five studies which assess recent development of palm plantation on peat based on a remote sensing analysis (see Table 23).[112] Gunarso et al. (2013) report that in 2010, palm plantations grown on peat accounted for 1.7 million ha in Indonesia and ca. 721,000 ha in Malaysia, which represents 22% and 18% of the total plantation area, respectively. Miettinen et al. (2012) found 1.3 million ha in Indonesia and ca. 780,000 ha in Malaysia. However, a considerable area of Peninsular Malaysia and East Kalimantan was not included in their analysis due to persistent cloud cover on satellite images, which might partly explain the lower estimations as compared to Gunarso et al. (2013). The third study covering both countries found notably lower numbers with ca. 508,000 ha of converted peat land in Indonesia and ca. 371,000 ha in Malaysia (Koh, Miettinen, Liew, & Ghazoul, 2011). This difference is likely due to the coarser scale satellite imagery applied in their study[113], which did not allow for identifying i) immature palm plantations (<80% canopy cover) and ii) small patches of plantations (<200 ha). Palm expansion after 2002 could therefore not be considered, whereas the annual expansion rate ranged between 8-10% in Indonesia and 3-6% in Malaysia on that period (Gunarso et al., 2013).

Dynamics of expansion: we analyse in details the expansion patterns provided by Gunarso et al. (2013).[114]

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[112] Some older assessments also exist that have based their estimation on analysis of palm concession maps and not on remote sensing analysis of current planted areas. This usually led to higher estimate of peat land occupation (for instance, 25% in Indonesia in Hooijer et al., 2006) because the full concession area can be sometimes little developed.[112] This however suggests that future expansion could still drive larger share of expansion into peat land, if all currently attributed concession areas were developed.

[113] For most papers, current distribution of plantations were analysed using high to medium resolution satellite imagery (5-30m resolution). Visual interpretation of satellite images followed by manual delineation of oil palm stands was the most common approach to identify plantation areas (Carlson et al., 2012; Gunarso et al., 2013; Miettinen et al., 2012), sometimes combined with object-oriented digital classification (Omar et al., 2010). Koh et al. (2011) use lower resolution imagery (250m resolution) and applied a different classification algorithm.

[114] We rely here on data on planted areas from Gurnaso et al. (2013). It is noteworthy that these statistics based on remote sensing differ from some governmental statistics for planted areas. Areas reported for Malaysia are higher in 2000 (3,467 Mha versus 3,056 Mha

These show a strong increase in the share of expansion in plantations occurring on peat land in Malaysia over the years 2000, in particular on the period 2005-2010 where this rate reached 46%. This increase in share of Malaysian expansion on peat is also confirmed by the Malaysian Palm Oil Board (Omar et al., 2010) that recorded on the period 2003-2009 a share of 34% of plantation going on peat.[115] Miettinen et al. (2012) found occupation rate even stronger on a short period with 52% (2007-2010), observing very large implantation on peat in Sarawak.[116] In Indonesia, marginal expansion also goes increasingly to peat, with a rate of expansion of 25.4% in 2005-2010, versus 22.2% in 2000-2005. This is mainly driven by a strongly increasing trend in Sumatra (from 28% to 51% in five years) and in Kalimantan (from 5% to 15%). These statistics on the trend of peat disappearance are in line with observation from Miettinen et al. (2012).

Future plantation expansion on peat: in order to project possible rate of expansion into peat, we reviewed four additional studies that project the likely future expansion of oil palm plantations in different provinces. Some works rely on an extrapolation of observed trend on the basis of a detailed spatial analysis (Miettinen et al. (2012)). Some other studies prefer a spatially explicit modelling based on suitability criteria (EPA 2012, Harris et al., 2013). A last approach looks at marginal occupation patterns by assuming areas currently under lease will be developed in the future (Carlson et al., 2012). Policy intervention in the form of a peat moratorium are sometimes considered, as in Harris et al. (2013). However, in the case of this latter scenario, macro-regional land use patterns are not strongly affected.[117] Table 24 provides an overview of the ratio of total future plantation area that is expected to occur on peat according to studies. For Indonesia, the estimations for 2020 range from 13% for the marginal projection of EPA (2012) to 28% for the study of Miettinen et al. (2012). For Malaysia, the lower bound is represented by an estimated 7% for 2020 and 2030 in the BAU scenario by Harris et al. (2013).[118]
Authors usually disagree on the direction of the trend in marginal expansion patterns. EPA (2012) and Harris (2013) keep an assumption of constant rate of expansion of peat, but use a 20 years average and do not take into account the higher levels observed on the decade 2000. Miettinen et al. (2012) and Carlson et al. (2013) assume increasing trend on the basis of recently observed estimations. Among sources of uncertainty, an important factor is, on the one hand, the localization of future production across provinces with very different patterns, and on the other hand, on the effect of changing policies in each province.

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for Malaysian department of statistics) and 2010 (5,230 Mha versus 4,202 Mha). For Indonesia, reported statistics are lower for 2000 (3,678 Mha versus 4,158 Mha for Indonesian Ministry of Agriculture) and closer in 2010 (7,724 Mha versus 7,700 Mha).

[115] Using satellite imageries, Omar et al. (2010) report that the average share of plantation on peat increased from 8.2% in 2003 and 13.3% in 2009 in Malaysia, and that 37.4% of plantations in Sarawak were on peat in 2009. This confirms the strong increase on the recent period even if the rate of occupation is slightly lower than in Gunarso et al. (2013) that report 46% for Sarawak in 2010 and 17.8% for total Malaysia.

[116] Miettinen et al. (2012) do not provide statistics on total planted, only on area planted on peat and we use here statistics from Gunarso et al. (2013). In the case of Sarawak, we find that rates in Miettinen et al. (2012) exceeds 100% of marginal expansion on peatland for 2007-2010, which shows some disagreement between the two studies on expansion patterns of plantation in that region.

[117] The moratorium scenario in Harris et al. (2013) affects marginally land use change projections but relies on the assumption that peat conversion will be completely stopped after 2020, both in Indonesia and in Malaysia, while plantations will go on expanding. In our approach, we use for our peatland conversion scenario on less extreme scenarios, relying on historical observations on different periods.

[118] After examinations of spreadsheets from Harris et al. (2013), it was observed that the low rate for Malaysia was due to a cell error and that 7% was used instead of 14% for future expansion.

Recalculating marginal expansion rate based on three policy developments: In order to properly disentangle these effects, we apply the scenarios of projections of plantations based on Harris et al. (2013) and Miettinen et al. (2012) across provinces, and assume various development in the trends of marginal expansion in each province. For Harris et al. (2013), we use the business-as-usual scenario for Malaysia only, due to some too irrealistic trends observed for projections in Indonesia.[119] For the approach from Miettinen et al. (2012), we consider two possible linear trends in plantation expansion, that we calculate for the 2000-2010 and the 2005-2010 periods.
Last, we also look at what the results would be if the expansion pattern observed over the past years (2012-2013) would continue for the next decade.[120] Projections were considered at the level of the three regions per country, as in Figure 32. The second effect we isolate is the marginal rate of expansion in each region to be applied. We consider three different development in each province:

1. A no regulation scenario ("Trend 10 years"), where the increasing trend on peatland encroachment observed over the past 10 years go on increasing;
2. a stabilization scenario ("Current stable"), where the expansion into peatland remains at the level observed on 2005-2010, without further increase;
3. a policy shift scenario ("Return to hist."), where the trend of expansion into peatland decrease to come back to historical average on the period 1990-2005.

We did not consider scenarios of complete enforced ban of expansion into peatland due the continuation of expansion pressure observed in Indonesia[121] and the high level of opposition to such regulation in the most exposed States, in particular in Sarawak.[122]
The results of our sensitivity analysis on expansion share are presented in Table 25.
As a consequence, we choose to reflect the full range of estimated values in our Monte-Carlo analysis for average expansion and assume the share of plantation going into peat land on the period 2010-2030 to be:

- For Indonesia: average of 32% (range 11%-57%)
- For Malaysia: average of 34% (range 14%-52%)

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[119] Projections from Harris et al. (2013) were leading to lower expansion into peatland due to a slowing down of production in Sumatra Island. However, the recent trends show that such projections were not realistic, as expansion of palm oil has reached 6.6 Mha in 2013 according Indonesian official statistics. Some serious limitations of the Harris study have also been pointed during the comment period to the study offered by US EPA (see ICCT, 2012 - http://www.theicct.org/sites/default/files/ICCT_EPA-palm-NODA-comments_Apr2012.pdf).

[120] We base our analysis of recent statistics on data from the Indonesian official statistics (www.bps.go.id) and the Malaysian Palm Oil Board statistics (http://bepi.mpob.gov.my). According to these statistics, expansion of plantation in Indonesia would have occurred for 60% in Sumatra and for 38% in Kalimantan (in 2013, no data found for 2012). For Malaysia, expansion was 61% in Sarawak and 20% in Malaysian Peninsula and 19% in Sabah. Overall, two third of expansion took place in Indonesia.

[121] USDA reported for the year 2013 10 Mha of oil palm plantation in Indonesia, which challenges optimistic scenarios where production would have declined in most dynamics regions such as Sumatra, an assumption found in Harris et al. (2013) scenarios.

[122] According to the Malaysian Palm Oil Board statistics, plantation expansion in Sarawak would have been 8% in 2013, and total planted area would represent 1.16 Mha in December 2013. Expansion is most likely to continue as the State of Sarawak has announced an objective of 3 million ha. International pressure has been put on Sarawak producers to reduce their expansion into peatland, in particular with the threat of Wilmar, an international oil trader representing half of the Sarawak production purchase to ban palm oil sourced from plantations on peat. The federation of producers (SOPPOA) opposed this measure and still claims 1.2 million ha more peatland with the backing of the government of Sarawak preoccupied by the situation of smallholders. Malaysian producers support a Malaysian standard on palm oil but are critical of standards proposed by the Roundtable of Sustainable Palm Oil, supposed to defend protectionist views of NGOs and to deny possibility of peat agriculture.
Sources: accessed June 2014.
http://www.theborneopost.com/2014/02/15/standing-firm-against-palm-oil-boycott-threat/
http://www.theborneopost.com/2014/01/17/soppoa-wilmars-declaration-detrimental-to-local-industry/
http://www.thestar.com.my/Business/Business-News/2014/02/18/Planters-Its-unfair/
http://www.newsarawaktribune.com/news/22041/SOPPOA-supports-govt-policy-on-oil-palm-devt-in-Sarawak/
http://mypalmoil.blogspot.co.at/2014/04/sarawak-oil-palm-planters-back-mspo.html
Possibility of other outlets than Western world
http://www.thestar.com.my/Business/Business-News/2014/03/10/Sarawak-plans-to-sell-CPO-in-Middle-East/

These ranges of values both show mean values and uncertainty bounds of comparable magnitude. The uncertainty range covers the historical rates observed on the period 2005-2010 (25.4% for Indonesia and 46% for Malaysia, due to the strong surge in the Sarawak state[123]).

<u>Implications for model results</u>

Alongside emission factors for drained peat, these estimations of the expansion patterns into peat will be used to calculate in the model a plausible range of total emissions attributable to oil palm production in Indonesia and Malaysia. No peat land emissions will be considered for other regions than Southeast Asia due their more marginal contribution to overall wetlands emissions associated to palm oil.

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[123] If trends observed on the period 2005-2010 were to continue in Sarawak, palm plantation could convert the total initial peat area in that State, i.e. 1.3 to 1.4 Mha (according to Gurnaso et al. (2013) and Mittienen et al. (2012), respectively), by the end of the decade 2020. Factoring in this consideration in the calculation leads to a lower rate for the subsequent period (2020-2030), which explains that the average rate over 2010-2030 hardly exceeds 50% in our estimation.

Table 23: Estimates of total oil palm planting area in 2010 (in ha), oil palm planting area on peat (in ha) and % of total planting area by region for Indonesia and Malaysia according to four studies with varying coverage

Source	**Gunarso *et al.* (2013)**			**Koh et al. (2011)**			**Carlson et al. (2012)**			**Miettinen *et al.* (2012)**	
Region	Total planting area (ha)	Planting area on peat (ha)	Share on peat	Total planting area (ha)	Planting area on peat (ha)	Share on peat	Total planting area (ha)	Planting area on peat (ha)	Share on peat	Planting area on peat (ha)	Share on peat*
Sumatra	4,743,308	1,395,733	29%	3,871,839	464,554	12%	n.d.	n.d.		1,047,000.00	22%
Kalimantan	2,896,952	307,515	11%	1,100,105	43,184	4%	3,164,005	402,166	13%	314,000.00	11%
Papua	83,622	1,727	2%	n.d.	n.d.		n.d.	n.d.		n.d.	
Total Indonesia	**7,723,882**	**1,704,975**	**22%**	**4,971,944**	**507,738**	**10%**	**n.d.**	n.d.		**1,361,000**	18%
	Gunarso *et al.* (2013)			**Koh et al. (2011)**			**Omar et al. (2010) (data from 2008/09)**			**Miettinen *et al.* (2012)**	
Peninsular Malaysia	1,510,809	215,984	14%	2,005,833	236,820	12%	2,503,682	207,458	8%	238,000	16%
Sarawak	1,033,260	475,946	46%	357,915	103,841	29%	1,167,172	437,174	37%	494,000	48%
Sabah	1,510,809	29,028	2%	918,739	30,166	3%	1,340,317	21,405	2%	50,000	3%
Total Malaysia	**4,054,878**	**720,958**	**18%**	**3,282,487**	**370,827**	**11%**	**5,011,171**	**666,038**	**13%**	**782,000**	**19%**

***** Calculated from Gurnaso et al. (2013) data on total oil palm plantation areas. Source: authors' compilation.

Table 24: Overview of studies that project oil palm expansion on peat in the future

Study (year)	Affiliation / funder	Methodology	Study area	Percent of plantations on peat (historical)		Percent of plantations on peat In 2020 (2030)		Underlying assumptions	Comment
				Indonesia	Malaysia	Indonesia	Malaysia		
Harris et al. (2013)	Roundtable for Sustainable Palm Oil	GEOMOD	Indonesia, Malaysia, Papua New Guinea	22%	18%	22% (22%)	7% (7%)	Historical average (constant rate of plantations on peat)	
				22%	18%	19% (17%)	13% (12%)	Peat Moratorium (no further expansion)	
Miettinen et al. (2012a, 2012b)	Univ. Singapore / International Council on Clean Transportation	Extrapolation from spatial trends	Indonesia, Malaysia	18%	19%	28%	42%	Linear projection based on 2007-2010 period	
EPA (2012)	U.S. Environmental Protection Agency	GEOMOD	Indonesia, Malaysia	22%	13%	15%	10%	Historical projection	Sensitive to the ratio of mature – immature palms Projected to 2022
		GEOMOD	Indonesia, Malaysia			13%	9%	Projected incremental expansion	
Carlson et al. (2012)	Univ. Yale & Stanford	Static model	Kalimantan	13%	n.d.	17%	n.d.	Development of all oil palm leases issued until 2012 by 2020	

Source: authors’ compilation.

Table 25: Projected expansion on peatland according to literature land use scenarios and local patterns of expansion on peat

	Indonesia 2010-2030			Malaysia 2010-2030		
	Local expansion pattern on peat			Local expansion pattern on peat		
Regional land use scenario	**Trend 10 yrs**	**Current stable**	**Return to Hist**	**Trend 10 yrs**	**Current stable**	**Return to Hist**
Proj. Harris et al. (2013)	31%	17%	6%	45%	44%	24%
Proj. Linear 2000-2010	51%	31%	14%	36%	32%	14%
Proj. Linear 2005-2010	44%	25%	11%	41%	38%	18%
Proj. Linear 2012-2013	57%	38%	19%	52%[b]	49%	20%
Min	**11%**[a]			**14%**		
Mean	**32%**[a]			**34%**		
Max	**57%**[a]			**52%**		

[a] We did not keep results based on Harris et al. (2013) projections for our summary statistics of Indonesia because projected numbers were at odd with current developments.

[b] This scenario leads to complete use of peatland in Sarawak by 2030, which decrease the expansion rate into peatland in that region at the end of the period. See note 124.

Source: authors calculation.

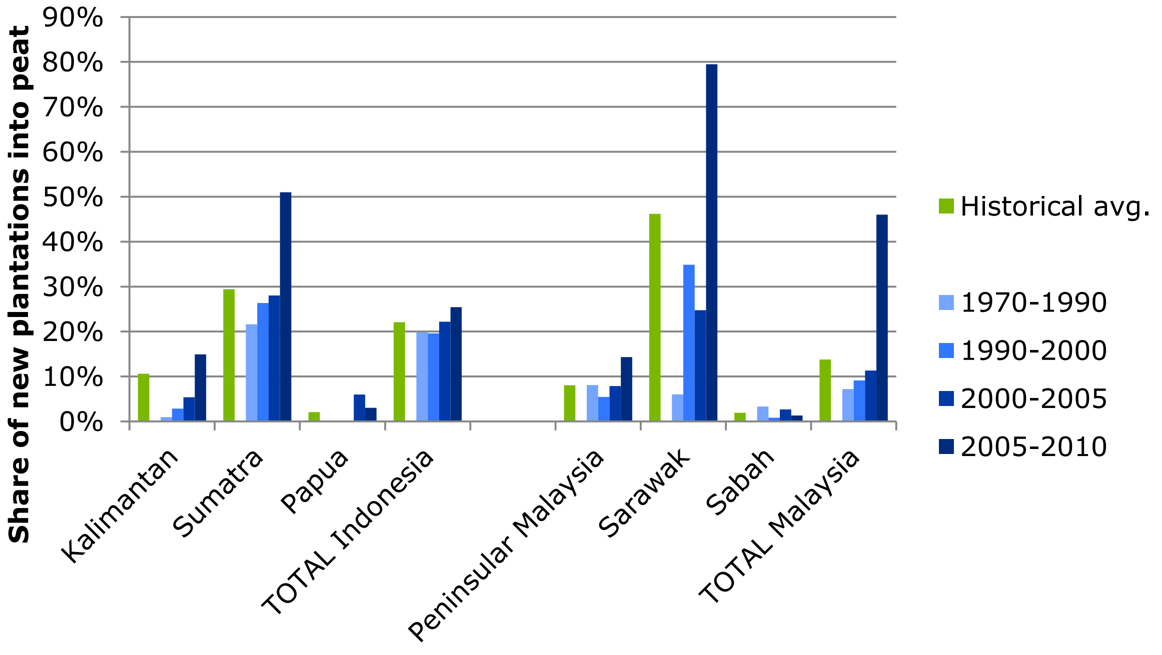

Figure 32: Percentage expansion of plantation into peat land in different regions of Indonesia and Malaysia over time. Source: Gurnaso et al. (2013)

II.5 Expand the inclusion of soil organic carbon (SOC) worldwide

Motivation for improvements

Soil organic carbon (SOC) is a prominent C stock and its representation is important for a comprehensive accounting of GHG emissions from agriculture and LUC. In previous versions of GLOBIOM, a refined SOC accounting design had been developed for the European Union. As ILUC from biofuels occurs in- and outside of the EU, there was a need to expand the representation of SOC accounting in the model to other regions of the world.

Methodological approach

We complemented the initial dataset of soil organic carbon in GLOBIOM with data from the Harmonized World Soil Database v1.2 (HWSD, see FAO et al., 2012). This database is a spatially explicit layer of soil information in the different regions of the world, such as organic carbon, water storage capacity, soil depth etc. The information on SOC is here used as input in GLOBIOM at the grid level. This database therefore complements the EU datasets already in the model (Lugato et al., 2013 for cropland, Jones et al., 2005 for other land use types). A summary of average SOC content by large region and land use type is displayed in Table 26.

In order to track in the model changes in SOC content in the different regions, we then applied a Tier 1 approach[124] based on GHG accounting IPCC guidelines (IPCC, 2006). The formula applied is as follows (Equation 2.25):

$SOC = \sum_{(c,s,i)} (SOC_{REF} * F_{LU} * F_{MG} * F_I * A)$, where:

c, s, i are respectively the climate zones, soil types and management systems in the region

SOC_{REF} is the carbon stock of reference, calculated using the initial 2000 data and the initial management information

F_{LU} is the land use factor informing on type of use among crop cover, flooded areas for rice, perennial crops, or set aside land;

F_{MG} is the management factor informing on tillage practice

F_I is the input factor informing on level of fertilizer input and use of manure

A is the land use area for climate zone c, soil type s and management type i.

Default values of F_{LU}, F_{MG}, F_I are sourced from Table 5.5 and Table 6.2 of IPCC guidelines. SOC_{REF} is determined in our setting on the basis of the HWSD and EU specific datasets, correcting for the land use, management and input factors when relevant. Therefore, we do not use here the averaged IPCC default value, in order to fully benefit from the spatially explicit information. Differences between IPCC reference SOC values and HWSD values are documented in Carré et al. (2010).

LUC and management information (crop type, fertilizer level) are calculated endogenously in the model. Tillage practice is another important component determining level of SOC. Because tillage practice is not explicitly modelled at the global level in GLOBIOM, we assume for most regions a full tillage practice for cropland, except for the EU and some large countries where more precise management information could be retrieved (USA, Brazil, Argentina). The tillage assumptions are summarized in Table 27. One additional management changed is considered for the agricultural residues where the effect of removing residues on C stock is accounted for (see Section II.1).

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[124] Tier 1 approach corresponds to the default methodology proposed by IPCC guidelines, when more local information is not available.

In order to keep the full consistency between SOC in Europe and Rest of the World, and prevent asymmetrical calculations, the same IPCC Tier 1 formula is here applied for EU and for the Rest of the World.

Implications for model results

Additional SOC at world level in the accounting will allow a more comprehensive coverage of indirect emissions related to expansion of agricultural land. The approach remains here however simplified, based on a Tier 1 approach but follows recommendation from JRC on accounting of soil organic carbon (Carré et al., 2010). A limitation of the approach is the impossibility to consider C stock change associated to restoration of degraded land, due to the too limited data on C stock and locations of degraded areas at world level.

Table 26: Reference level for soil organic carbon in t C/ha by GLOBIOM region. Reference levels correspond to C stocks in an undisturbed grassland area

	SOC_{REF}
Australia / New Zealand	20
Argentina	27
Brazil	34
Canada	58
China	33
Congo Basin	35
Former USSR	48
India	27
Indonesia	48
Japan	56
Malaysia	34
Mexico	29
Mid-East North Africa	17
Pacific Islands	39
Rest of Central America	40
Rest of Eastern Europe	34
Rest of Western Europe	58
Rest of South America	35
Rest of South Asia	22
Rest of Southeast Asia	32
South Africa	20
South Korea	33
Eastern Africa	26
Southern Africa	24
Western Africa	22
Turkey	26
Ukraine	47
USA	35
EU28	59

Note: Reference SOC level is calculated based on HWSD, except for the EU where a more detailed map is used (Jones et al., 2005). In that latter case, it has been calculated as the average SOC stocks on forests, grassland and other natural vegetation.

Table 27: Average tillage assumption for GLOBIOM regions in the base year

Region	Share Full tillage	Share reduced tillage	Share no tillage
European Union	76%	18%	6%
Canada	40%	30%	30%
USA	75%	--	25%
Brazil	65%	--	35%
Argentina	30%	--	70%
Paraguay	28%	--	72%
Australia	75%	--	25%
Rest of the world	100%	--	--

Source: PICCMAT project data for the European Union http://climatechangeintelligence.baastel.be/piccmat/ , Canadian Agricultural Census for Canada, Derpsch et al. (2010) for other regions.

II.6 Include forest regrowth and reversion time on unmanaged land

Motivation for improvement

GLOBIOM usually assumed that, when cropland or grassland is abandoned, it can either be turned into managed forest or forest plantation, if economically profitable, or abandoned into other natural vegetation. Carbon stock in living biomass for other natural vegetation was taken from the Ruesch and Gibbs (2008) database. However, even if not actively managed as forest or plantation, abandoned land can lead to progressive forest regrowth in some regions, with carbon stock higher than typically assumed for natural grassland, for instance; it was therefore decided to implement a more detailed representation. The question of the timing of this carbon sequestration is also important, because the model solves by 10 year time steps and the evaluation period of the policy is limited to 20 years.

Methodological approach

IPCC (2006) guidelines distinguish two types of carbon reversion associated to forest regrowth, natural and artificial regeneration.[125] Considering that managed forests are already represented in GLOBIOM, we only look here at the carbon accumulation in land converted into unmanaged forest. The typical type of conversion of land to Forest is assumed according to IPCC to have an average transition period of 20 years, after which the land can be considered classified as Forest again. IPCC default table provides a single value per type of forest for different regions (see overview in Table 28). However, GLOBIOM contains geographically information on the carbon stocks in natural forest for each Production Unit in the model. We therefore use the geographical heterogeneity of stock distribution to vary geographically the default value for carbon growth. For each production unit, we assume that the annual growth rate equals 2% of the total carbon stock in living biomass of a mature forest.

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[125] "Land is converted to Forest Land by afforestation and reforestation, either by natural or artificial regeneration (including plantations). The anthropogenic conversion includes promotion of natural re-growth (e.g., by improving the water balance of soil by drainage), establishment of plantations on non-forest lands or previously unmanaged Forest land, lands of settlements and industrial sites, abandonment of croplands, pastures or other managed lands, which re-grow to forest. […] Land conversion may result in an initial loss of carbon due to changes in biomass, dead organic matter, and soil carbon. But natural regeneration or plantation practices lead to carbon accumulation and that is related to changes in the area of plantations and their biomass stocks." [IPCC (2006) Guidelines, Vol 4., Chapter 4, p. 4.30]

However, forest regrowth does not systematically take place when land is abandoned, because of various environmental factors. Indeed, the abandoned land can be too infertile or degraded, as indicated by IPCC guidelines.[126] A land classified as "Other land" (i.e. not cropland, grassland, forest land, wetland or settlement) is under IPCC accounting rule considered by default not accumulating carbon (see IPCC, 2006, Vol.4, Chap. 9). To distinguish what share of land can be considered returning to forest or only to other natural vegetation (with constant carbon stock), we apply the same method as suggested by the U.S. Environmental Protection Agency (EPA, 2010). Within each Production Unit, we assume that, forest regrowth takes place at the same share on abandoned land as is the share of forest already observed on fertile land (forest, other natural vegetation, grassland).

Implications for model results

Carbon balance in the model is changed with this improvement, with better representation of carbon sequestration when land is abandoned. Former and new carbon stocks associated to abandoned land are summarised in Table 29. In the former accounting approach, other natural land carbon stock was allocated to abandoned land using data from Ruesch and Gibbs but without any dynamic consideration. Therefore, after 10 years, the carbon stock was already maximum, a pattern that is changed with the new approach, which decreases the carbon stock typically reached after 10 years. Additionally, the new approach considers possibility to reach higher level of stock directly through forest regrowth (e.g. in Europe).

Table 28: Carbon accumulation in living biomass for natural forest regrowth in different regions (first 20 years)

Region	Ecological zone	Average above-ground biomass growth (tonnes d.m. / ha / yr)	Ratio below-ground to above ground biomass [a]	Average above and below ground C accumulation (tonnes C / ha / yr)
Tropical and subtropical zones				
Africa	Tropical rainforest	10	0.37	6.4
Africa	Tropical moist deciduous forest	5	0.20 – 0.24	7.5
Africa	Tropical and subtropical dry forest	2.4	0.28 – 0.56	1.6
Africa	Tropical shrubland and subtropical steppe	0.2 – 0.7	0.32 – 0.4	0.3
Africa	Tropical and subtropical montain systems	2.0 – 5.0	0.27	2.1
Asia (continental)	Tropical rain forest	7.0	0.37	4.5
Asia (continental)	Tropical moist deciduous and subtropical humid forest	9.0	0.20 – 0.24	13.5
Asia (continental)	Tropical and subtropical dry forest	6.0	0.28 – 0.56	4.0

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[126] "Some abandoned lands may be too infertile, saline, or eroded for forest re-growth to occur. In this case, either the land remains in its current state or it may further degrade and lose organic matter. Those lands that remain constant with respect to carbon flux can be ignored. However, in some countries, the degradation of abandoned lands may be a significant problem and could be an important source of CO2. Where lands continue to degrade, both above-ground biomass and soil carbon may decline rapidly, e.g., due to erosion. The carbon in eroded soil could be re-deposited in rivers, lakes or other lands downstream. For countries with significant areas of such lands, this issue should be considered in a more refined calculation." [IPCC (2006) Guidelines, Vol 4., Chapter 4, p. 4.30]

Region	Ecological zone	Average above-ground biomass growth (tonnes d.m. / ha / yr)	Ratio below-ground to above ground biomass [a]	Average above and below ground C accumulation (tonnes C / ha / yr)
Asia (continental)	Tropical shrubland and subtropical steppe	5.0	0.32 – 0.4	3.2
Asia (continental)	Tropical and subtropical mountain systems	1.0 – 5.0	0.27	2.1
Asia (insular)	Tropical rain forest	13	0.37	8.4
Asia (insular)	Tropical moist deciduous and subtropical humid forest	11	0.20 – 0.24	16.5
Asia (insular)	Tropical and subtropical dry forest	7.0	0.28 – 0.56	4.7
Asia (insular)	Tropical shrubland and subtropical steppe	2.0	0.32 – 0.4	1.3
Asia (insular)	Tropical and subtropical mountain systems	3.0 – 12	0.27	4.5
North America	Tropical rain forest	0.9 – 18	0.37	6.1
South America	Tropical rain forest	11	0.37	7.1
North and South America	Tropical moist deciduous and subtropical humid forest	7.0	0.20 – 0.24	10.5
North and South America	Tropical and subtropical dry forest	4.0	0.28 – 0.56	2.7
North and South America	Tropical shrubland and subtropical steppe	4.0	0.32 – 0.4	2.6
North and South America	Tropical and subtropical mountain systems	1.8 – 5.0	0.27	2.0
Temperate zones				
Europe	Temperate oceanic forest	2.3	0.40 – 0.46	1.5
Europe	Temperate continental forest	4.0	0.40 – 0.46	2.7
Europe	Temperate mountain systems	3.0	0.40 – 0.46	2.0
North America	Temperate oceanic forest	15	0.40 – 0.46	10.1
North America	Temperate continental forest	4.9	0.40 – 0.46	3.3
North America	Temperate mountain systems	3.0	0.40 – 0.46	2.0
South America	Temperate oceanic forest	2.4 – 8.9	0.40 – 0.46	3.8
Asia	Temperate continental forest	4.9	0.40 – 0.46	3.3
Asia	Temperate mountain systems	3.0	0.40 – 0.46	2.0
Boreal zones				
Asia, Europe, North America	Boreal coniferous forest	0.1 – 2.1	0.39	0.7
Asia, Europe, North America	Boreal tundra woodland	0.4	0.39	0.3
Asia, Europe, North	Boreal mountain systems	1.0 – 1.1	0.39	0.7

Region	Ecological zone	Average above-ground biomass growth (tonnes d.m. / ha / yr)	Ratio below-ground to above ground biomass [a]	Average above and below ground C accumulation (tonnes C / ha / yr)
America				

[a] For the below to above ground ratio, the coefficient selected correspond to biomass density below or equal to a growth period of 20 years. Source: IPCC (2006), Vol. 4, Chap. 4, Table 4.4 and Table 4.9. Last column calculated using carbon fraction value of 0.47.

Table 29: Average carbon stock from sequestration in abandoned land in old and new GLOBIOM approach (tonnes C/ha). Weighting within each region is done by agricultural area, as this is the areas of particular interest for abandonment

Region	Forest annual regrowth rate	Regrowth mix			Forest full regrowth	Natural vegetation full regrowth
		10 years	20 years	Full regrowth		
Latin America	1.8	14.0	22.7	38.4	88.1	27.4
South Asia	0.9	7.5	14.1	31.7	42.9	27.3
North America	1.0	7.6	11.9	24.4	50.3	14.5
Europe	1.5	9.9	17.2	37.9	73.2	7.1
Eastern Asia	0.5	5.1	9.2	20.4	26.1	18.6
Southeast Asia	1.5	12.7	22.8	45.9	73.2	29.7
Former Soviet Union	0.9	4.8	7.3	14.6	41.2	4.7
Sub-Saharan Africa	1.3	7.2	13.6	34.9	37.0	31.5
Oceania	0.6	4.8	8.9	24.8	25.7	24.3
Middle East North Africa	0.5	4.0	7.3	12.8	20.9	11.8

II.7 Refine co-product substitution

Motivation for improvements

Co-products are an essential component of the lifecycle analysis of biofuel production. Biodiesel from rapeseed, soybeans, and sunflower leads to significant amounts of protein meals being delivered on the market. These products are used in animal diet as protein supplement and the biofuel sector strongly interacts with the livestock sector through this channel. Similarly, dried distillers’ grains with solubles (DDGS) and sugar beet fibers, generated by cereals and sugar beet processing respectively, are also used for feed preparation and displace consumption of other agricultural products. To understand the final balance associated to these changes, it is important to understand which products are being substituted to which extent through increased supply of co-products from the biofuel processing chain.

The present improvement focuses on the representation of the feed nutrients in terms of energy and proteins, and complements efforts on the modeling of oilseeds markets from Section II.9 on substitution mechanisms and II.12 on oilseeds transformation chains.

Methodological approach

GLOBIOM already incorporates a precise description of animal diets for each livestock system and species, which can be used to best represent the substitution patterns for biofuel co-products. We calculate for each species modified diet specifications incorporating more co-products, subject to some maximum incorporation constraints.

Diet specifications are calculated taking into account digestibility patterns and metabolisable energy and proteins for the different animal types. Feed requirements are calibrated on the current data used in GLOBIOM, and derived from the RUMINANT model (Herrero et al., 2013). For each feed item, we calculate the exact nutrient content using feed tables from U.S. National Research Council (NRC, 1982), as presented in Table 30.[127] These tables contain all major crop types traditionally used for feeding, including protein meals and DDGS. In the case of DDGS, however, as technology evolved a lot over time in terms of protein extraction efficiency, we used more recent data on DDGS characteristics. Because composition of co-products can vary across places and refineries, sensitivity analysis will also explore slight variation around the values presented in Table 30.

This information on feed composition is used to specify substitution patterns for each animal type, by ensuring that both the energy and protein balance are preserved. This diet substitution pattern is applied only to the livestock systems based on grain and protein meals consumption (of type intensive, mixed-intensive or mixed-extensive). Substitution with co-products for grass-based production systems is not considered. To represent substitution, we allow mobility in the feed intake of the animals while satisfying two inequalities directly coded in the model: 1) the crude protein intake should be higher or equal to initial intake; 2) the metabolisable energy intake should be higher or equal to initial intake. These equations are applied to protein meals and to the main feed grain type used in the region (usually corn or wheat), to adjust on energy content. For cattle, where we have more detailed information, we directly use the average of Net energy for growth and for maintenance, whereas for dairy cows, we refer to the Net Energy for lactation to capture the specific dietary needs in the respective livestock sectors.[128]

Because each species and each feedstuff have different characteristics, the replacement results used differ depending on the livestock sector and the biofuel pathway. The advantage of this approach is to be able to directly trace the substitution efficiency on the basis of nutrient content of co-products, instead of relying on substitution coefficients from the literature. The large number of animals coexisting in different systems and rations mixes guarantee smooth substitution profile leading to continuous transition patterns in the feed substitution.

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[127] Although this source might appear old, changes in feedstuff nutrient composition remained limited, as illustrated by a comparison with more recent tables (for instance for beef, NRC, 2000).

[128] Different beef and dairy cattle have different feed requirements. Maintenance energy intake is required for all animals to ensure the appropriate level of feed for normal metabolism, at equilibrium, without production of any other output. For beef cattle, it needs to be supplemented by energy for growing with different ratios depending on the stage of development of the animal. For dairy cows, milk production requires an additional regular intake of energy that leads to the lactation energy requirement (that includes maintenance energy).

Table 31 shows the substitution patterns obtained when applying the composition found in Table 30. We calculate in this table a simple bilateral substitution between one biofuel by-product and two feed products. Sign indicate if the co-product replaces a feedstuff (positive) or requires an additional provision of cereals to preserve the energy balance (negative).

For example, one unit of rapeseed meal for beef triggers an additional consumption of 0.085 unit of corn while substituting 0.832 unit of soya meal. Because several protein meals can substitute with each other, some more complex substitution can also appear. For instance, wheat DDGS can substitute with soybean meal - and with some cereals to satisfy the complete energy balance - but soybean meal can also in turn substitute with some other oilseed meals.

Table 31 is therefore only illustrative of the simplest substitution patterns with a pair of feed products. Additionally, in the case of the US, we directly used another source (Hoffman and Baker, 2011) that specifies the rate of substitution observed in that region, with a greater substitution towards corn than protein meals. For the US, we therefore assume that 1 tonne corn DDGS substitute with 1.1 tonne corn for ruminants and with 0.8 tonne corn and 0.2 tonne soybean meal for swine.

In complement to substitution possibilities, for each animal type, incorporation of DDGS is limited due to the nutrient characteristics of co-products, some of them not directly accounted for in the model substitution patterns. In particular, DDGS too high incorporation rates can lead to an oversupply of proteins and phosphorus, leading to waste disposal issues that affect manure management (Hoffman & Baker, 2011). For DDGS, we therefore capped the incorporation levels at some selected values on the basis of a literature review by Hoffman and Baker (2011). These incorporation constraints are provided in Table 32 and were chosen at the mid-range of low and high values in the literature, except when higher incorporation rates were already observed in U.S. statistics (beef cattle).

Implications for model results

The new representation of co-product substitution in the model will allow to specify the substitution of animal feeding with different diet possibilities specific to each species, on the direct basis of nutrient composition and their properties per type of animal. For instance, wheat DDGS will substitute more cereals in the ruminant sector than with the non-ruminant, and sugar beet pulp will be little used by the poultry sector due to poor digestibility. We also observe that, as long as other nutrient constraints (e.g. amino-acids) are not taken into account,[129] rapeseed and sunflower meal can appear as appealing substitutes with other protein sources due to their high protein level, but may require cereals complement to preserve the energy balance, which was not captured before. This new design will allow for a more accurate accounting of the substitution possibilities of co-products in the feed and to better measure the LUC effects implications associated their incorporation.

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[129] For sake of time, it was unfortunately not possible in the framework of this exercise to develop more sophisticated substitution rules than the one developed here, although considering additional component requirements would probably affect further the substitution possibilities.

Table 30: List of metabolisable energy and protein content associated to the different feed crops and supplements in the model. All values below are expressed for dry matter feed. ME = metabolisable energy, NEm = net energy for maintenance, NEg = net energy for growth, NEl = net energy forlactation, MEn = metabilisable energy, nitrogen corrected (for poultry)

Feed stuff	Ruminant ME (Mcal/kg)	Ruminant NEm(Mcal/kg)	Ruminant NEg(Mcal/kg)	Dairy cattle NEl(Mcal/kg)	Chicken MEn (kcal/kg)	Swine ME (kcal/kg)	Crude protein (%)	Crude Fiber (%)
Barley grain	3.29	2	1.35	1.94	2843	3299	13.5	5.7
Dry bean	3.29	2	1.35	1.94	2593	3.772	25.3	5
Corn grain	3.42	2.09	1.42	2.01	3818	3724	10.9	2.9
Corn silage	2.62	1.55	0.94	1.57	NA	2981	8.3	25.1
Oats grain	2.98	1.79	1.17	1.77	2862	3012	13.3	12.1
Pea	3.42	2.09	1.42	2.01	2385	3416	25.3	6.9
Potato	3.16	1.91	1.27	1.87	NA	3516	9.5	2.4
Rapeseed meal solv extd	2.62	1.55	0.94	1.57	1924	2935	40.6	13.2
Rye, grain	3.29	2	1.35	1.94	3001	3327	13.8	2.5
Soybean seeds	3.60	2.22	1.52	2.11	3674	3905	42.8	0.1
Soybean meal solv extd, 44% protein	3.29	2	1.35	1.94	2485	3155	49.9	7
Soybean oil	8.23	5.25	4.02	4.66	8667	7283	1.4	NA
Sugar beet pulp, with molasses, dehydrated	2.93	1.76	1.14	1.74	719	3139	10.1	16.5
Sunflower meal, wo hulls, meal solv extd	2.45	1.44	0.82	1.47	2242	2851	49.8	12.2
Triticale grain	3.29	2	1.35	1.94	3521	3396	17.6	4.4
Wheat grain	3.47	2.12	1.45	2.04	3401	3660	16	2.9
Wheat durum grain	3.34	2.03	1.37	1.96	3652	3492	15.9	2.5
Source : National Research Council, 1982, 2000								
Corn distillers grains with solubles, dehydrated	**3.90**	**2.38**	**1.69**	**2.28**	**2531**	**3790**	**31.2**	**8.6**
Wheat distillers grains with soluble, dehydrated	**3.75**	**2.29**	**1.62**	**2.14**	**2406**	**3472**	**36.6**	**7.6**

Sources:

Wheat DDGS : Noblet, Cozannet & Skiba (2012) for pigs and poultry; extrapolated from Kalscheur et al. (2012) for ruminant.

Corn DDGS: Kalscheur et al. (2012) for ruminant; extrapolated from Anderson et al. (2012) for pigs and Noblet, Cozannet & Skiba (2012) for poultry.

Table 31: Substitution pattern for each animal species for one unit of co-product consumed by the livestock sector. Positive values correspond to a replacement of feed, negative value to a joint addition of another feedstuff to preserve the energy balance. For example, one kg of rapeseed meal for beef triggers an additional consumption of 0.08590 kg of corn while substituting 0.8332 kg of soya meal

	Corn DDGS	Wheat DDGS	Sugar beet pulp	Rapeseed meal	Sunflower meal
Feed item					
SUBSTITUTE FOR CORN & SOYBEAN MEALS					
Beef					
Corn	0.711	0.523	0.800	-0.085	-0.390
Soya meal*	0.470	0.619	0.028	0.832	1.083
Dairy					
Corn	0.673	0.452	0.849	-0.005	-0.294
Soya meal*	0.478	0.635	0.017	0.815	1.062
Swine					
Corn	0.559	0.382	0.824	0.121	-0.098
Soya meal*	0.494	0.650	0.022	0.787	1.019
Poultry					
Corn	0.298	0.178	0.066	-0.030	-0.073
Soya meal*	0.560	0.695	0.188	0.820	1.014
SUBSTITUTE FOR WHEAT & SOYBEAN MEALS					
Beef					
Wheat	0.791	0.582	0.890	-0.094	-0.434
Soya meal*	0.371	0.547	-0.083	0.844	1.137
Dairy					
Wheat	0.753	0.506	0.950	-0.006	-0.329
Soya meal*	0.384	0.571	-0.102	0.816	1.103
Swine					
Wheat	0.686	0.437	0.944	0.139	-0.112
Soya meal*	0.405	0.593	-0.100	0.769	1.034
Poultry					
Wheat	0.375	0.224	0.083	-0.038	-0.091
Soya meal*	0.505	0.662	0.176	0.826	1.027

Note: Soybean meals are not represented here as they are largely used already as feed in rows. Their substitution values can be found by reading the table from row to column and inverting the cereal contribution. For instance, 0.832 unit of soybean meal substitute for beef with 1 unit of rapeseed meal and 0.085 unit of corn (corn is now replaced as the negative sign needs to be inversed).

Table 32: Maximum incorporation constraint for DDGS as percent of daily dry matter intake

Animal type	Observed	Maximum incorporation in literature	Value in

	incorporation rate			**GLOBIOM**
	US Widwest (2007)	**Low**	**High**	
Beef [a]	22%	10%	30%	30% [b]
Dairy [c]	8%	10%	30%	20%
Swine	10%	10%	30%-50% [d]	20%
Poultry	NA	10%	15%	12.5%

[a] Statistics reported here are based on calculation for cows. Beef cattle on feed high bound up to 40%.

[b] High bound taken to take into account observed rate.

[c] Incorporation statistics reported here for dairy cows (not replacement heifers).

[d] Low bound for market swine, high bound for breeding swine.

Source: Hoffman and Baker (2011).

II.8 Represent multi-cropping

Motivation for improvement

In several regions of the world, the possibility of harvesting more than one crop per year in a same field has been used to increase output per hectare. Most famous examples are the multi-harvest of rice in Southeast Asia or the soybean-maize double cropping practice in Latin America. GLOBIOM was not taking into account so far this possibility and annually harvested areas of cropland were calculated on the basis of harvested areas of each crop, without any specific correction. Multi-cropping (or inter-cropping) possibilities were therefore not considered. Additionally, when cropland area was found larger than harvested areas, the “unused” cropland was considered kept constant, to reflect the presence of other not referenced crops or various conservation uses. No change in cropland harvest frequency was then represented. Therefore, it was decided to better represent the trend of multi-cropping in the baseline of GLOBIOM by introducing some cropping intensity change and the potential of this development to free some agricultural land.

Useful definitions [largely based on Ray and Foley (2013)]

Harvested area: Area of crop that has been harvested through one year, possibly several time in case of successive cropping seasons in the same year.

Annually harvested cropland: Area of cropland which is used for cultivation (possibly several times a year).

Total standing cropland: total area of land declared as cropland, including fallow land.

Cropland harvest frequency (CHF) or cropping intensity: defined as Harvested area divided by Total standing cropland.

Double-/Multi-cropping: practice of harvesting two/several crops successively in a same year on the same cropland area.

Inter-cropping: practice of planting several crops simultaneously in the same field, with alternate rows of crop of the different species.

Methodological approach

First, FAO statistics were used to calculate cropland harvest frequency (CHF) of the different regions. CHF calculation is not sufficient to identify all places where muti-cropping could be observed due to disparity of cropping practices within a region. However, it provides a sufficient criteria to locate some of them.

Indeed, if this ratio is greater than one, some areas of land have necessarily been used to grow several crops in the same year. If this ratio is below one, a share of cropland has necessarily not been used for production, but this does not exclude multi-cropping practices in some other locations in the region.

Nine countries were found with CHF > 1 for the calibration year (2000), which reveals the presence of multi-cropping in these regions. The list of regions and corresponding countries can be found in Table 33. They are consistent with assessment of multi-cropping location in the literature (Langeveld et al., 2013; Siebert et al., 2010). For these regions, annual crop yield assumptions were adjusted in GLOBIOM to better reflect the current average output per hectare of harvested cropland and per year. As a consequence, cultivated areas were decreased in these regions, and land areas erroneously allocated to the cultivation of the crop were reclassified as "other natural vegetation". For regions with CHF >1, we also implemented a trend in the baseline for cropland harvest frequency. For this we used the trend on the period 2000-2011, following a methodology similar to Ray & Foley (2013), who have calculated trends in ratio of harvested land over cropland area over time.[130]

In the case of China and India, we refined our estimates by a closer look to the literature specific to these regions. For China, we relied a remote sensing historical analysis of change in multi-cropping patterns (Zuo et al., 2013). According to this study, CHF in 2005 is found to be 1.53 and multi-cropping efficiency is assessed to be 87.6% with significant barriers to multi-cropping improvements (max CHF would be 1.75). We assume that the maximum would be reached in 2030. For the case of India, we use another remove sensing analysis (Biradar and Xiao, 2011). These authors observe than Indian CHF was 1.267 in 1993, and 1.371 in 2005. We use this trend to refine our projections for India.

For regions with CHF<1, it is not possible to derive frequency of harvest for the different crops, without studying some specific national datasets, a process too time consuming for this project. As an exception to this general rule, we had a closer look on the case of Brazil, well known for his increasingly use of multi-cropping practices (on corn and soybeans). According to Spera et al. (2014), use of double cropping in the State of Matto Grosso grew from 500,000 ha in 2001 to 2.8 Mha in 2011. Therefore we also apply the trend on cropland harvest frequency in Brazil (+0.9% per year on frequency), although the cropland harvest frequency is lower than 1 in this region.

Implications for model result

The first effect of multi-cropping representation will be, for the countries with CHF > 1, a reevaluation of annually harvested cropland area for the base year 2000, after adjusting the yield values. Additionally, the trend on yield will be modified for these regions as well as for Brazil. So far, the exogenous yield trend was only representing the effect of technical change, but it will now also incorporate an additional component for change in management related to multi-cropping. Yields are likely to grow faster for the regions concerned, reducing the impact of additional production in the baseline on LUC.

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[130] It should be noted that the trend in historical data may also be associated to change in fallow land (decreasing) and not only to multi-cropping. However, as unused cropland is kept constant in the model (see improvement 27 for more explanations), this approach is consistent to replicate the trend in cropland harvest frequency.

Table 33: Cropland harvest frequency and associated indicators according to FAOSTAT in 1999-2001

Region with multi-cropping	Harvested area – cropland (1000 ha, only >1Mha reported)	Cropland harvest frequency (2000)	Annual growth rate (2000-2011)	Maximum cropland harvest frequency (Ray and Foley, 2013)
China[*]	29,089	1.53	0.4%	1.75
Nigeria	8,537	1.26	-1.7%	2.00
India[**]	6,514	1.32	0.7 %	1.63
Bangladesh	5,544	1.63	1.1%	1.99
VietNam	3,865	1.47	-0.5%	1.95
Philippines	2,779	1.28	0.2%	2.00
Myanmar	2,551	1.24	1.6%	1.80
Nepal	2,052	1.84	0.8%	1.06
Egypt	1,271	1.38	0.5%	1.01
Others (<1 Mha)	1,347	1.02	--	--
TOTAL	**63,549**	**1.13**	**--**	**--**
Brazil		***0.78***	0.9%	1.71
World		***0.82***		

Source: authors' own calculation using FAOSTAT data, except for last column from Ray and Foley (2013). Note that we report here growth rates for the index, whereas Ray and Foley report rate of annual change. * For China, we use data from Zuo et al, 2013. ** For India, data from Biradar and Xiao, 2011.

II.9 Represent imperfect substitution between vegetable oils

Motivation for improvements

Vegetable oils were represented in the standard version of GLOBIOM with distinct demand functions, and the level consumed was only determined by an exogenous shifter for the income effect and an own-price demand elasticity for the price effect. No distinction was made between demand for food and demand for industrial use, to the exception of biofuel use. However, vegetable markets are to some extent connected, as illustrated by the strong correlation between the different oil prices. It was agreed that a better representation of these linkages should be introduced into GLOBIOM, by introducing some substitution possibilities between vegetable oil on the supply side, while keeping in mind the restrictions to such substitution related to the different properties of these oils, the specific needs of industries, as well as the preferences of consumers.

Methodological approach

The question of patterns of change in the oilseed market is complex and we investigated different sets of statistics to better understand the mechanisms at play, provided by the industry, by FAOSTAT and by the USDA.[131] Stylized facts were examined to address a certain number of questions in the debate. We observed the following points:

- Food consumption per capita of vegetable oil has been relatively stable in Europe for rapeseed over the past decade (-9% according to USDA). But sunflower oil consumption as food has notably increased between 2002 and 2012 (USDA: +38%), as well as palm oil (+63% between 2000 and 2012). Soybean oil has decreased in the same time by 30% according to USDA. In the EU, the use of soybeans and rapeseed has decreased to the benefit of sunflower and palm oil;
- Most of substitution in the EU on vegetable oils has been observed through imports and on the industrial uses market. By contrast however, the substitution patterns in the US were larger for final consumption, and soybean oil used as food was significantly substituted by palm oil (Figure 34);
- Decrease in EU food consumption of rapeseed has remained limited compared to total increase in supply (see Figure 7 and Figure 34). The main sources of additional supply have been increased rapeseed production, and additional rapeseed imports (see Figure 36);
- Palm oil imports to the EU have significantly expanded over the period 2000-2012 (see Figure 36). Parts of these imports have been driven by a direct use by the industrial sector, in particular biofuels. But one third of these imports have also been absorbed by the food sector. The food sector has absorbed a similar quantity of sunflower oil, half of it being imported. These products compensated in the food sector for rapeseed and soybean oil transferred to the industrial uses.

For instance, we analysed whether the food consumption varied for the different oils types in the EU, or whether difference of price between rapeseed and palm oil could explain some changes in trade patterns. On the basis of this analysis, we concluded that some substitution of vegetable oil was observed in food demand but was overall relatively limited compared to the industrial demand. Therefore, a relatively low elasticity of substitution should be used in the case of the EU. On the model side, in order to implement this limited substitution effect, we created an aggregated vegetable oil food item, in which the fluctuation of the different oil shares is relatively constrained. For this purpose, the objective function of GLOBIOM was modified to include some non-linear costs associated to the change in composition of the vegetable oil aggregate. In the version of IFPRI-MIRAGE used in Al-Riffai, Dimaranan & Laborde (2010), an elasticity of substitution of 2 was used in the different regions for substitution of vegetable oils and a trade Armington elasticity of 10.[132] When prices increase, both rapeseed imports and other oil demand react to compensate the shock.

An analysis of historical development in the EU for oilseed markets shows that rapeseed oil and rapeseed imports increased five times more than food demand for rapeseed oil decreased, between 2000 and 2012 (Figure 36). In MIRAGE, the contribution of rapeseed demand change through substitution was found contributing more than two times more to the new demand for rapeseed oil.[133]

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[131] Methodology applied by USDA to split consumption across uses was found more consistent with the data provided by the industry than the one from FAOSTAT. The latter allocate a large part of consumption to other uses, whereas such use is usually better allocated in USDA and FEDIOL databook. Unfortunately, the USDA data do not provide the decomposition of demand between the different industrial uses. Therefore, the substitutability of vegetable oil within the non-biofuel industrial uses is not discussed here.

[132] Data retrieved on ec.europa.eu/energy/renewables/studies/doc/land_use_change/iluc_report_annex_1.xls

[133] Analysis of MIRAGE results from Al Riffai et al., 2010 suggests that for a shock of 324,000 tonnes of rapeseed oil to the biofuel, the EU food market provides 65,000 tonnes, ie 20%.

Uncertainty on the right substitution level is therefore key for the magnitude of responses on the vegetable oil market. As starting point, we will consider in our analysis an elasticity value of 0.8 for the EU, smaller than MIRAGE. The value of this elasticity will be part of the sensitivity analysis. However, for other regions like the US, observed recent changes in consumption of soybeans suggest that higher substitution is possible within the food sector. We will therefore keep a value of 2 in the USA. These values will be varied through the Monte-Carlo, in order to capture effect of having lower or higher substitution effects.

Implications for model results

Vegetable oil markets were already connected in GLOBIOM through demand for biofuel use. The present improvement in the model will introduce some possibility of substitution on the food market side, but with a more limited possibilities, reflecting the stickiness observed in the past time series, in particular in the case of the EU. Trade should therefore remain for the EU the most important driver of propagation of demand shock. In the rest of the world, markets will also be connected through the industrial demand and through the food market, in particular for some regions like the US showing larger substitution patterns.

Table 34: Analysis of vegetable oil final consumption in the EU in the biofuel scenario from Al-Riffai et al., 2010 (using appendix results tables)

	Feedstock use for biofuels (1000 t) (Al-Riffai et al., 2010, Table S6b)			Food consumption change (%) (Al-Riffai et al., 2010, Table S7)	Food consumption level (1000 t) (USDA, 2010)	Food consumption change (1000 t)	Ratio food change / feedstock demand for biofuel
	Baseline 2020	Scenario 2020	Difference				
Palm oil	824	1008	185	1.08%	2750	30	0.161
Rapeseed oil	4997	5320	324	-2.39%	2733	-65	-0.202
Soybean oil	2978	3441	463	-0.41%	1290	-5	-0.011
Sunflower oil	430	511	81	0.30%	3191	10	0.121

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shows that as the rapeseed consumption increased by 6 million tons in the EU in the 2000s, rapeseed decreased by 500,000 tons, ie the food sector did not contribute more than 8%, ie 2.5 times less. See Table 34 for calculation details.

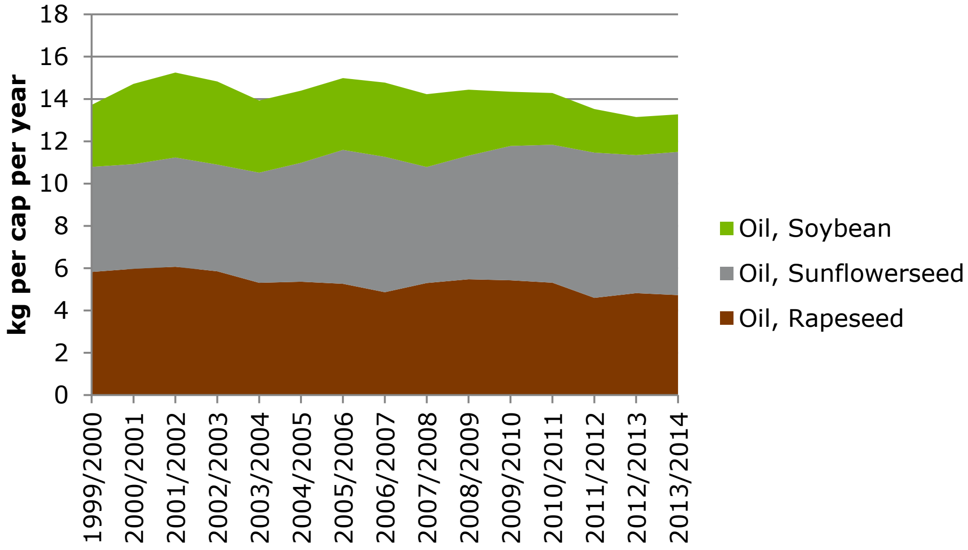

Figure 33: Consumption per capita of vegetable oil by EU consumer according to USDA PSD statistics

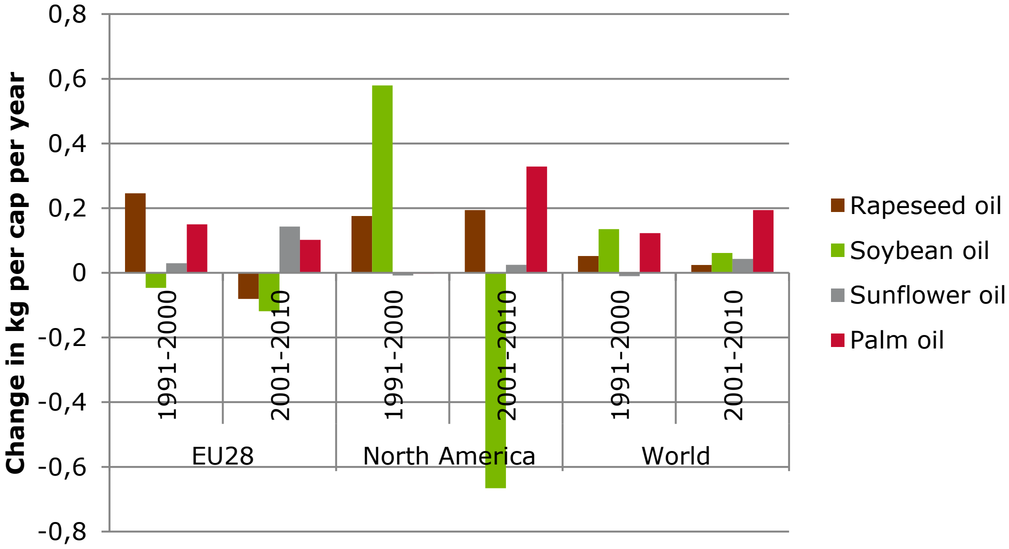

Figure 34: Change in consumption per capita of vegetal oil in EU28, North America and World on two periods 1991-2000 and 2001-2010. Rate of change are obtained by regression of consumption per capita on each period using USDA PSD data on food use

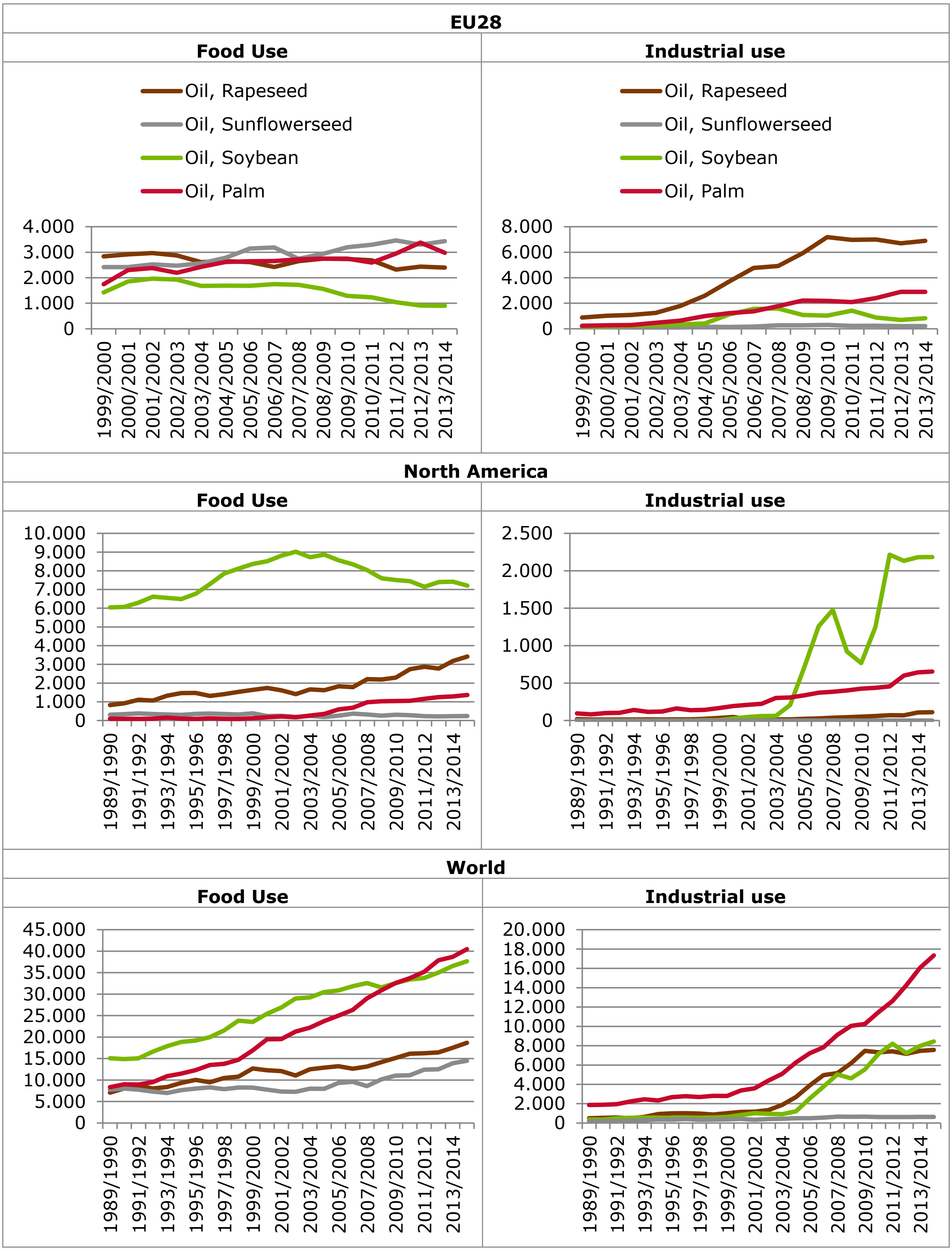

Figure 35: Vegetable oil consumption in the food and the industrial sectors (including biofuels) between 1990 and 2014 according to USDA PSD database. (1000 tonnes)

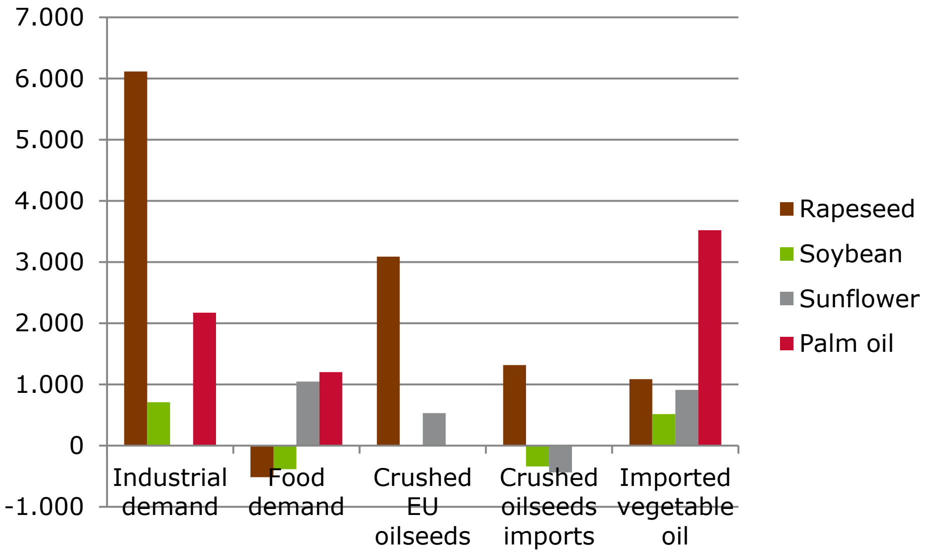

Figure 36: Changes in EU market between 2000 and 2012 for four vegetable oil types (1000 tonnes, source: USDA)

II.10 Separate representation of Argentina, Indonesia, Malaysia and Ukraine

Motivation for improvements

Argentina, Indonesia and Malaysia are important player on the international biofuel market today: Argentina is a major producer of soybeans and Indonesia and Malaysia concentrate a large majority of the palm oil production. Ukraine could play an important role in the future as a supplier of agricultural products to the EU market, in particular cereals but also rapeseed and sunflower. In order to better represent how these countries can interact with the international markets, it was recommended for the purpose of this project to single them out in order to more precisely trace their trade and how their production level can influence land use patterns, in response to policy scenarios on biofuels.

Methodological approach

Most model parameters for the parameterization of the supply side in GLOBIOM (land use, crop area and yield, animal distribution and systems, etc.) are provided at the Simulation Unit level and sourced from biophysical models and downscaling of some national datasets. For these data, input were reprocessed and made compatible with the new regional levels. The demand side had to be disaggregated, using data on quantities and prices from FAOSTAT. Argentina was separated out from previous "Rest of South America" region; Indonesia and Malaysia – previously Rest of South East Asia and Ukraine – previously Former USSR we also singled out. New price elasticities were sourced from USDA. Bilateral trade flows were recalibrated for all the new regions based on COMTRADE and tariffs from MAcMap, following the methodology used so far in GLOBIOM.

Although most data on the supply side were already available through the different input datasets, some adjustments had to be performed to represent adequately some production patterns of the new regions. Indeed, 2000 data from SPAM (Spatial Production Allocation Model), used for the calibration of the initial crop areas, was not available for rape and sunflower in some regions, in particular Ukraine. Some special treatment had to be applied to allocate these crops spatially.

Initial crop areas were distributed across Simulation Units und management system using the SPAM information on potential “pre-crops” in the rotations of sunflower and rapeseed (typically barley, corn, or wheat).

Implications for model results

The new regional mapping of GLOBIOM now gives access to more precise characterization of trade and uses of products in the new regions. Demand quantities, trade flows, prices can now be reported for these regions separately. On the supply side, LUC patterns can be more precisely connected to trade, as market resolution has been increased in the new areas of interest and localization of production changes is now more precisely assessed.

Table 35: List of regions newly represented in GLOBIOM for the ILUC study (new countries in bold)

GLOBIOM region	Definition
ANZ	Australia, New Zealand
Argentina	**Argentina**
Brazil	Brazil
Canada	Canada
China	China
Congo Basin:	Cameroon, Central African Republic, Congo Republic, Democratic Republic of Congo, Equatorial Guinea, Gabon
EU28, each country is treated as separate region	Baltic: Estonia, Latvia, Lithuania East: Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, Central: Austria, Belgium, Germany, France, Luxembourg, Netherlands North: Denmark, Finland, Ireland, Sweden, United Kingdom South: Cyprus, Greece, Italy, Malta, Portugal, Spain
Former USSR	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Uzbekistan
India	India
Indonesia	**Indonesia**
Japan	Japan
Malaysia	**Malaysia**
Mexico	Mexico
Middle East and North Africa	Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, Yemen
Pacific Islands	Fiji Islands, Kiribati, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu
RCAM	Bahamas, Barbados, Belize, Bermuda, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Netherland Antilles, Panama, St Lucia, St Vincent, Trinidad and Tobago
RCEU	Albania, Bosnia and Herzegovina, Macedonia, Serbia-Montenegro
ROWE	Gibraltar, Iceland, Norway, Switzerland
RSAM	Bolivia, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
RSAS	Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka
RSEA OPA	Brunei Daressalam, Singapore, Myanmar, Philippines, Thailand
RSEA PAC	Cambodia, Korea DPR, Laos, Mongolia, Viet Nam
South Africa	South Africa
South Korea	South Korea
Eastern Africa	Burundi, Ethiopia, Kenya, Rwanda, Tanzania, Uganda
Southern Africa	Angola, Botswana, Comoros, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Reunion, Swaziland, Zambia, Zimbabwe
Western Africa	Benin, Burkina Faso, Cape Verde, Chad, Coted Ivoire, Djibouti, Eritrea, Gambia, Ghana,

GLOBIOM region	Definition
	Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, SierraLeone, Somalia, Sudan, Togo
Turkey	Turkey
Ukraine	**Ukraine**
United States of America	United States of America

II.11 Represent unused agricultural land in Europe

Motivation for improvements

Agriculture represented 44% of land use in the European Union in 2000. In GLOBIOM, this land is represented through various land categories: "Cropland" corresponding to the share of this land used to produce the crops represented in GLOBIOM; "Grassland" corresponding to areas used for ruminant grazing. A part of this land is also occupied by other agricultural activities that are not represented for the moment in GLOBIOM (e.g. vegetables, vineyards, orchards). These are identified as "other agricultural land" and this land is kept fixed in the model. Beside these managed land, some unmanaged land are also input to the model: "natural forest", "wetlands", and "other natural land", that contain all remaining types of fertile areas.

Unused agricultural land falls in three categories:

- set-aside land is represented in the EU directly in the crop rotation as a crop management option subject to profit maximization;
- other fallow land declared as cropland is part of the "Other agricultural land category";
- abandoned land no longer declared as cropland is accounted outside of the agricultural land under the category "other natural land".

The extent of "other natural land" in GLOBIOM is usually much greater than the "other agricultural land" category. Therefore, even if "other agricultural land" is fixed, the potential agricultural land expansion is large. However, depending on the location, "forest" land can also be used in the expansion. In the standard version of GLOBIOM, both "forest" and "other natural land" are used when agricultural land expand, with proportions determined by the calibration parameters and based on observations of past land use changes.

It has been argued that the potential contribution of unused land in Europe has been underestimated in past assessments of LUC dynamics and should be better represented in GLOBIOM. For that reason, it was decided to perform some scenarios where the access to unused land would be facilitated in the EU as well as in Ukraine, a large potential supplier of agricultural products to Europe which already today provides significant quantities of biofuel feedstock to the EU.

Methodological approach

This improvement is performed as a new scenario (scenario C) with a change of parameterisation of the model. For this scenario, we model possibilities of expansion through the third unused agricultural land category detailed above. Access cost to "other natural land" is therefore reduced for this land use type in all countries of the European Union as well as for Ukraine.

For all EU regions, this land use category is large. In the case of Ukraine, input data were also improved to better account for recent assessment on abandoned land based from Alcantara et al. (2013) who find that 9.2 Mha of farmland is currently abandoned in Ukraine.

This land area was therefore classified under "Other natural vegetation" instead of "Other agricultural land", homogeneously across the country.

Implications for model results

Scenario C has been especially designed to represent the effect of improved access to unused agricultural land. The effect of the change in access cost in scenario C will be an increased share of agricultural expansion in the EU and Ukraine, with greater use of the "other natural vegetation" land use category.

Table 36: Land use in the EU and in Ukraine in the GLOBIOM nomenclature in 2000 (1000 ha)

Country	Cropland	Pasture	Other agricultural land	Forest	Other natural vegetation	Wetlands
Austria	1,319	1,705	97	3,828	494	16
Belgium	809	675	104	653	191	10
Bulgaria	2,570	1,511	192	3,507	2,303	11
Croatia	852	1,609	488	2,129	301	
Cyprus	71	46	195	148	410	
CzechRep	2,846	631	137	2,569	1,170	8
Denmark	2,264	107	80	526	906	62
Estonia	610	48	7	2,170	1,076	188
Finland	1,712	460	28	21,953	4,893	867
France	17,989	7,637	736	13,787	9,783	181
Germany	11,505	4,360	851	10,751	4,784	178
Greece	2,173	1,836	187	1,188	6,054	39
Hungary	3,229	1,025	366	1,661	2,093	63
Ireland	264	2,778	126	461	2,039	1,002
Italy	7,091	3,328	641	7,452	6,553	58
Latvia	940	231	73	3,148	1,661	149
Lithuania	1,490	408	405	1,924	1,862	55
Luxembourg	38	46	17	89	48	
Malta	5	0	14		6	
Netherlands	851	932	149	345	710	31
Poland	12,067	3,774	1,072	8,879	3,752	132
Portugal	1,263	1,102	104	3,825	1,491	25
Romania	6,815	4,836	354	6,698	2,591	247
Slovakia	1,355	494	78	1,980	647	5
Slovenia	154	276	11	1,188	284	3
Spain	11,185	6,495	603	12,580	13,514	93
Sweden	2,734	206	120	24,077	8,911	3,514
UK	5,539	7,950	275	2,603	5,579	438
Ukraine	14,419	17,392	7,415	8,893	10,361	259

II.12 Refine biofuel feedstock processing coefficients

Motivation for improvements

The past assessment of ILUC has raised some concerns about the conversion coefficients to be used at different stages of the processing of agricultural materials into biofuels. GLOBIOM offers an explicit representation of conversion technologies and it was decided to document the current conversion assumptions to give opportunity to agriculture and industry stakeholder to comment on the assumptions for i) oilseeds crushing supply chains (improvement 34), ii) bioethanol and biodiesel transformation chains (improvement 35).

Methodological approach

A data document was compiled containing most important assumptions for GLOBIOM supply chains. This document will be made public once all input from stakeholders will have been reviewed and initial GLOBIOM assumptions improved when relevant. A list of input and comments on assumptions received during the consultation period is provided in Table 37. Corrections performed are also reported in that table when they were considered relevant. In some cases, reported issues led to direct adjustments in the initial GLOBIOM data (e.g. on biofuel supply chains), or only in adjustment of coefficients along the baseline (e.g. for crushing rates that vary over time).

Comments received were in particular on the following topics:

- Crushing rate values in Europe and rest of the world (FEDIOL)
- Conversion efficiency for corn and maize (Epure)
- Conversion efficiency for sugar beet and sugar cane (CGB)
- Final use of vegetable oils (FEDIOL)
- Production level of sugar beet (CGB)
- Conversion efficiency of sugar beet (CGB)
- Conversion efficiency of sugar cane (CGB)

Implications for model results

Adjustments of supply chains parameters will allow a more precise description of land use requirements associated to the different feedstocks, and improve the assessment of indirect LUC effects.

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Table 37: List of comments received on supply chains specifications in GLOBIOM and actions taken

Source	Comment	Comment	Correction necessary
FEDIOL (Jan 14)	Crushing rates for the EU	We compared EU crushing rates with our numbers. Values are very close to our estimates but with slightly higher moisture content (2-3%). These estimates were updated in contribution from FEDIOL from May 2014.	Yes
FEDIOL (Jan 14)	Split end-use for the EU in 2011-2012	We compared these data with our FAO and EUROSTAT sources and we found some consistent shares of uses overall. The data will be compared again after the baseline has been produced.	Yes
FEDIOL (May 2014)	Crushing rates for major producing countries	EU crushing coefficients were found very close for rapeseed and sunflower, and identical for soybeans to GLOBIOM assumptions. We adjusted our coefficient to FEDIOL values for the year 2010 and following. For other countries than EU, our estimates were also very close but adjusted as well.	Yes
EBB (April 2014)	Production of glycerin	Due to its too loose connection to LUC dynamics, it has been decided not to change the supply chain representation in the model to introduce glycerin. Although glycerin can impact the life cycle assessment of biofuels, only LUC emissions are the focus of the study.	No
Epure (June 2014)	Corn ethanol conversion coefficient in the EU: 400-427 l/t	Estimates provided are 6 to 13% above JRC values. However, US EPA usually uses a value of around 417 l/ton. This value will be used as a reference unless more specific data on the EU are provided by JRC.	Yes
Epure (June 2014)	Wheat ethanol conversion coefficient in the EU: 0.29-0.295 t/t.	The value proposed by Epure are 1-3% above Biograce values. Except if authoritative reference is provided, we assumed Biograce default was acceptable.	No
Epure (June 2014)	Wheat DDGS and corn DDGS output should be comparable: 0.29-0.32 t/t crop at 10% mc	Biograce value for corn was updated with latest version of Wells to Tank analysis from JRC (2014 version 4a). Yields are now for DDGS of 0.31 tons DDGS 0% mc for wheat and corn at 10% mc.	Yes
Epure (June 2014)	Wheat DDGS conversion ratio is too low.	The numbers provided is 0.294 with 0% mc, which is equivalent to 0.326 with 10% mc. The value from Biograce for wheat DDGS seems therefore in line with Epure input.	No
Epure (June 2014)	Sugar processing co-products vinasse and carbonate lime are not represented.	We did not change the supply chains to add products that do not interact with LUC dynamics, because the project only looks at LUC emissions.	No
Epure (June 2014) /	Sugar content assumed for sugar beet is too low: average of 17.6% should be assumed for past 5	We analysed in details statistics received from CGB. We concluded that in order to best reflect the heterogeneity of sugar content across production of	Yes

Source	Comment	Comment	Correction necessary
CGB (March 2014)	years.	member states, the most consistent approach in GLOBIOM was to recalculate all yield values for beet at 16% sugar content. We will for this use CIBE information on yield in ton sugar / ha per Member State and divide by 0.16 to obtain beet yield and production.	
Epure (June 2014)	Sugar production volume are not correct at EU MS level	As explained above, our production statistics will be updated taking harmonizing yield at 16% sugar content.	Yes
CGB (March 2014)	Average yield values should be used rather than point estimates	This is currently the way it is done in GLOBIOM: we use a 3 year average on the period 1999-2001 for the base year yield level.	No
CGB (March 2014)	Yield improvement should be taken into account, sugar beet had a strong yield improvement over past years.	We take yield improvement into account in our baseline; our yield improvement assumptions will be calibrated on CAPRI model projections used by DG Agriculture. If longer time series on sugar yield per ha are provided, we can also introduce a trend on sugar content in beet.	Yes
CGB (March 2014)	Sugar cane area not harvest should be accounted to reflect correct apparent sugar cane yield (different from field yield)	After check, area reported by FAOSTAT as "harvested" for Brazil correspond to the total area under sugar cane.	No
CGB (March 2014)	Sugar beet sugar content for ethanol production should take into account the fact that EU ethanol producers have higher sugar content in beet than average EU.	We will adjust our production statistics to reflect the actual average sugar content of each Member state and correct production for 16% sugar equivalent. Therefore, the conversion of ethanol will be the same for all EU beet based on this 16% and no further adjustment will be needed. The yield will be equal to the actual 18.2% once ethanol production will be adequately allocated across member states.	No
CGB (March 2014)	Sugar cane conversion rate should be checked to reflect dehydrated conversion efficiency instead of hydrated one.	We checked the value used in our tables based on Biograce/JRC of 1.77 GJ / ton sugar cane. This corresponds after conversion to 83.6 liter ethanol / ton sugar cane. This is slightly lower than the 86.3 liter reported by CGB but considering the past average sugar content over 5 years was found to be 138 kg / ton sugar cane, this seems consistent (CGB assumed for their calculation 142 kg/ton sugar cane).	No
CGB (March 2014)	Sugar beet conversion factor from JRC should be applied to beet at 16% sugar content, not to actual yield.	As explained above, we will indeed adjust our production and yield values in GLOBIOM to reflect production of beet at 16% sugar content and not at actual content. The JRC conversion factor will therefore remain relevant.	Yes

Annex III Technical background of modelling

III.1 Modelling supply of forestry residues

In order to estimate the land use emissions effect of using forestry residues, we proceeded along two steps: i) determining the supply curves of residues in the different EU forest; ii) assessing the carbon impact of increasing residues removals.

III.1.1 Calculation of sustainable potential

The “logging residues” potential considered here include:

- Losses from harvesting of roundwood at the forest site (i.e. rooten wood, piece of wood unsuitable for roundwood), excluding bark (bark is assumed to be harvested and delivered to the industry with roundwood);
- Branches, including all branches attached to the tree stem;
- Tops, as the stemwood section dimensionally unsuitable for production of roundwood (i.e. the roundwood top diameter threshold was Country adjusted in the G4M forest model, e.g. 7-10 cm of diameter).

The “theoretical potential volume” of logging residues is obtained from the G4M forest model developed at IIASA, for the year 2020. The volume of logging residues from branches is calculated with biomass expansion factors applied on the tree stem volume in the G4M model. The volume of residues in tops is calculated as a difference between total stem and roundwood volume. The wood harvesting losses are sourced from country-level data.
The potential volume is calculated on the basis of spatially explicit information on a 5 × 5 km forest grid and divided between clear cuttings, thinnings and thinnings of young forests.

A “sustainable harvestable potential” is then calculated by applying the following restrictions:
A “technical recovery rate” is applied for the forest operations carried out in each cell of the forest grid. This rate is estimated to be 70% after mechanized cutting (Nurmi 2007; Wihersaari 2005) and 60% after motor manual operations. The recovery rate reflects the percentage of branches left on the forest stand due to the technical difficultly to be collected (e.g. sparse small branches). The mechanization degree in EU countries is defined according to Asikainen et al. (2008).

A “techno-ecological restriction” is then also applied in order to exclude sensitive sites. The restriction excluded from calculations stands difficult to be harvested for technical reasons (i.e. steep slope, scarce accessibility, poor ground bearing capacity) and sensible for ecological reasons (i.e. soils poor in nutrients, steep slopes sensible to erosion). According in Asikainen et al. (2008), in the EU after applying these restrictions, 75% of clear cuts and 45% of thinnings are available for harvesting logging residues. In the thinning of young forests, an average of previous values was assumed (60%), in order to reflect developing technologies for whole tree harvesting in such sites.

Once applying the two restrictions above, the sustainable harvestable potential is estimated to 39% of the initial theoretical potential (186 Mm3). After removal of the current uses, and exclusion of residues whose marketable price would be higher than current wood chip prices, we finally find a total remaining potential for the EU of 14.4 Mm3 available for biofuels.

III.1.2 Supply cost calculations

The supply costs are calculated as sum of costs for piling the biomass, extraction, chipping and road transportation to industries. The calculations are performed on a spatially explicit grid of 5 ×5 km. Road transportation distances from each forest cell to industrial hubs located in the major cities in each country are with geographical information systems (GIS) analysis. According to the mechanization degree in the different EU countries (Asikainen 2008), the piling of biomass is assumed to be carried out by a forest harvester (i.e. mechanized) or by a forest operator equipped with chainsaw (i.e. motor-manual). The efficiencies for forest operations in each cell are calculated according to literature models (Brunberg 2007; Di Fulvio & Bergström 2013; Stampfer et al. 2003; Nurmi 2007; Ghaffariyan et al. 2013) and different parameters are used in case of thinning or clear cuts. The efficiency in road transportation of wood chips is modeled according to Johansson & Liss (2006), trucking load capacities are adjusted according to maximum allowable payloads (European Commission 2014) and transportation distances are determined from the GIS calculations for each forest cell. The unitary costs for each operation are obtained in some countries of reference (i.e. Sweden for harvester, forwarder, chipper and truck and trailer; Austria for operator with chainsaw) and adapted to each of the EU countries by using specific econometrics relations for fixed costs (i.e. Risk Adjusted Discount Rates (c.f. Benitez et al. 2007)), for labor cost (i.e. Purchase Power Parity Index (World Bank, 2014)) and for operational costs (i.e. fuel prices according to GIZ (2013)).

The sum of harvesting and transportation cost for each forest cell determines the supply cost associated to the amount of logging residues extractable. The costs are aggregated in each country in cost supply curves, showing the cumulative amounts of biomass deliverable when increasing progressively the supply cost.

III.1.3 Soil carbon losses

The modeling of the soil carbon losses due to a sustainable harvesting of logging residues are estimated according to Repo et al. (2014) for the EU. These authors estimate that the sustainable share of extractable residues range from 2 to 44% of potential, depending on the country. The carbon losses estimates are dependent on the decomposition time of soil litter which is function of temperature and precipitation in each country.

Losses in Repo et al (2014) study also include the impact of removing stumps (i.e. in total branches, tops and stumps are considered). According to Strömgren et al. (2013), stumps account for the largest share of residues impacting soil carbon and other residues account for 42% of total carbon losses. Therefore, only 42% of the values from Repo et al. (2014) are considered in our analysis, as we consider the impact from removing branches and tops only. Associated carbon losses are presented in Table 1.

Table 38: Development of the average litter and soil carbon loss on forest land resulting from sustainable removals of forest harvest residues (i.e. branches and tops) in the EU countries

Soil Carbon Loss (t C ha^{-1})				
	5 years	20 years	50 years	80 years
Germany	0.6	1.5	2.7	2.9
United Kingdom	0.5	1.3	2.1	2.5
Czech Republic	0.5	1.1	2.1	1.9
Denmark	0.4	1.1	1.6	1.8
Luxembourg	0.4	1.0	1.5	1.8
Sweden	0.3	0.8	1.3	1.6
Italy	0.3	0.7	1.3	1.5
Finland	0.2	0.7	1.2	1.4
Latvia	0.3	0.8	1.2	1.4
Hungary	0.3	0.7	1.2	1.3
Netherlands	0.3	0.6	1.0	1.2
Ireland	0.2	0.7	1.0	1.2
Belgium	0.3	0.6	1.0	1.1
Poland	0.3	0.6	1.1	1.1
France	0.2	0.6	1.0	1.0
Austria	0.2	0.5	0.9	0.9
Slovakia	0.2	0.5	0.8	0.8
Estonia	0.2	0.5	0.7	0.8
Bulgaria	0.1	0.4	0.7	0.8
Romania	0.1	0.3	0.5	0.5
Slovenia	0.1	0.3	0.4	0.4
Portugal	0.1	0.2	0.4	0.4
Spain	0.1	0.2	0.4	0.4
Greece	0.1	0.1	0.3	0.4
Lithuania	0.0	0.1	0.1	0.2

Source: Repo et al. (2014)

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III.2 Amortisation of emissions over 50 instead of 20 years

One might assume that with the choice to distribute LUC emissions over 20 years, there will be no further LUC emissions after that period. This section assesses how the results would change if a longer reference period is adopted.

The timing of GHG emissions over time for the different GHG emission and sink sources are represented in Figure 37, for a stylized 1% shock (land use footprint with the back dashed line). In line with the policy scenario B chosen for this study, land use change occurs on the period 2010 (2008 in reality, but simplified for illustration purposes) to 2020 as new areas are allocated to biofuels as the EU approaches its 10% target for renewable energy in transport.

This leads to **natural vegetation conversion** emissions during this period and in parallel, land cover change for cropping leads to some sequestration in the agricultural biomass, that are accounted on the period of the deployment.[135] These emissions are then divided by the reference period considered for land use emission accounting, 20 years in the case of this study.

Natural vegetation reversion (or foregone sequestration) on abandoned land leads to some carbon sequestration that does not any longer occurs if this land is used for agriculture. This constitutes an additional source of emissions, the time span of which goes much beyond the reference period. In the current accounting, foregone sequestration is accounted on the period 2010-2030. Accounting for a longer time-frame would increase the amount of cumulated emissions, and beyond 50 years of forest regrowth, we consider here that the forest is reverted, i.e.cumulative emissions from natural vegetation reversion would then equal those of clearing of a forest in the same location.[136]

Soil organic carbon is usually released for long periods after cropland management is changed, e.g. in case of tillage of new land. However, IPCC Tier 1 approach simplifies the representation of SOC emissions and considers all emissions occur in the first 20 years after management change. This is also the approach taken here, therefore we account in our setting for all SOC emissions for mineral soils. Changing the reference period of 20 years would proportionally lower these emission values, because, for this element, the cumulated emissions remain unchanged.

Peatland oxidation (carbon emissions from organic soils) follows a different dynamics than that from mineral soil, because continuous drainage maintains the level of carbon emissions, which continue until the total oxidation of the peat. As moderate peat depth is considered 1-2 meters, whereas deep peat can be more that 4 meters deep. At a subsidence rate of 5 cm/year in first decades, usually declining over time due to peat compaction, time for total exhaust of carbon stock can reach easily 50 to 100 years.[137]

We compare in Table 39 what the LUC emission factors would be in the case of the EU2020 mix scenario if the reference period was not any longer 20 years but was instead 50 years. Under such assumption, emission from natural vegetation conversion, agricultural biomass and soil organic carbon decrease proportionally (by a factor 20/50). However, emissions from peatland are unchanged and emission from foregone sequestration are even slightly higher because the full forest regrowth is now considered. As a consequence, the decrease in the total LUC value is not as large as it would have occurred by just rescaling all emission factors by 20/50. For the EU2020 mix scenario, the decrease in LUC value is only 19%. In other words, the cumulative LUC emissions double if the reference period is extended from 20 to 50 years, due to long living emissions sources, such as peatland oxidation and natural vegetation reversion.

Contributions of the different sources vary however significantly across feedstocks. Therefore, the change in LUC value can be more notable in the case of some particular feedstocks, as illustrated in Figure 2. The largest differences are observed in the case of soybean oil (-49%), because a large contribution to emissions is coming from natural vegetation conversion, to the difference of palm oil where peatland is the largest contributor and remains much less affected. Other notable changes are

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[135] For palm plantation, the C regrowth could go slightly beyond 2020 but still would fall within the first 20 years.

[136] The reference period of 2010-2030 was chosen here to align with the reference period for natural vegetation conversion and reversion. Taking a later 20 year reference period than 2010-2030 would potentially increase further the cumulated reversion value because all biofuel deployment would already have taken place. It should however be kept in mind that the pace of C sequestration for reversion is highly uncertain in the short to medium run. Long term estimates for foregone sequestration– beyond 50 years – are more accurate in case of forest regrowth, because most of the regrowth can be assumed to have taken place.

[137] Note that because our modelling of peatland drainage is not spatially explicit, it is not possible here to know the exact timing of peatland emissions. In any case, no large-scale map of peatland depth in Indonesia and Malaysia could be found at the time of this study.

for perennials that now show positive emissions (2 gCO_2/MJ instead of -12 gCO_2/MJ) and short rotation coppices also strongly decrease their benefits (-5 gCO_2/MJ instead of -29 gCO_2/MJ). This is because reversion of forest in the long term is a better sink than these feedstocks. For such long time horizon, these feedstocks remain beneficial only in case where they are grown in areas where natural forest would not regrow.

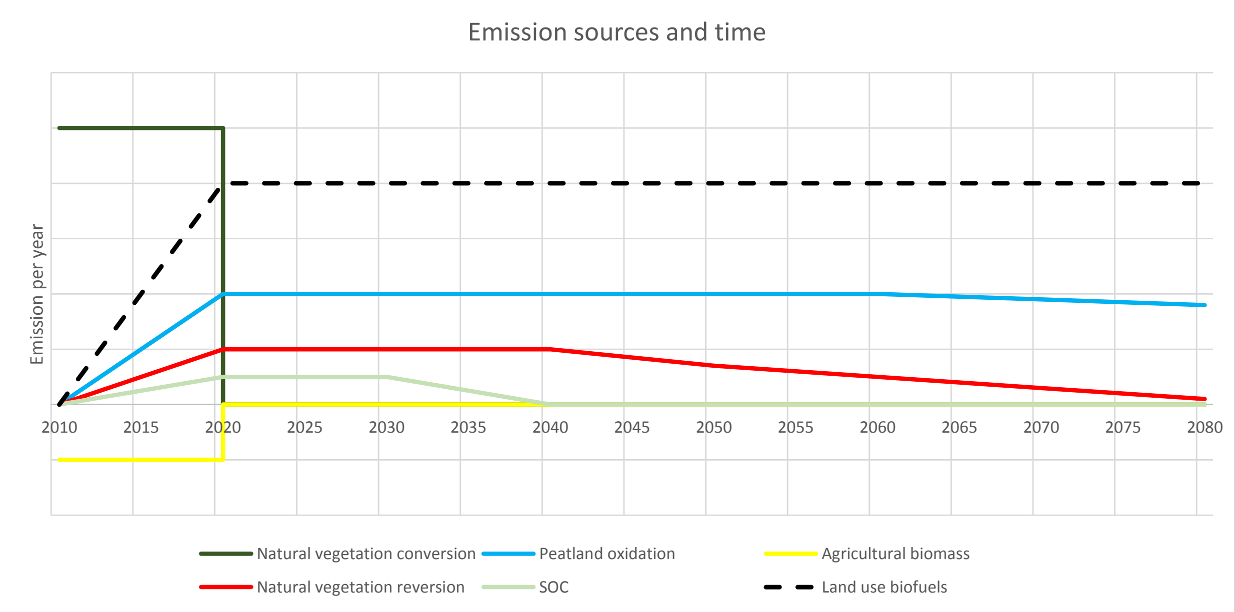

Figure 37. GHG emission flow overtime in this study, in difference to the baseline, corresponding to a marginal shock of 1%. Magnitude of emissions represented here are not corresponding to a specific feedstock. The dashed line represent the land occupied by the biofuel feedstock, expanding on 2010-2020 and then stable after the shock.

Table 39. Change in accounting of each emission source for the EU 2020 mix scenario with 20 years and 50 years reference period.

gCO2/MJ	Reference period 20 years	Reference period 50 years
Natural vegetation conversion	56	22
Natural vegetation reversion	7	9
Agricultural biomass	-37	-15
Soil organic carbon	15	6
Peatland oxidation	57	57
Natural vegetation conversion	56	22
Total	**97**	**79**

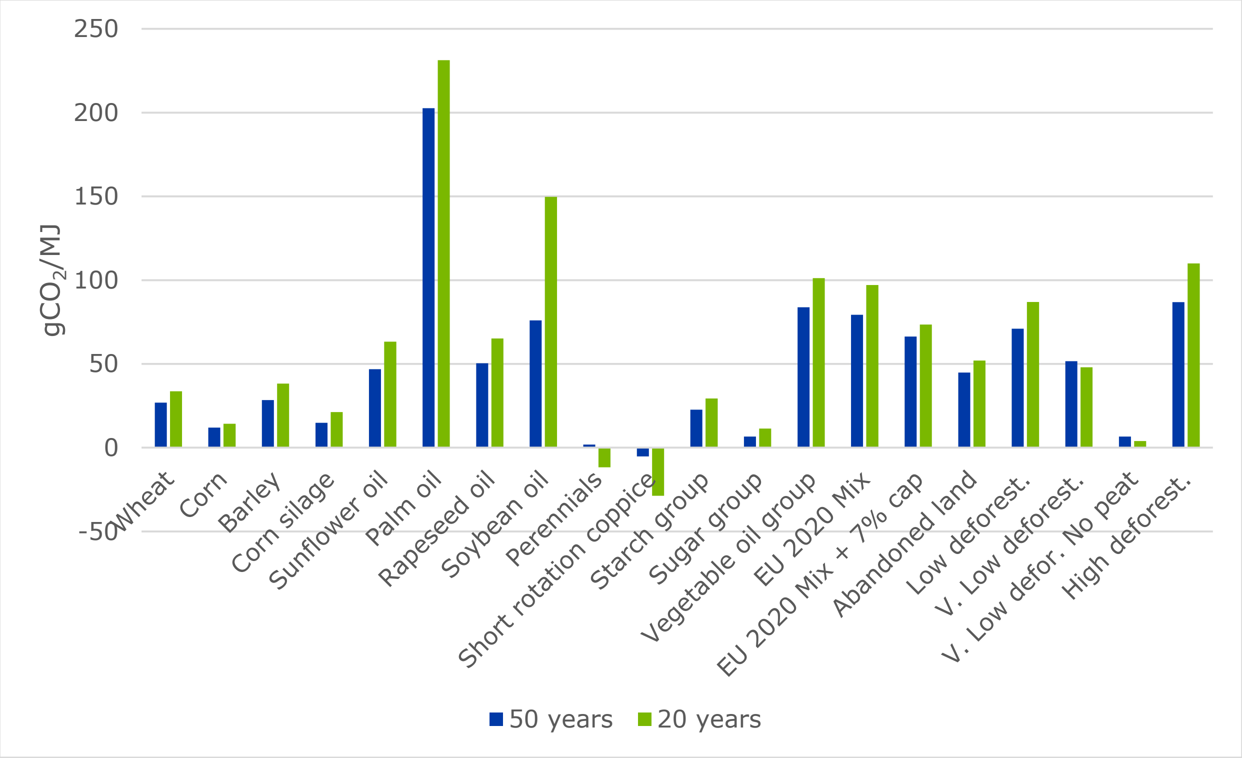

Figure 38. LUC value for different feedstocks with reference period of 50 years compared to 20 years

Finally, in this context, it is also interesting to briefly reflect on an alternative policy scenario which was not assessed in this study. Both, scenario B and B1 assume no further change in biofuel use from 2020, i.e. continued LUC emissions during the reference period (and - as explained above – with LUC emission even beyond the reference period in reality). The European Commission has adopted the view that "food-based biofuels should not receive public support after 2020"[138]: Assuming such a change in EU policy towards a phase-out of (conventional) biofuels , LUC emissions would be reduced accordingly, because the new cropland initially converted due to the biofuel policy would be taken over by expanding agricultural production for non-biofuels uses, the net cropland take of 64Mha which is eight times higher than the net cropland conversion of 8Mha due to biofuels during 2008-2020. Consequently, as long as overall net land take continues at a strong pace, the EU has, in theory, the option to revert to a "zero LUC" situation[139] by phasing out (conventional) biofuels. It would mean that the LUC emissions transitorily attributable to the RED stimulus for biofuels are gradually transferred to the overall expanding agricultural system where they are not accounted for.

III.3

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[138] COM(2014)15

[139] Even when reverting to a no biofuels policy a net carbon debt may still remain, not least because the EU biofuels policy anticipated the overall land use change as compared to the baseline.

Annex IV Data used in the GLOBIOM model

IV.1 Parameters

Table 39: Energy content of various biofuel types, as Lower Heating Value (LHV) at 0% mc

Bioethanol [a]	26.8 MJ_{LHV}/kg
Biodiesel (FAME) [a]	37.2 MJ_{LHV}/kg
Biodiesel (HVO) [a]	44 MJ_{LHV}/kg
Biodiesel (Fischer Tropsch) [a]	44 MJ_{LHV}/kg
Butanol [b]	33 MJ_{LHV}/kg
Methanol [b]	20 MJ_{LHV}/kg
Bio DME [b]	28 MJ_{LHV}/kg
Methane (upgraded biogas) [b]	50 MJ_{LHV}/kg (or about 33 MJ_{LHV}/m^3)

a) (Biograce 2014).
b) Renewable Energy Directive 2009/28/EC.

IV.2 Land cover data

Land use data are important for GLOBIOM because it constitutes the backbone of the bottom-up modelling structure (see Annex I). In particular it indicates where crops are grown (informing on their potential yield), where other uses of land compete with it (livestock on grassland, forestry) and where some land is available.

Land cover at the global level is based on the Global Land Cover 2000 dataset (GLC2000) but more detailed land cover maps exist for the EU. The European Environment Agency in particular disseminate the CORINE land cover maps, that provide information on base year 2000 land cover for Europe at a 1x1 km resolution. We build on this information to represent the land cover in Europe at a detailed level. GLOBIOM cropland areas mainly include CORINE class 210 arable land and heterogeneous areas (class 240) and is adjusted in Europe to match the harvested area in GLOBIOM (including fallow). Forest areas in GLOBIOM consist of total forests (class 310) harmonized with forest areas from the G4M model. For grassland, pastures (class 230) is used. However, these areas are then adjusted in relation to grazing quantities to represent only productive grassland. This allows to represent the possibility of expansion of livestock within the current grassland areas, and the possibility to convert unused grassland to other uses. The heterogeneous areas cover (class 240) is then used as a buffer for this adjusment. Other cropland which represents crop not covered currently by the model is calculated using EUROSTAT data. The remaining CORINE land cover classes artificial areas (class 100), permanent crops (orchards, vineyard, etc., class 220), open space (i.e. natural land with sparse or no vegetation, class 330), wetlands (class 400) and water bodies (class 500) are kept constant over time.

Table 40: Land cover data used as input for GLOBIOM in 2000 (1,000 ha) [Source: Corine land cover 2000]

	Total [1]	Cropland	Grassland [2]	Forest	Other natural vegetation	Other arable land	Wetlands
Austria	7,515	1,284	1,600	3,828	629	159	16
Belgium	2,456	813	867	653	0	112	10
Bulgaria	10,363	3,293	2,276	3,507	877	398	11
Croatia	5,196	669	22	2,129	301	2,074	0
Cyprus	861	63	0	148	456	195	0
Czech Republic	7,409	2,495	1,955	2,568	163	220	8
Denmark	3,945	1,920	1,349	526	0	88	62
Estonia	4,100	613	807	2,169	307	15	188
Finland	29,912	2,050	180	21,953	4,838	24	867
France	51,514	18,027	14,251	13,783	3,404	1,868	181
Germany	32,687	11,312	9,543	10,754	0	898	178
Greece	12,383	2,232	2,310	1,185	5,773	845	39
Hungary	8,618	4,197	1,866	1,661	215	616	63
Ireland	6,671	673	4,056	461	435	43	1,002
Italy	27,210	7,704	5,246	7,457	3,518	3,227	58
Latvia	6,204	1,137	1,631	3,148	68	72	149
Lithuania	6,153	1,479	2,230	1,924	145	320	55
Luxembourg	241	37	23	89	6	85	0
Malta	23	3	5	0	0	14	0
Netherlands	3,026	851	1,582	345	37	180	31
Poland	29,769	12,389	6,502	8,878	347	1,521	132
Portugal	8,492	1,732	2,088	3,825	0	821	25
Romania	22,135	8,777	2,575	6,698	2,991	847	247
Slovakia	4,600	1,374	984	1,979	144	114	5
Slovenia	1,933	148	499	1,189	56	39	3
Spain	47,527	12,538	7,759	12,583	9,248	5,307	93
Sweden	39,561	2,577	9,298	24,077	0	96	3,514
UK	22,395	5,539	8,337	2,602	5,123	356	438

[1] This does not include here artificial areas and mountains, deserts, lakes and other not relevant areas. Total is therefore lower than country official area.

[2] Before adjustment in GLOBIOM to distinguish productive grassland from not grazed areas.

IV.3 Carbon stocks

The table below contains the average carbon stock values in tonnes per hectare per region.

Table 42: Average carbon stock values per carbon pool per region (t/ha) [source: GLOBIOM model based on estimates from Forest Resource Assessment 2010 (FAO) for forestry and Ruesch and Gibbs (2008) dataset for living biomass carbon stock in other natural vegetation and in grassland.]

	Forest	**Forest**	**Other Natural Land**	**Grassland**
	Above-and-Below-Ground-Biomass	Dead Organic Matter	Above-and-Below-Ground-Biomass	Above-and-Below-Ground-Biomass
Latin America	128	14	26	7
South Asia	64	9	29	3
North America	66	19	10	3
EU28	88	22	9	3
Eastern Asia	43	11	14	2
Southeast Asia	120	13	29	5
Russia and neighbouring countries formerly part of the USSR	59	21	4	4
Sub-saharan Africa	111	12	35	4
Oceania	69	15	17	3
Middle East and North Africa	71	15	13	2

IV.4 Crop yields

For the EU, EPIC simulations are performed for different crop rotations and tillage systems (conventional, reduced, and minimum tillage) with statistically computed fertilizer rates and irrigation management. Crop rotations have been derived from crop shares calculated from EUROSTAT statistics on crop areas in NUTS2 regions explicitly taking into account data on relative crop shares and agronomic constraints such as maximum frequency in a rotation. Average NUTS2 EPIC yields are harmonized with EUROSTAT/CAPRI data to match production and area data in the base year. The yield values are based on a 1998-2002 average. For 2010 we implement yield changes according to historic data while we apply an exogenous yield trend 2010 onwards which has been estimated based on 1998-2012 data (see Section 2.2.3 for yield trends in the baseline). Endogenous yield response is operated in the model through system shifts, as explained in Annex I, Section I.2.4).

In the case of sugar beet, the yield value indicated below are raw data not adjusted by sugar content. These data have then been rescaled in the model to represent yield at 16% sugar content.

Table 41: Crop yield (fresh matter tonne/hectare)

	Barley	Corn	Peas	Potato	Rapeseed	Soybean	Sugar beet	Sunflower seeds	Soft wheat	Durum wheat	Oats	Rye
Dry matter content (%)	**89**	**85**	**90**	**20**	**91**	**90**	**24**	**94**	**85**	**85**	**85**	**85**
Austria	4.5	11	2.7	30.3	2.7	2.3	64.7	2.6	5.1	3.9	4	4
Belgium	6.5	11	3.9	44.7	3.2		65.7		7.6		5.3	5
Bulgaria	3.1	2.8	0.8	10.2	1.2	0.9	14.6	1.1	2.9	3.7	1.7	1.9
Croatia	3.2	5.2	0.7	13.2	2.1	2	33.5	1.8				
Cyprus	1.8		0.9	20.3								
Czech Republic	3.8	6.6	2.3	20.5	2.7	1.4	46.5	2.1	4.7		4	4
Denmark	5.5		3.3	37.8	2.8		55.8		7.7		5.4	5.2
Estonia	1.9		1.6	14.3	1.4				2.1		1.7	1.9
Finland	3.4		2	24.2	1.4		33.9	0.5	3.4		2.6	3.1
France	6.1	8.9	4.6	39.2	3	2.6	70.9	2.3	7.4	3.5	1	
Germany	6.2	9.2	3.4	39	3.5		58.1	2.4	7.7	4.2	3.1	3.7
Greece	2.9	9.2	1.8	24.2		2.6	66.7	1.5	1.8	2.6	5.2	5.3
Hungary	3.2	5.6	1.9	20.9	1.7	2	47.6	1.7	4	3.8	1.6	2.1
Ireland	7.1		2.3	31.7	3.5		41.5		9.4		3.2	2.5
Italy	3.7	9.7	2.1	24.7	1.1	3.7	46.9	2.1	3.8	2.8	4.3	4.7
Latvia	1.9		1.6	13.4	1.6		31.4		2.7		5	5.8
Lithuania	2.5	2.3	1.4	13	1.3		30.4		3.4		2.1	2.1
Luxembourg	6.5	11	3.9	44.7	3.2				7.6		2.4	2.2
Malta	4.6		1.5	19							7.4	
Netherlands	6.1	9.3	3.8	45.7	2.7		60.1	5.1	8.2		2.4	2.9
Poland	3.3	6.4	1.6	17.7	2.3	2.9	37	1.1	3.9		1.5	2
Portugal	1.4	6.2	0.5	14.3			58.5	0.5	0.9	1.8	1.7	2.5
Romania	2.7	2.8	1.4	13.8	1.2	1.3	19.4	1.1	2.9		1.6	2.2
Slovakia	2.7	4.3	1.6	14.5	1.9	1.2	37.3	1.6	3.6	4.1	1.6	2.5
Slovenia	3.5	6.3	2.4	20	2.3	2.1	42.6	2.4	4.4		2.6	3.1
Spain	2.8	9.3	0.7	26.2	1.4	2.3	64	0.9	2.7	2.6	1.8	1.5
Sweden	4.1	7.7	2.7	32.7	2.2		46.6		6.1		3.7	5.4
UK	5.6		3.7	39	3.5		46.1	3.1	7.5		5.8	5.8

At the global level, yields are also estimated through EPIC estimation, and harmonised with FAO statistics by country. Yield values from FAO are used from the period 1998-2002.

Reference values are reported below. For sugar cane in Brazil and palm oil in Malaysia and Indonesia, FAO harvesting yield values are corrected to correspond to average yield by planted area instead of harvested area.

Table 42: Crop yields in selected world regions and countries (fresh matter tonne/ha)

	Barley	Cassava	Corn	Oil palm fruit	Potatoes	Rapeseed	Rice	Soybean	Sorghum	Sugar cane	Sunflower seed	Wheat
Dry matter content (%)	**89**	**21**	**85**	**53**	**20**	**91**	**85**	**90**	**89**	**25**	**94**	**85**
Australia	1.9		6.0		34.3	1.2	8.9	1.9	2.8	85.7	1.0	1.8
Argentina	2.4	10.0	5.7		26.9	1.4	5.4	2.5	4.8	63.9	1.8	2.3
Brazil	2.0	13.3	3.0	10.0	17.4	1.6	3.0	2.5	1.7	69.3	1.6	1.7
Canada	2.8		7.2		27.3	1.4		2.4			1.6	2.2
China	3.0	16.1	4.9	14.2	14.3	1.5	6.3	1.8	3.6	66.5	1.6	3.8
Congo Basin	0.6	7.8	1.1	8.2	4.7		0.9	0.6	1.2	18.7		1.3
Former_USSR	1.6		2.5		10.7	0.7	2.7	1.0	1.2		0.9	1.6
India	2.0	26.0	1.8		17.8	0.9	2.9	1.0	0.8	69.3	0.6	2.7
Indonesia		12.6	2.8	17.5	14.8		4.3	1.2		55.9		
Japan	3.5		2.4		31.4	1.5	6.5	1.8		65.0		3.7
Malaysia		10.1	2.5	18.1			3.1	0.3		75.6		
Mexico	2.2	13.4	2.5	14.8	22.9	1.2	4.5	1.6	3.2	73.9	0.8	4.7
Middle East North Africa	0.9		5.4		20.2	1.7	6.3	1.6	2.1	105.0	0.9	1.9
Central America	0.9	6.0	1.5	17.2	21.3		3.3	2.5	1.2	46.7		1.6
Rest of South America	1.3	12.0	2.4	15.0	12.1	2.3	4.6	2.3	2.4	74.6	1.1	2.4
Rest of South Asia	1.0	8.5	1.8		12.3	0.8	3.2	0.8	0.6	45.9	1.4	2.3
South Korea	3.8		4.0		24.8	1.3	6.6	1.4	1.4			3.2
Eastern Africa	1.1	10.1	1.3	13.3	7.6	0.8	1.6	1.1	1.2	86.1	0.7	1.3
Southern Africa	3.7	7.0	1.1	12.1	10.2		1.9	1.9	0.7	68.8	0.6	4.2
Western Africa	0.8	9.7	1.4	3.3	5.2		1.6	0.8	0.8	57.2	0.7	1.8
Turkey	2.2		4.2		26.1	2.3	5.7	2.8			1.5	2.1
Ukraine	2.1		3.0		10.4	0.9	3.4	1.1	1.0		1.1	2.6
USA	3.2	2.5	8.4		40.4	1.5	6.9	2.6	3.9	78.2	1.5	2.7

IV.5 Bioenergy transformation pathways

For most biofuel pathways, the total feedstock to fuel conversion is described as one step. For some pathways, the conversion is described in two steps via an intermediate product (e.g. vegetable oil). Conversion coefficients are applied worldwide, except where indicated otherwise. These coefficients are kept constant over time.

IV.5.1 Production of ethanol

Table 43: Conversion of corn to ethanol

Product	Region	Unit	Input	Output
Corn		tonne (15% mc)	**-1**	
Ethanol	USA [a)]	GJ		**8.68**
		tonne (0% mc)		**0.324**
	EU & ROW [b)]	GJ		**8.72**
		tonne (0% mc)		**0.325**
Corn DDGS	USA [a)]	tonne (0% mc)		**0.304**
		GJ		**5.42**
	EU & ROW [c)]	tonne (0% mc)		**0.295**
		GJ		**5.26**

a) 2.76 gallon (= 10.5 litre) ethanol and 17 lbs (=7.7 kg) of dried distillers grains per bushel corn (=25.4012 kg at 15.5% mc) (EPA, 2010), with LHV corn at 18.5 MJ/kg at 0% mc, LHV ethanol at 26.81 MJ/kg at 0% mc and LHV DDGS at 16.0 MJ/kg at 10% mc.

b) Edwards et al. (2004). Revision V4 (2014). Pathway "Production of Ethanol from Corn (Community produced) (steam from natural gas CHP)". Overall yield is 0.6032 MJ ethanol/MJ corn, with LHV corn at 17 MJ/kg at 0% mc and LHV ethanol at 26.81 MJ/kg at 0% mc.

c) Ibid, Yield of DDGS is 1.392 tonne DDGS/tonne ethanol, with DDGS at 10% mc. LHV DDGS is 16.0 MJ/kg at 10% mc. Biograce does not make distinction between the energy content of corn DDGS and wheat DDGS. Note that Globiom will not use LHV for DDGS but more metabolizable energy by animal.

Table 44: Conversion of wheat to ethanol

Product	Region	Unit	Input	Output
Wheat		tonne (15% mc)	**-1**	
Ethanol [a)]	Global	GJ		**7.68**
		tonne (0% mc)		**0.286**
Wheat DDGS [b)]	Global	tonne (0% mc)		**0.294**
		GJ		**5.22**

a) Biograce (2014). Pathway "Production of Ethanol from Wheat (steam from natural gas CHP)". Overall yield is 0.5313 MJ ethanol/MJ wheat, with LHV wheat at 17.0 MJ/kg at 0% mc and LHV ethanol at 26.81 MJ/kg at 0% mc

b) Ibid. Yield of DDGS is 1.14 tonne DDGS/tonne ethanol, with DDGS at 10% mc. LHV DDGS at 16.0 MJ/kg at 10% mc.

Since the starch content of rye is approximately the same as for wheat, the same conversion efficiencies and costs are assumed. Wheat and rye are processed in the same ethanol facility, with feedstock mix depending on availability and cost.

Table 45: Conversion of rye to ethanol

Product	Region	Unit	Input	Output
Rye		tonne (15% mc)	**-1**	
Ethanol	Global	GJ		**7.68**
		tonne (0% mc)		**0.286**
Rye DDGS	Global	tonne (0% mc)		**0.294**
		GJ		**5.22**

Table 46: Conversion of sugar beet to ethanol

Product	Region	Unit	Input	Output
Sugar beet		tonne (76% mc, 16% sugar content)	**-1**	
Ethanol [a)]	Global	GJ		**2.13**
		tonne		**0.079**
Sugar fibre [b)]	Global	tonne (0% mc)		**0.055**
		GJ		**0.857**

a) Biograce (2014). Pathway "Production of Ethanol from Sugar beet (steam from NG boiler). Overall yield is 0.5436 MJ ethanol/MJ sugar beet, with LHV sugar beet at 16.3 MJ/kg at 0% mc and LHV ethanol at 26.81 MJ/kg at 0% mc.

b) Ibid. Yield of co-product is 0.219 MJ sugar beet pulp/MJ sugar beet, with LHV sugar beet pulp at 15.6 MJ/kg at 0% mc.

Table 47: Conversion of sugar cane to ethanol

Product	Region	Unit	Input	Output
Sugar cane		tonne (75% mc)	**-1**	
Ethanol [a)]	Global	GJ		**1.77**
		tonne (0% mc)		**0.066**
Bagasse [b)]	Global	kWh		**N/A**

a) Biograce (2014). Pathway "Production of Ethanol from Sugarcane". Overall yield is 0.3607 MJ ethanol/MJ sugar cane, with LHV sugar cane at 19.6 MJ/kg at 0% mc and LHV ethanol at 26.81 MJ/kg at 0% mc.

b) Electricity cogeneration is not explicitly represented in GLOBIOM for sugar cane processing but accounted for through the absence of energy cost for production.

IV.5.2 Oilseed crushing

The crushing ratios currently used in the model are derived from data provided by national statistic offices and accessible through Eurostat or FAOSTAT. Crushing rates and crushing efficiency are then reproduced in the model as they appear and kept constant over time. Within EU, national statistics display some variations that may not necessarily correspond to differences in technologies used but most likely in heterogeneity in crop processed. For that reason, we only use one average EU crushing rate.

The crushing ratios for oil used here should be interpreted as fresh seed to crude oil crushing ratios. Conversion to biodiesel later requires a vegetable oil refining stage that is accounted for separately. Cake and oil do not sum to 100% due to seed moisture extraction and in some cases additional losses.

Table 48: Crushing ratio oilseeds (1999-2001 average) [a)]. Weight fractions

		Rapeseed				Soybean				Sunflower		
		Cake	Oil	Total		Cake	Oil	Total		SunC	SunO	Total
Dry matter content (%)		89	100	(91)		89	100	(90)		92	100	(94)
(Total refers to seed)												
EU28 [b)]		**56**	**42.5**	**98.5**		**80**	**18**	**98**		**54**	**44.5**	**98.5**
Other regions												
Brazil						79	20	99				
Canada		56	42	98		78	18	96				
China		62	36	98		82	18	100		50	35	85
Former USSR										54	43	97
India		60	35	95		80	18	98				
Japan		57	42	99		77	19	96				
Mexico						80	15	95				
Middle East & North Africa						80	17	97				
Rest of South America						80	19	99		57	41	98
Rest of South Asia		62	33	95								
South-East Asia						80	18	98				
South Korea						76	18	94				
Turkey										45	38	83
USA						79	19	98				

a) FAOSTAT, UN Food and Agriculture Organization and FEDIOL. We report here ratios for crushed quantities higher than 1 million tonnes.

b) EUROSTAT/CAPRI database and FEDIOL.

IV.5.3 Vegetable oil refining

The use of crude vegetable oil as a feedstock for biodiesel involves a refining stage, leading to some losses. We currently apply 4% by mass loss for all regions and vegetable oil types.

Table 49: Vegetable oil refining

Product	Unit	Input	Output
Crude vegetable oil	tonne	**-1**	
Refined vegetable oil [a)]	tonne		**0.960**

a) Edwards et al. (2004).

IV.5.4 Production of FAME biodiesel via (trans)esterification

Table 50: Conversion of vegetable oil to FAME biodiesel

Product	Region	Unit	Input	Output
Refined oil		tonne (0% mc)	**-1**	
FAME [a)]	Global	GJ		**36.6**
		tonne (0% mc)		**0.983**

a) Biograce (2014). Pathway "Production of FAME from Rapeseed (steam from natural gas boiler)". Yield is 0.9936 MJ FAME/MJ refined oil, with LHV FAME at 37.2 MJ/kg at 0% mc. The LHV refined oil is not given by Biograce, we assume it is similar to that of soybean and palm oil at 36.8 MJ/kg at 0% mc. Furthermore, refined glycerol is coproduced at 105.6 kg / tonne FAME. The co-production of glycerol is accounted for in the processing costs. The Globiom model does not take into account trickle down effects of glycerol, even though it can be used to produce biofuels, such as biomethanol (production of fuels on basis of residues is separately accounted for).

IV.5.5 Production of HVO biodiesel via hydrotreatment

Table 51: Conversion of vegetable oil to HVO biodiesel

Product	Region	Unit	Input	Output
Vegetable oil		tonne (0% mc)	**1**	
HVO [a)]	Global	GJ		**34.8**
		tonne (0% mc)		**0.791**

a) Biograce (2014). Pathway "Production of HVO from Rapeseed (steam from natural gas boiler)". Yield is 0.967 MJ HVO/MJ oil (not refined), with LHV HVO at 44.0 MJ/kg at 0% mc. Assume that LHV vegetable oil is 36.0 MJ/kg at 0% mc. Biograce does not specify co-product, although other sources mention gasoline and propane as side products.

IV.5.6 Production of biogas

Table 52: Conversion of maize silage to biogas

Product	Region	Unit	Input	Output
Maize silage		tonne (0% mc)	**1**	
Biogas [a)]	Global	GJ		**9.9**
		tonne (0% mc)		**0.198**

a) Typical yield from (IEA, 2011) slide 5, biogas from whole crop maize is 178 – 400 m3 methane per tonne dry matter (mainly depending on the feedstock quality and retention time), so we use 300 m3 as average value, with lower heating value methane at 33 MJ/m3. However, about 25% of energy produced is used to drive the complete process (digester and upgrading). Density methane is 0.66 kg/m3.

IV.5.7 Production of cellulosic ethanol via hydrolysis-fermentation

This pathway is included as a container of future technologies producing alcohols from lignocellulosic biomass.

Table 53: Conversion of wood to cellulose ethanol

Product	Region	Unit	Input	Output
Wood		tonne (0% mc)	**-1**	
Ethanol [a)]		GJ		**6.99**
		tonne (0% mc)		**0.348**

a) IRENA (2013) Table 4.2: The average yield is 440 liters of ethanol per tonne (0% mc) wood. However the same report explains yield beyond 330 liters of ethanol per tonne are not economically profitable, therefore we assume here a yield of 330 liters per tonne. Assume LHV ethanol at 26.81 MJ/kg at 0% mc as in other tables above, and a density of 0.79 kg/litre.

IV.5.8 Production of diesel via gasification and Fischer-Tropsch synthesis

This pathway should be seen as a container of future technologies producing diesel-like fuels from lignocellulosic biomass.

Table 54: Conversion of wood to Fischer-Tropsch diesel

Product	Region	Unit	Input	Output
Wood		tonne (0% mc)	**-1**	
FT Diesel [a)]		GJ		**9.37**
		tonne (0% mc)		**0.213**

a) Dimitriou (2013) compares FT diesel production via entrained flow gasification and circulating fluidised bed gasification and finds comparable outcomes. We have used the parameters for the CFB pathway here: At an input of 120 tonne/hr wet biomass (30% mc and LHV 13,056 MJ/kg), thus 84 tonne at 0% mc, the output is 17.93 tonne/hr FT diesel at 43.92 MJ/kg.

IV.6 Co-product replacement coefficients

Insertion of co-product in animal feed is part of selected improvements to GLOBIOM. See Annex II.7 for full data.The table below reports substitution coefficients used for co-product substitution.

In the case of the US, as the substitution of co-products have been over recent year performed more on energy than protein basis, we apply the coefficients reported by USDA (Hoffman & Baker, 2011).

Table 55: Substitution pattern applied in the EU for each animal species for one unit of co-product consumed by the livestock sector. Positive values correspond to a replacement of feed, negative value to a joint addition of another feedstuff to preserve the energy balance

Feed item	Corn DDGS	Wheat DDGS	Sugar beet pulp	Rapeseed meal	Sunflower meal
SUBSTITUTE FOR CORN & SOYBEAN MEALS					
Beef					
Corn	0.711	0.523	0.800	-0.085	-0.390
Soya meal*	0.470	0.619	0.028	0.832	1.083
Dairy					
Corn	0.673	0.452	0.849	-0.005	-0.294
Soya meal*	0.478	0.635	0.017	0.815	1.062
Swine					
Corn	0.559	0.382	0.824	0.121	-0.098
Soya meal*	0.494	0.650	0.022	0.787	1.019
Poultry					
Corn	0.298	0.178	0.066	-0.030	-0.073
Soya meal*	0.560	0.695	0.188	0.820	1.014
SUBSTITUTE FOR WHEAT & SOYBEAN MEALS					
Beef					
Wheat	0.791	0.582	0.890	-0.094	-0.434
Soya meal*	0.371	0.547	-0.083	0.844	1.137
Dairy					
Wheat	0.753	0.506	0.950	-0.006	-0.329

Feed item	Corn DDGS	Wheat DDGS	Sugar beet pulp	Rapeseed meal	Sunflower meal
Soya meal*	0.384	0.571	-0.102	0.816	1.103
Swine					
Wheat	0.686	0.437	0.944	0.139	-0.112
Soya meal*	0.405	0.593	-0.100	0.769	1.034
Poultry					
Wheat	0.375	0.224	0.083	-0.038	-0.091
Soya meal*	0.505	0.662	0.176	0.826	1.027

Note: Soybean meals are not represented here as they are largely used already as feed in rows. Their substitution values can be found by reading the table from row to column and inverting the cereal contribution. For instance, 0.833 unit of soybean meal substitute for beef with 1 unit of rapeseed meal and 0.09 unit of corn (corn is now replaced as the negative sign needs to be inversed).

IV.7 Biofuel feedstock demand

Tables below provide statistics for the model base year on different uses of biofuel feedstocks. This information is useful to understand with what uses the incorporation of feedstocks conflict with on the markets. In GLOBIOM, food and feed are represented separately and other uses are assumed to respond similarly to food in case of price changes. These uses are distinguished between food, feed and other uses (which in principle include biofuels, although the biofuels production in 1999-2001 was relatively limited). These data represent EU consumption, therefore it includes imports to the EU market, but not exports from the EU. Food and Other uses can include some industrial processing, but crushing is accounted as specific category in the case of oilseeds, because corresponding supply chains are explicitly represented in GLOBIOM.

IV.7.1 Demand for ethanol feedstocks (1,000 t FM, average 1999-2001)

		Barley	Corn	Oats	Rye	Sugar beet	Wheat
Austria	Food	3	133	10	111	1,498	578
Austria	Feed	652	1,357	155	89	78	384
Austria	Other uses	242	669	13	18	1,234	89
Belgium	Food	50	107	1	14	2,737	1,353
Belgium	Feed	538	842	80	6	413	1,403
Belgium	Other uses	293	125	1	8	2,282	474
Bulgaria	Food	50	339	2	10	1,207	1,570
Bulgaria	Feed	485	972	67	22	50	1,060
Bulgaria	Other uses	219	110	10	4	351	333
Croatia	Food	1	343	4	9	811	461
Croatia	Feed	168	1,287	65	0	14	139
Croatia	Other uses	70	115	4	1	390	76
Cyprus	Food	3	23	0	0	0	71
Cyprus	Feed	320	181	0	0	0	37
Cyprus	Other uses	102	19	0	0	0	6
CzechRep	Food	112	81	24	204	2,475	1,142
CzechRep	Feed	1,287	320	112	45	0	2,288
CzechRep	Other uses	458	16	18	17	792	397
Denmark	Food	10	16	32	84	1,019	501

		Barley	Corn	Oats	Rye	Sugar beet	Wheat
Denmark	Feed	2,736	53	181	103	592	3,370
Denmark	Other uses	645	5	15	29	452	269
Estonia	Food	9	2	4	52	0	70
Estonia	Feed	246	10	81	16	0	142
Estonia	Other uses	61	1	16	13	0	19
Finland	Food	8	7	47	100	1,072	348
Finland	Feed	1,173	51	819	1	134	144
Finland	Other uses	455	27	88	14	336	123
France	Food	160	200	36	35	11,907	8,129
France	Feed	3,370	5,830	662	105	2,067	11,331
France	Other uses	559	935	18	4	7,172	1,890
Germany	Food	239	765	191	984	15,122	6,783
Germany	Feed	8,626	3,105	1,084	1,812	2,640	9,374
Germany	Other uses	2,859	641	107	508	2,004	1,645
Greece	Food	12	16	11	9	2,120	2,165
Greece	Feed	449	2,460	92	16	223	49
Greece	Other uses	50	34	8	4	420	177
Hungary	Food	17	249	3	13	2,021	1,510
Hungary	Feed	750	3,972	133	72	83	1,065
Hungary	Other uses	238	605	14	9	979	303
Ireland	Food	30	65	10	3	659	380
Ireland	Feed	918	153	101	0	395	775
Ireland	Other uses	340	26	11	0	1,296	62
Italy	Food	14	610	7	4	8,015	9,221
Italy	Feed	1,778	9,474	353	20	1,676	1,041
Italy	Other uses	320	85	30	1	2,157	658
Latvia	Food	14	0	11	42	340	170
Latvia	Feed	222	21	74	47	22	160
Latvia	Other uses	65	1	14	27	78	47
Lithuania	Food	33	12	7	126	625	413
Lithuania	Feed	773	30	78	157	30	481
Lithuania	Other uses	178	4	19	79	54	152
Luxembourg	Food	50	107	1	14	2,737	1,353
Luxembourg	Feed	538	842	80	6	413	1,403
Luxembourg	Other uses	293	125	1	8	2,282	474
Malta	Food	1	4	0	0	0	60
Malta	Feed	48	70	1	0	0	5
Malta	Other uses	3	1	0	0	0	1
Netherlands	Food	11	71	28	75	3,258	1,003
Netherlands	Feed	585	1,169	36	74	2,954	1,920
Netherlands	Other uses	394	411	1	3	2,136	989
Poland	Food	261	62	47	1,265	8,355	4,500
Poland	Feed	2,847	1,214	4,635	2,995	417	4,404
Poland	Other uses	895	76	802	1,066	1,261	1,322
Portugal	Food	37	105	25	49	2,211	1,130
Portugal	Feed	173	1,681	85	1	407	554
Portugal	Other uses	154	298	8	9	504	91
Romania	Food	2	870	9	18	3,474	3,795
Romania	Feed	391	6,776	334	9	166	910
Romania	Other uses	679	767	53	4	493	911
Slovakia	Food	6	14	5	58	942	600
Slovakia	Feed	318	390	27	10	51	701
Slovakia	Other uses	179	158	6	14	197	160
Slovenia	Food	15	52	1	10	545	224
Slovenia	Feed	90	475	8	5	29	70

		Barley	Corn	Oats	Rye	Sugar beet	Wheat
Slovenia	Other uses	43	47	1	1	139	16
Spain	Food	457	147	28	29	7,194	4,080
Spain	Feed	8,010	5,888	695	264	1,949	4,375
Spain	Other uses	1,313	1,041	108	20	2,458	514
Sweden	Food	156	20	57	120	1,953	673
Sweden	Feed	1,149	6	694	31	617	837
Sweden	Other uses	271	51	104	13	221	353
UK	Food	114	1,153	221	50	11,516	5,976
UK	Feed	3,484	313	222	8	3,179	6,623
UK	Other uses	1,888	94	27	1	2,353	1,064
Rest of World	Food	19,774	117,799	N/A*	N/A*	N/A*	376,142
Rest of World	Feed	61,249	371,358	N/A*	N/A*	N/A*	72,674
Rest of World	Other uses	4,165	544,170	N/A*	N/A*	N/A*	25,749

Source: Consolidated EUROSTAT/CAPRI database for EU countries; FAOSTAT for Rest of the World.
*N/A refers to sectors that are only represented in the EU for this version of GLOBIOM.

IV.7.2 Demand for biodiesel feedstocks (1,000 t, average 1999-2001)

		Rape-seed	Sun-flower	Soy-bean	Rape-seed oil	Sun-flower oil	Soy-bean oil	Rape-seed cake	Sunflower cake	Soy-bean cake
Austria	Food	0	2	7	9	26	14	0	0	0
Austria	Feed	2	13	10	4	0	1	83	54	492
Austria	Processing	175	105	10	0	0	0	0	0	0
Austria	Other uses	9	1	4	32	27	15	1	1	9
Belgium	Food	0	0	0	33	39	61	0	0	0
Belgium	Feed	0	0	1	43	3	15	167	88	1,328
Belgium	Processing	565	126	1,272	0	0	0	0	0	0
Belgium	Other uses	0	0	0	59	30	121	0	0	0
Bulgaria	Food	0	27	1	5	137	8	0	0	0
Bulgaria	Feed	0	0	2	0	2	3	9	174	62
Bulgaria	Processing	11	368	7	0	0	0	0	0	0
Bulgaria	Other uses	0	22	1	2	12	9	0	0	0
Croatia	Food	0	1	0	8	22	7	0	0	0
Croatia	Feed	0	3	87	0	0	0	9	26	95
Croatia	Processing	14	46	37	0	0	0	0	0	0
Croatia	Other uses	1	3	13	1	1	0	0	0	1
Cyprus	Food	0	0	0	1	5	4	0	0	0
Cyprus	Feed	0	0	1	0	0	0	0	10	96
Cyprus	Processing	0	0	4	0	0	0	0	0	0
Cyprus	Other uses	0	0	0	2	0	1	0	0	1
CzechRep	Food	0	0	2	92	20	33	0	0	2
CzechRep	Feed	10	0	1	12	1	3	189	9	467
CzechRep	Processing	583	33	16	0	0	0	0	0	0
CzechRep	Other uses	10	1	0	114	2	6	0	0	5
Denmark	Food	0	5	0	102	2	50	0	0	0
Denmark	Feed	42	6	21	0	0	0	421	276	1,549
Denmark	Processing	304	70	70	0	0	0	0	0	0
Denmark	Other uses	18	0	0	0	0	0	0	0	0
Estonia	Food	0	0	0	5	1	5	0	0	0
Estonia	Feed	1	0	0	0	0	0	16	9	22
Estonia	Processing	41	1	0	0	0	0	0	0	0
Estonia	Other uses	1	0	0	11	0	0	0	1	1
Finland	Food	0	0	1	12	3	13	0	0	1
Finland	Feed	107	7	15	1	0	1	82	2	193

		Rapeseed	Sunflower	Soybean	Rapeseed oil	Sunflower oil	Soybean oil	Rapeseed cake	Sunflower cake	Soybean cake
Finland	Processing	67	5	130	0	0	0	0	0	0
Finland	Other uses	2	0	1	12	0	3	0	0	2
France	Food	0	0	2	144	355	23	0	0	0
France	Feed	281	129	399	62	33	47	1,001	896	4,668
France	Processing	1,312	1,272	523	0	0	0	0	0	0
France	Other uses	85	50	29	322	72	18	0	0	0
Germany	Food	0	22	45	540	197	244	0	0	0
Germany	Feed	42	44	0	15	1	39	1,566	257	3,960
Germany	Processing	4,331	295	3,974	0	0	0	0	0	0
Germany	Other uses	114	2	0	439	24	24	2	0	11
Greece	Food	0	6	1	0	57	40	0	0	0
Greece	Feed	0	0	0	0	0	0	0	39	424
Greece	Processing	0	68	333	0	0	0	0	0	0
Greece	Other uses	0	0	0	0	0	0	0	0	1
Hungary	Food	0	9	5	1	87	3	0	0	0
Hungary	Feed	1	17	27	1	0	1	18	297	743
Hungary	Processing	90	362	41	0	0	0	0	0	0
Hungary	Other uses	5	21	5	31	6	22	0	4	7
Ireland	Food	0	0	0	16	11	21	0	0	0
Ireland	Feed	0	0	4	0	0	0	122	146	336
Ireland	Processing	10	1	32	0	0	0	0	0	0
Ireland	Other uses	0	0	0	0	0	0	0	0	0
Italy	Food	0	0	0	62	214	236	0	0	0
Italy	Feed	8	24	174	3	6	20	97	560	3,592
Italy	Processing	46	559	1,567	0	0	0	0	0	0
Italy	Other uses	2	9	53	16	33	7	0	0	0
Latvia	Food	0	0	0	8	3	8	0	0	2
Latvia	Feed	0	0	2	1	0	2	6	6	19
Latvia	Processing	8	3	2	0	0	0	0	0	0
Latvia	Other uses	1	0	0	8	0	2	0	0	1
Lithuania	Food	0	0	0	12	4	12	0	0	0
Lithuania	Feed	4	0	0	6	1	5	2	12	63
Lithuania	Processing	5	3	0	0	0	0	0	0	0
Lithuania	Other uses	7	0	0	6	0	1	0	0	0
Luxembourg	Food	0	0	0	33	39	61	0	0	0
Luxembourg	Feed	0	0	1	43	3	15	167	88	1,328
Luxembourg	Processing	565	126	1,272	0	0	0	0	0	0
Luxembourg	Other uses	0	0	0	59	30	121	0	0	0
Malta	Food	0	0	0	2	1	2	0	0	0
Malta	Feed	1	1	1	0	0	0	0	2	25
Malta	Processing	0	0	3	0	0	0	0	0	0
Netherlands	Food	0	3	3	55	29	82	0	0	5
Netherlands	Feed	7	2	171	6	10	53	579	596	2187
Netherlands	Processing	152	572	4,092	0	0	0	0	0	0
Netherlands	Other uses	7	0	18	101	32	68	0	6	510
Poland	Food	0	17	1	169	15	17	0	0	0
Poland	Feed	0	2	0	9	4	31	315	66	1,137
Poland	Processing	804	1	11	0	0	0	0	0	0
Poland	Other uses	70	1	0	158	15	71	0	0	1
Portugal	Food	0	0	0	0	128	13	0	0	0
Portugal	Feed	0	0	128	0	0	11	1	184	952
Portugal	Processing	1	276	687	0	0	0	0	0	0
Portugal	Other uses	0	5	8	0	17	16	0	2	12
Romania	Food	0	19	0	2	266	3	0	0	0

		Rapeseed	Sunflower	Soybean	Rapeseed oil	Sunflower oil	Soybean oil	Rapeseed cake	Sunflower cake	Soybean cake
Romania	Feed	2	3	16	1	0	5	0	353	122
Romania	Processing	17	731	102	0	0	0	0	0	0
Romania	Other uses	3	34	21	4	37	8	0	0	1
Slovakia	Food	0	1	0	31	14	3	0	0	1
Slovakia	Feed	0	1	1	4	0	0	46	8	182
Slovakia	Processing	145	42	2	0	0	0	0	0	0
Slovakia	Other uses	3	2	1	36	1	1	0	0	2
Slovenia	Food	0	0	1	7	9	11	0	0	1
Slovenia	Feed	0	0	0	3	0	1	0	20	120
Slovenia	Processing	33	0	0	0	0	0	0	0	0
Slovenia	Other uses	0	0	0	8	1	3	0	0	3
Spain	Food	0	39	1	18	450	263	0	0	220
Spain	Feed	4	118	338	0	0	0	84	667	4,175
Spain	Processing	40	1,230	2,684	0	0	0	0	0	0
Spain	Other uses	1	26	1	4	36	18	0	9	0
Sweden	Food	0	0	1	66	8	14	0	0	0
Sweden	Feed	41	0	0	7	0	3	201	20	331
Sweden	Processing	236	13	8	0	0	0	0	0	0
Sweden	Other uses	6	0	0	65	1	4	0	0	0
UK	Food	0	22	3	692	137	145	0	0	0
UK	Feed	188	1	127	0	0	0	824	458	2,034
UK	Processing	1,389	9	823	0	0	0	0	0	0
UK	Other uses	28	1	0	0	0	0	0	0	0
Rest of the World	Food	619	381	9,290	6,264	5,461	17,388	0	0	0
Rest of the World	Feed	1,990	1,702	9,835	0	0	0	13,778	5,314	82,544
Rest of the World	Processing	22,716	15,099	125,356	0	0	0	0	0	0
Rest of the World	Other uses	1,171	416	5,279	2,825	704	5,535	0	0	0

Source: Consolidated EUROSTAT/CAPRI database for EU countries; FAOSTAT for Rest of the World.

IV.8 Demand elascititities

In GLOBIOM, demand for food react to prices and the response magnitude is determined by the values of the demand elasticities. For instance, an elasticity of -0.1 means that for a 10% increase in price, the quantity of consumption will change by 10% x -0.1 = -1%.

Crop product elasticities are based on data provided by USDA that estimated demand elasticities per categories of product (e.g. cereals, sugar, vegetable oil) at the consumer level. These elasticities are applied in GLOBIOM to the demand in each crop providing the product. Because USDA data do not go at the level of detail of each product separately, we assume that all sub-product within one category have the same values[140] (e.g. barley has identical values to corn), which can mask some potentially more heterogeneous response in some particular cases. For two countries of particular importance for the future of food demand, China and India, we relied on nationally estimated data to obtain more precise estimates and describe better the differences between some sub-products.

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[140] For some regional aggregates, values can still differ because weights for the aggregation (consumption in each country) can vary from one product to another.

Table 56: Demand elasticities

	Barley, Corn, Whear, Oats, Rye , Rice	Palm oil, Rapeseed oil, Sunfower oil, Soybean oil	Potato, Peas	Sugar
Austria	-0.05	-0.05	-0.21	-0.27
Belgium	-0.05	-0.08	-0.23	-0.28
Bulgaria	-0.20	-0.23	-0.35	-0.53
Croatia	-0.16	-0.19	-0.32	-0.49
Cyprus	-0.05	-0.18	-0.22	-0.33
CzechRep	-0.10	-0.14	-0.29	-0.41
Denmark	-0.07	-0.11	-0.25	-0.21
Estonia	-0.12	-0.17	-0.31	-0.49
Finland	-0.05	-0.10	-0.25	-0.34
France	-0.05	-0.07	-0.23	-0.28
Germany	-0.05	-0.08	-0.23	-0.26
Greece	-0.19	-0.22	-0.31	-0.39
Hungary	-0.14	-0.18	-0.31	-0.46
Ireland	-0.05	-0.09	-0.24	-0.37
Italy	-0.05	-0.06	-0.24	-0.27
Latvia	-0.16	-0.19	-0.33	-0.54
Lithuania	-0.09	-0.14	-0.31	-0.52
Luxembourg	-0.05	-0.05	-0.16	-0.11
Malta	-0.05	-0.08	-0.26	-0.33
Netherlands	-0.05	-0.08	-0.23	-0.30
Poland	-0.15	-0.19	-0.32	-0.50
Portugal	-0.05	-0.08	-0.27	-0.38
Romania	-0.21	-0.24	-0.36	-0.52
Slovakia	-0.14	-0.18	-0.31	-0.48
Slovenia	-0.09	-0.13	-0.28	-0.42
Spain	-0.05	-0.05	-0.22	-0.38
Sweden	-0.08	-0.12	-0.25	-0.31
UK	-0.05	-0.05	-0.21	-0.28

Source: (Muhammad, et al. 2011)

Rest of the world	Barley	Corn	Potato	Rice	Soybean	Sugar cane	Sunflower	Wheat	Vegetable oil
Australia	-0.05	-0.05	-0.24	-0.05	-0.08	-0.27	-0.09	-0.05	-0.08
Argentina	-0.18	-0.18	-0.34	-0.18	-0.22	-0.44	-0.22	-0.18	-0.22
Brazil	-0.27	-0.27	-0.38	-0.27	-0.29	-0.53	-0.29	-0.27	-0.29
Canada	-0.06	-0.06	-0.23	-0.06	-0.1	-0.24	-0.1	-0.06	-0.1
China [a]	-0.39	-0.48	-0.45	-0.35	-0.4	-0.63		-0.3	-0.4
CongoBasin	-0.39	-0.45	-0.49	-0.44	-0.46	-0.61		-0.43	-0.45
Former_USSR	-0.21	-0.27	-0.35	-0.21	-0.22	-0.55	-0.23	-0.22	-0.23
India [b]	-0.39	-0.19	-0.46	-0.25	-0.4	-0.63	-0.4	-0.34	-0.4
Indonesia	-0.32	-0.32	-0.42	-0.32	-0.34	-0.59		-0.32	-0.34
Japan	-0.06	-0.06	-0.24	-0.06	-0.1	-0.25	-0.1	-0.06	-0.1
Malaysia	-0.28	-0.28	-0.39	-0.28	-0.3	-0.55		-0.28	-0.3
Mexico	-0.14	-0.14	-0.32	-0.14	-0.18	-0.51	-0.18	-0.14	-0.18
MidEastNorthAfr	-0.29	-0.27	-0.38	-0.27	-0.31	-0.54	-0.29	-0.28	-0.29
Central America	-0.33	-0.33	-0.44	-0.33	-0.35	-0.54	-0.35	-0.33	-0.32
Rest of Latin America	-0.26	-0.27	-0.39	-0.28	-0.31	-0.56	-0.28	-0.27	-0.35
Rest of South Asia	-0.37	-0.37	-0.45	-0.38	-0.37	-0.63	-0.38	-0.36	-0.26
Southeast Asia	-0.35	-0.35	-0.43	-0.35	-0.36	-0.60	-0.33	-0.35	-0.06
SouthAfrReg	-0.27	-0.27	-0.38	-0.27	-0.29	-0.66	-0.29	-0.27	-0.3
SouthKorea	-0.19	-0.19	-0.31	-0.19	-0.21	-0.39	-0.21	-0.19	-0.38
Eastern Africa	-0.45	-0.43	-0.48	-0.42	-0.44	-0.67	-0.43	-0.44	-0.32
Southern Africa	-0.41	-0.46	-0.5	-0.42	-0.46	-0.64	-0.47	-0.42	-0.4
Western Africa	-0.41	-0.41	-0.46	-0.41	-0.41	-0.66	-0.41	-0.39	-0.29
Turkey	-0.25	-0.25	-0.37	-0.25	-0.27	-0.52	-0.27	-0.25	-0.21

Source: (Muhammad, et al. 2011) except for :

[a] Zhuang R., Abbott P., 2005. Price Elasticities of Key Agricultural Commodities in China. Paper presented at the AAEA Annual Meeting.

[b] Kumar, P., Kumar, A., Parappurathu, S., Raju, S.S. 2011. Estimation of Demand Elasticity for Food Commodities in India. Agricultural Economics Research Review 24.

Annex V Sensitivity and uncertainty analyses

V.1 Most important uncertainties in LUC modelling

A sensitivity analysis on the model was carried out through a set of Monte Carlo runs. This means that the calculation is carried out repeatedly with randomly varied parameters. In this case, about 250 runs have been performed for each of the feedstock specific scenarios A, A1, A2 and the NREAP scenario. For this analysis, 11 parameters were varied along the specifications reported in Table 55 below.

The first set of elasticities to be varied is related to the model behavioral responses. Elasticities were varied for demand response, trade response, management response (irrigation), vegetable oil substitution and impact of the biofuel policy on the feedstock yield. These elasticities determine how much LUC occur and in what regions.
A second set of elasticities concerns biophysical parameters. Co-product protein content is the first important one, as it determines the degree of substitution of co-products with other oilseed meals. Additional testing was applied on the impact of removing yield residues on yield and soil organic carbon. Last, the emission factors for peat land as well as the share of (palm oil) plantation expanding into peat land were varied for Indonesia and Malaysia.
In the Monte Carlo analysis, the chosen parameters are randomly varied, but still this involves a pre-defined distribution shape[141]. Some parameters are varied between -50% and +100%. For parameters that are known with more accuracy, the range and shape of variation is pre-set in line with this project's Data document and Improvement Document. Parameters can be changed by a same amount when the uncertainty is not region or product specific (correlated parameters – see last column of the table). When the uncertainty is specific to each region or product – the variation in parameters is different for each region and/or product.

Two important settings for the Monte-Carlo analysis are also reported in Table 55 below. The first one is related to the parameter distribution shape. Because elasticities are parameters calculated as log response (percentage change of quantity compared to percentage change of price), we varied them along a loguniform distribution (a distribution where log of the parameter is uniformly distributed). We then consider that the response can be, for instance for trade elasticity (-50% to 100%), twice stronger or twice smaller. When parameters are known with relatively more accuracy (e.g. demand elasticities), the range of values considered was narrower. Because the central value of the distribution is not necessarily more plausible than another point in the distribution, we also preferred a loguniform distribution to a lognormal one. Biophysical parameters were associated different distribution shapes, either uniform when no better information was known on the distribution, or for peatland related factors, along the distributions determined in the improvement document.

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[141] Most values are varied along a loguniform distribution, because the central value is not necessarily more plausible than other points in the distribution. Biophysical parameters were varied along different distribution shapes, either uniform when no better information was known, or along the distribution determined in the Improvement document.

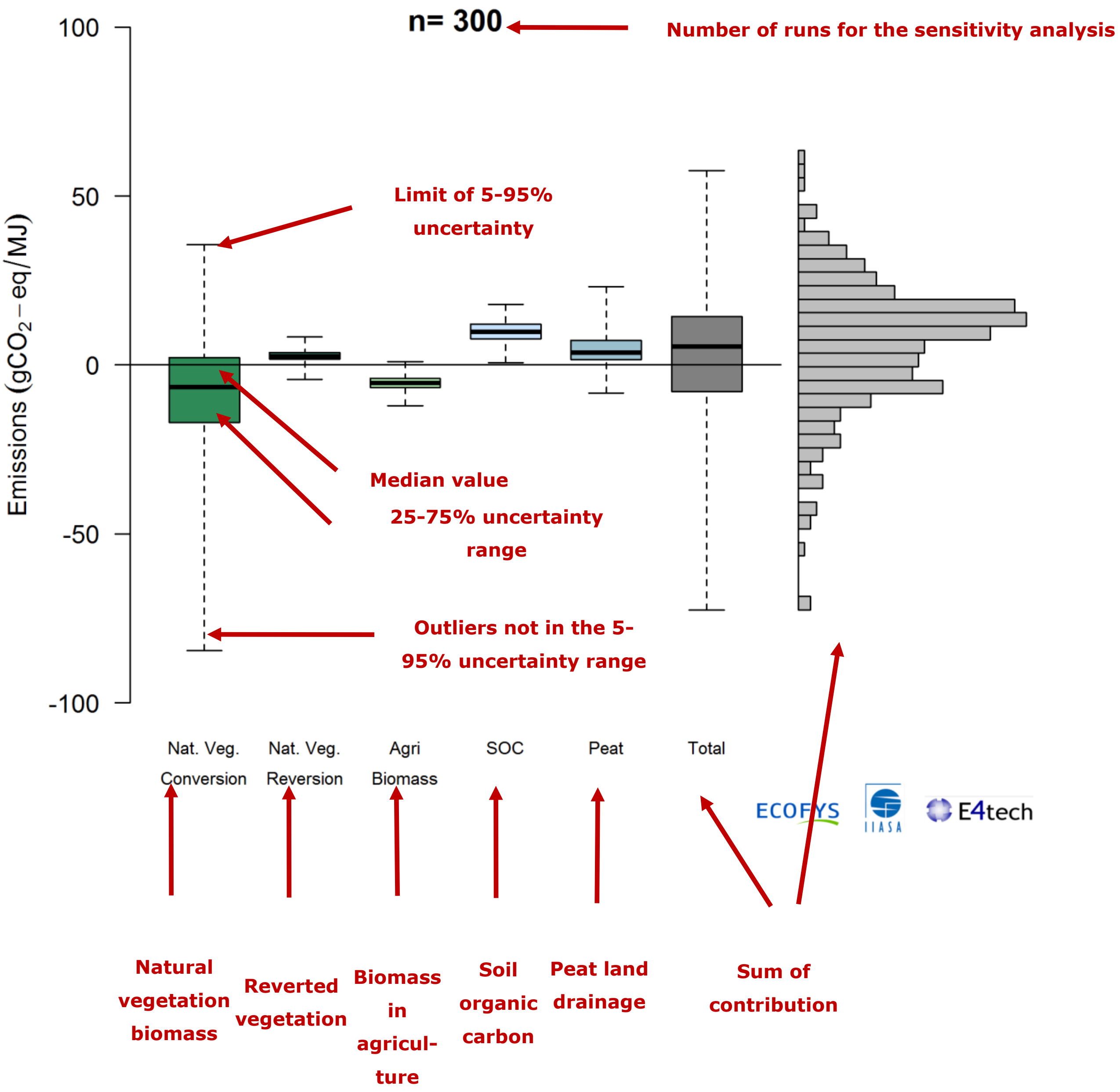
Table 57: Parameter variation used for the Monte Carlo analysis

Parameter	Value range		Distribution assumption	Correlation of parameter between products/regions
	Minimum	Maximum		
Behavioral parameters				
Demand elasticity	- 33%	+50%	loguniform	Correlated across regions and products
Trade elasticity	-50%	+100%	loguniform	Not correlated across regions and products
Water supply elasticity	-50%	+100%	loguniform	Not correlated across regions
Vegetable oil substitution elasticity	-50%	+100%	loguniform	Not correlated across regions
Land expansion elasticity	-50%	+100%	loguniform	Not correlated across regions and land use types
Yield response feedstock	Elasticity model	Elasticity model + 0.2	uniform	Same assumption for all regions
Biophysical parameters				
Co-product protein content	-10%	+10%	uniform	Correlated across regions and products
Soil carbon impact straw	-10%	0%	uniform	Same assumption for all EU regions
Yield impact straw	-4%	0%	uniform	Same assumption for all EU regions Correlated with SOC impact
Peat land emissions factor	27 tCO_2 ha^{-1} yr^{-1}	113 tCO_2 ha^{-1} yr^{-1}	lognormal	Same assumptions for Indonesia and Malaysia
Palm expansion into peat land	12%	54%	lognormal	Same assumptions for Indonesia and Malaysia

How to read results in this section?
Each graph of this section presents the detailed results of the sensitivity analysis performed for the feedstocks scenarios. The total distribution of results (right-hand side of the figure in grey) is decomposed across the different sources of GHG emissions accounted for in the study. These categories are the same as the ones used in the results section for the calculation of cumulated emissions and they follow the same color codes.

For each emission source, a box-and-whisker plot is used to represent the distribution of results. The colored box indicates the 25-75% range of central values, with the thick bar marking the median value. The limit of the whiskers indicate the 5%-95% distribution limits. Single points represent the outliers outside if this range.

The histogram on the right-hand side of the figures replicates the distribution shown in the results section. The length of the bars is proportional to the number of runs which lead to a value in the y-axis. The distribution corresponds to the values of the last box-and-whisker plot.



Number of runs for the sensitivity analysis

Limit of 5-95% uncertainty

Median value

25-75% uncertainty range

Outliers not in the 5-95% uncertainty range

Natural vegetation biomass

Reverted vegetation

Biomass in agriculture

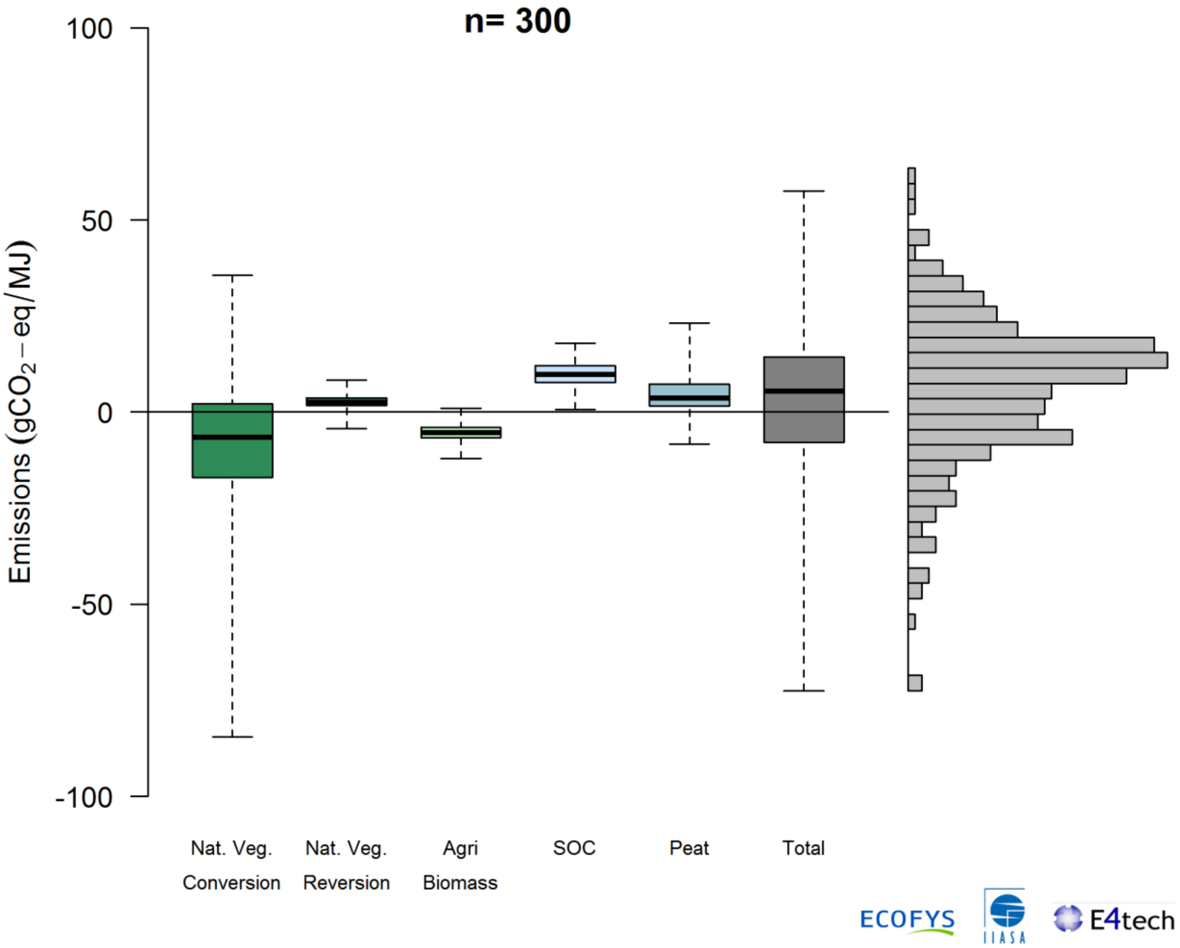
Soil organic carbon

Peat land drainage

Sum of contribution

V.2 Detailed results per scenario

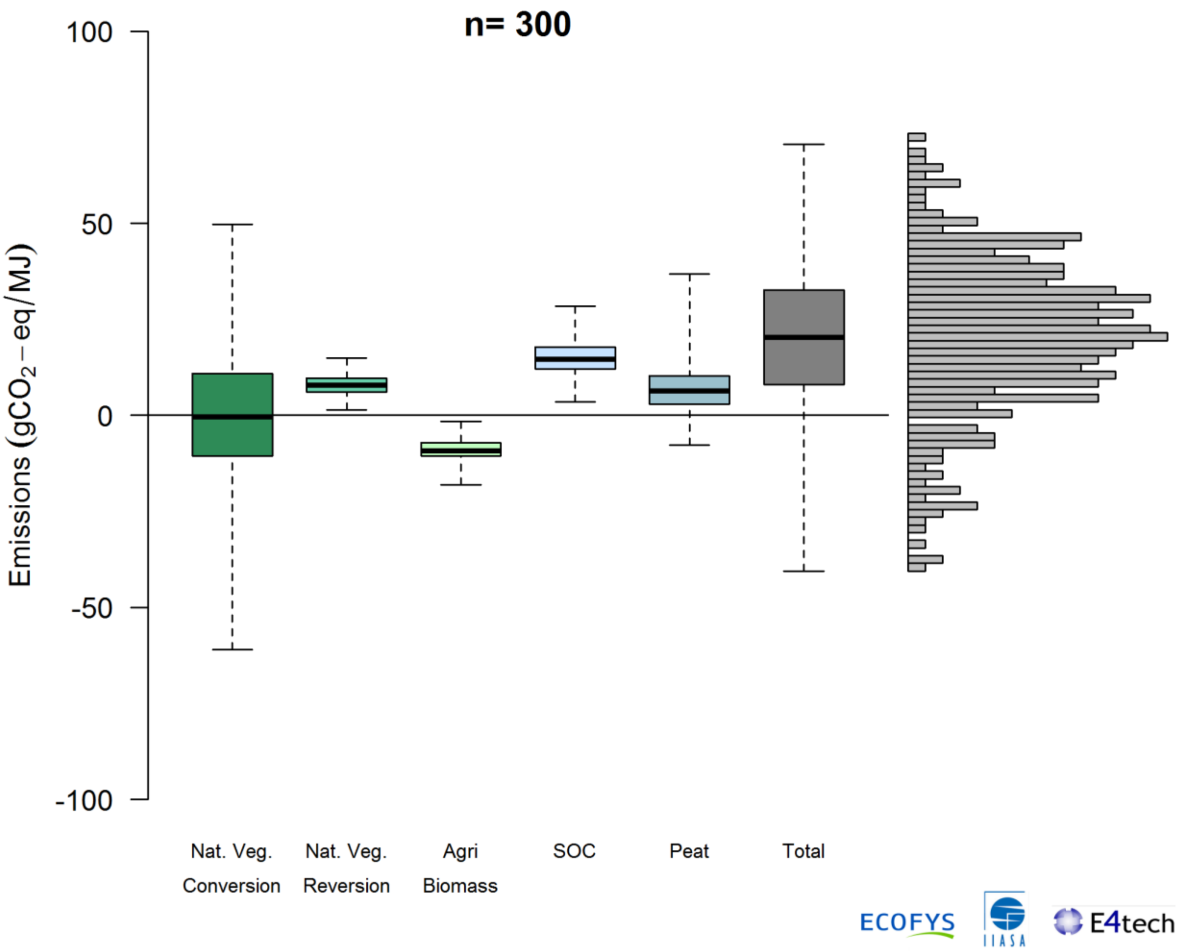
V.2.1 Maize



Uncertainty on emissions associated to maize come mostly from natural vegetation emissions due to the combination of reduction of deforestation in Latin America due to substitution of soybean meal and DDGS, and to increase of palm oil in Southeast Asia to replace soybean oil.

Negative ILUC is observed for a certain number of cases, when a decrease of cropland expansion in Latin America, is not counterbalanced by emissions in Southeast Asia (low substitution of vegetable oil). However, these cases concern only values in the first quartile of the distribution.

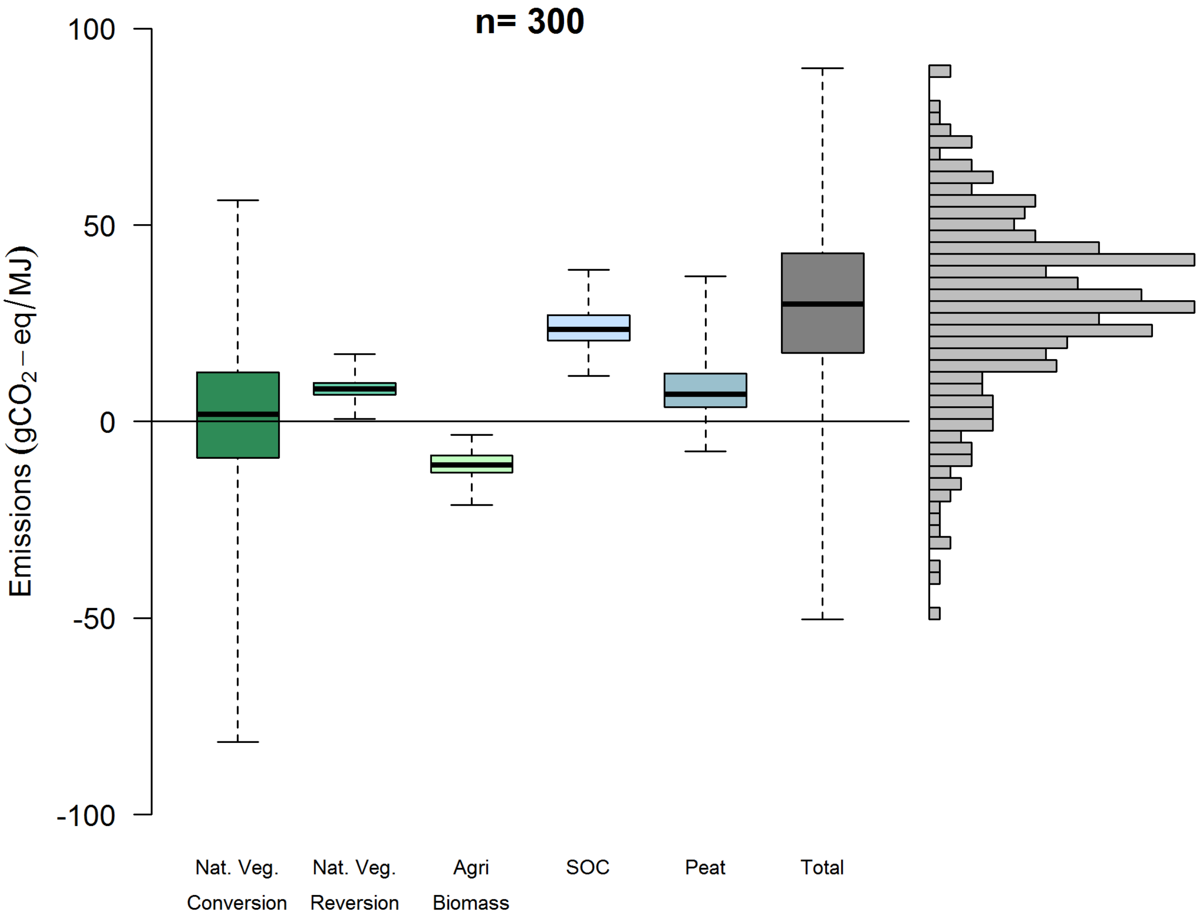
V.2.2 Wheat



Uncertainty on emissions associated to wheat come mostly from natural vegetation emissions due to the combination of reduction of deforestation in Latin America due to substitution of soybean meal and rapeseed meal, and to increase of palm oil in Southeast Asia to replace soybean oil. Effects is slightly higher in the case of wheat than for maize because of the slightly higher protein content assumed for wheat DDGS in comparison to maize DDGS.

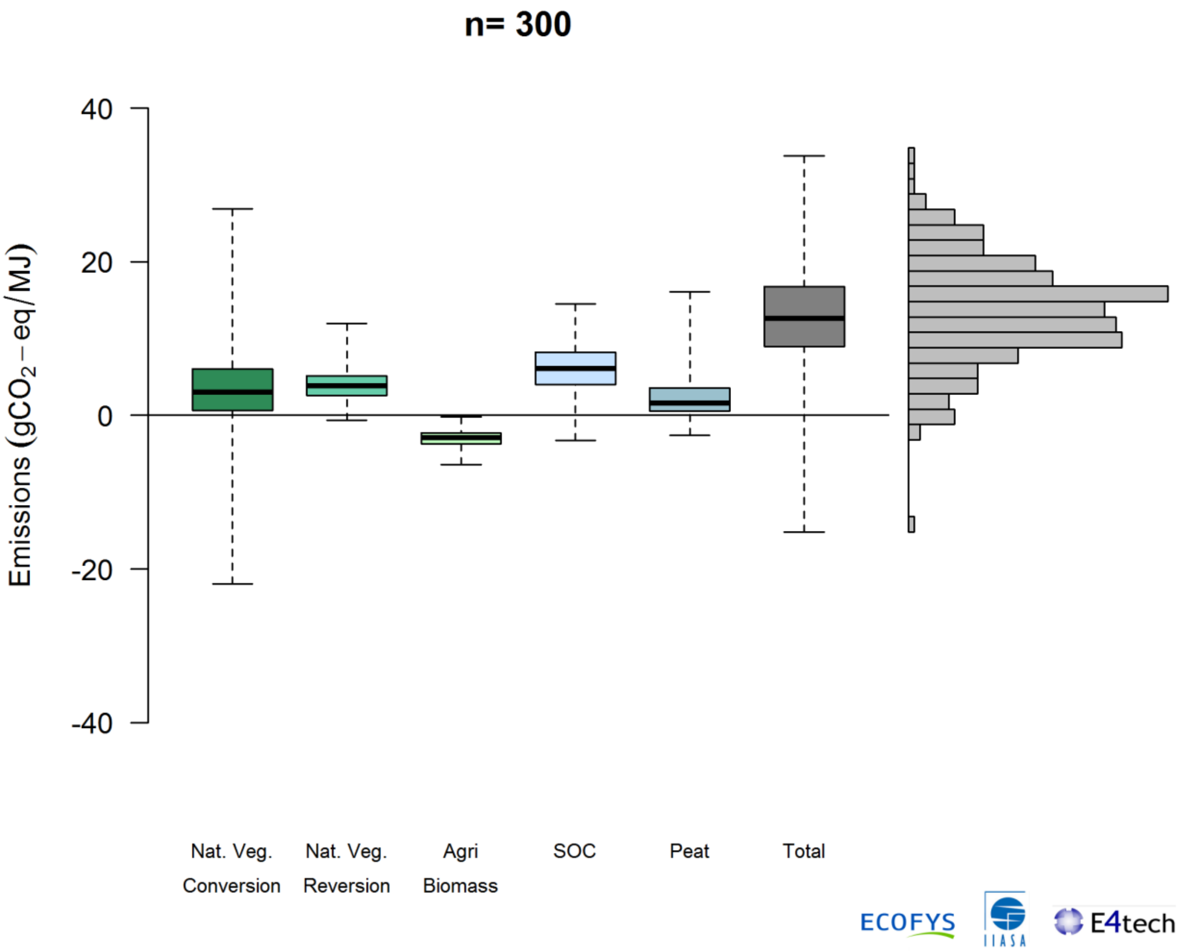
Negative LUC is observed for a significant number of cases, corresponding to decrease of cropland expansion in Latin America. This effect is however often counterbalanced by emissions in Southeast Asia (substitution of vegetable oil). As a consequence, about one third of the distribution correspond to negative values.

V.2.3 Barley



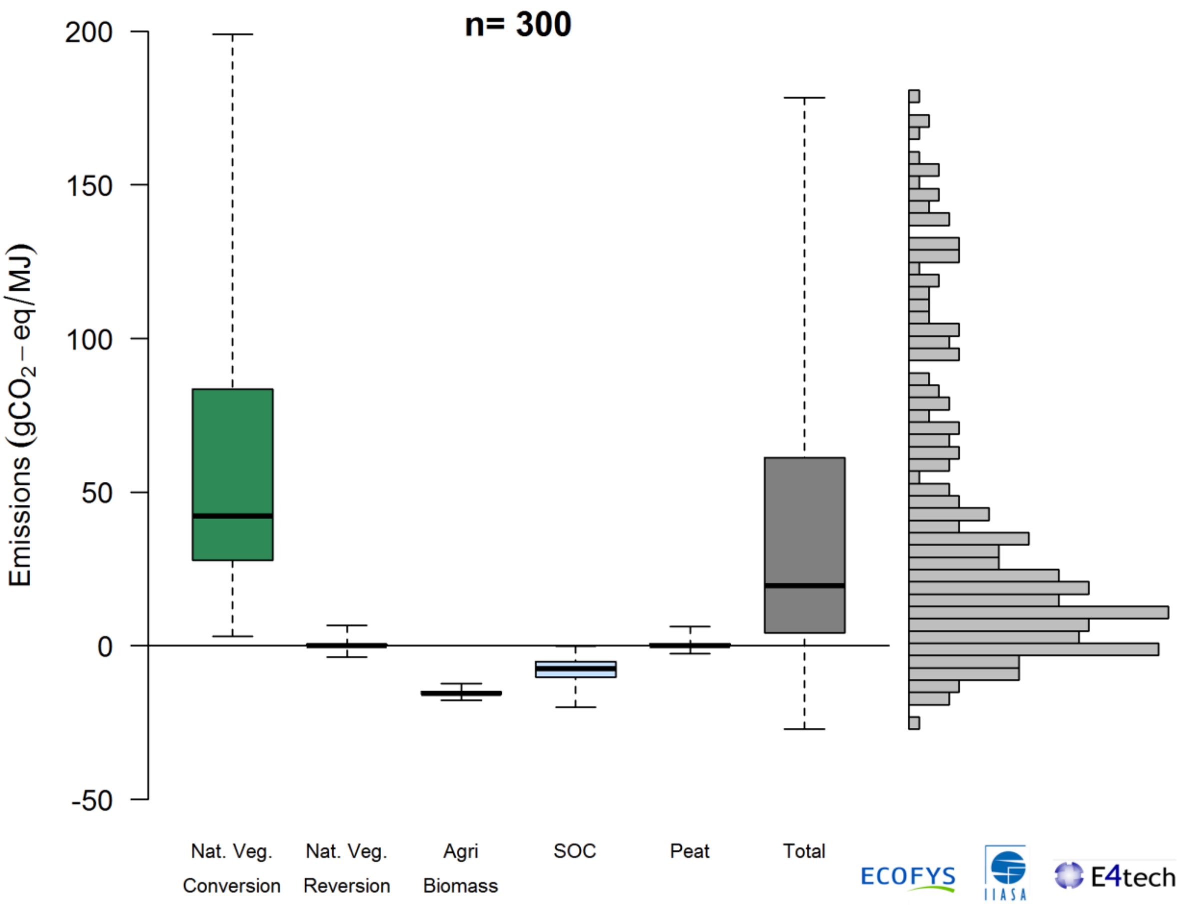
In the case of barley, similar effects are observed as for wheat and maize. Due to the slightly lower yield of barley compared to wheat, emissions are overall slightly higher and the number of negative emission case is reduced.

V.2.4 Sugar beet



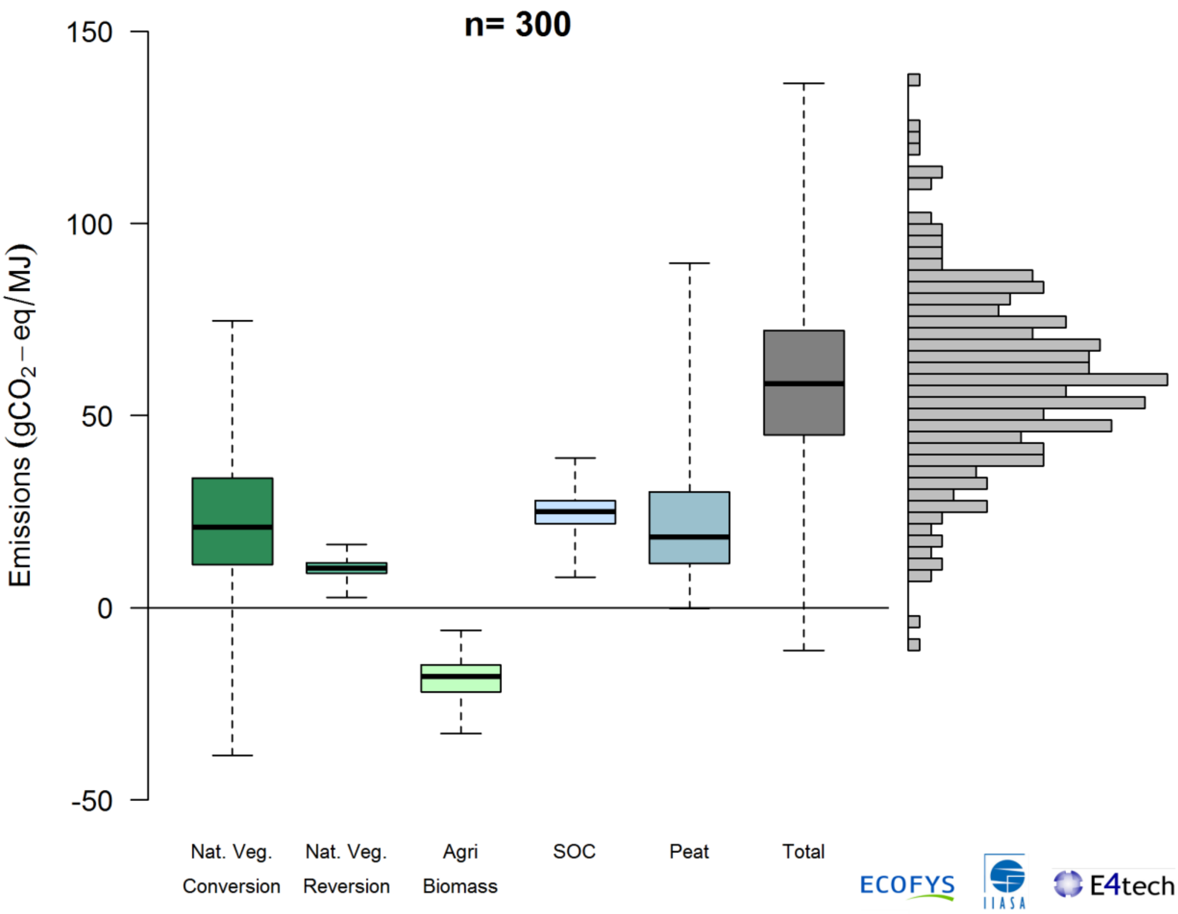
For sugar beet, the main source of uncertainty comes from natural vegetation emissions but these remain relatively limited compared to those of other feedstocks. As a consequence, the distribution is more skewed with a range of values between 0 and 50 gCO_2-eq.

V.2.5 Sugar cane



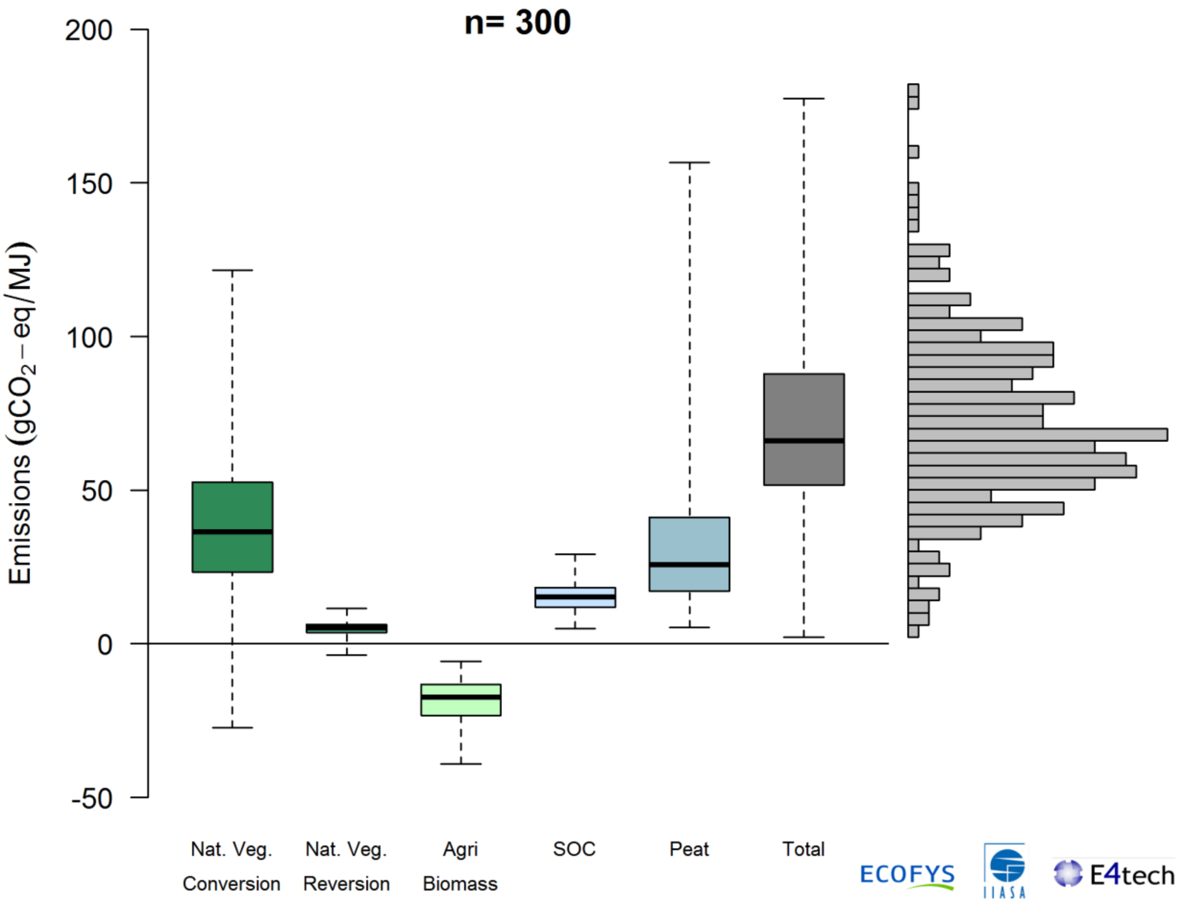
Concerning sugar cane, uncertainty is considerable as soon as behavioral parameters are varied. Indeed, depending on the response of land use, natural vegetation emissions can reach high values. Most sugar cane is located in the South of Brazil in the region of Sao Paulo where agricultural land is well developed and far from the Amazon and Cerrado. However, some other sectors, in particular cattle, are present both in the South and on the agricultural expansion frontier, which can generate some leakage. The possibility of land displacement from the South to the agricultural expansion frontier in Brazil leads to high upper-tail of emissions up to 200 gCO_2-eq. At the same time, if no natural vegetation emission occur, the sequestration effect of sugar cane plantations through agricultural biomass and soil organic carbon can lead to some negative emissions.

V.2.6 Rapeseed



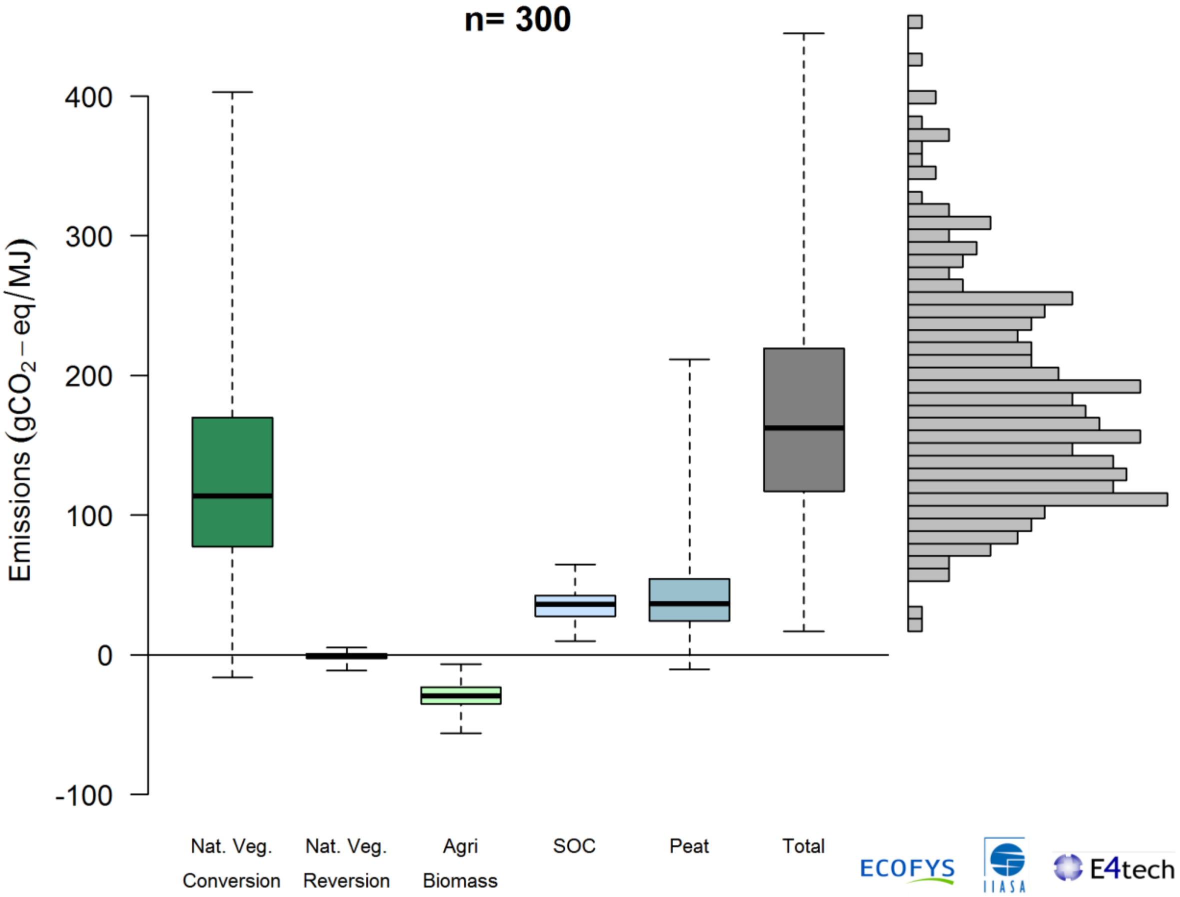
Uncertainty in emissions for rapeseed come mainly from two sources: i) conversion of natural vegetation, directly dependent on the degree of leakage to palm oil on the vegetable market, and on the substitution effect between rapeseed meal and soybean meal; ii) degree of peatland emissions due to palm oil. When combining these two sources of uncertainty, the range of results fall with a symmetrical distribution with most values between 0 and 100 gCO_2.

V.2.7 Sunflower



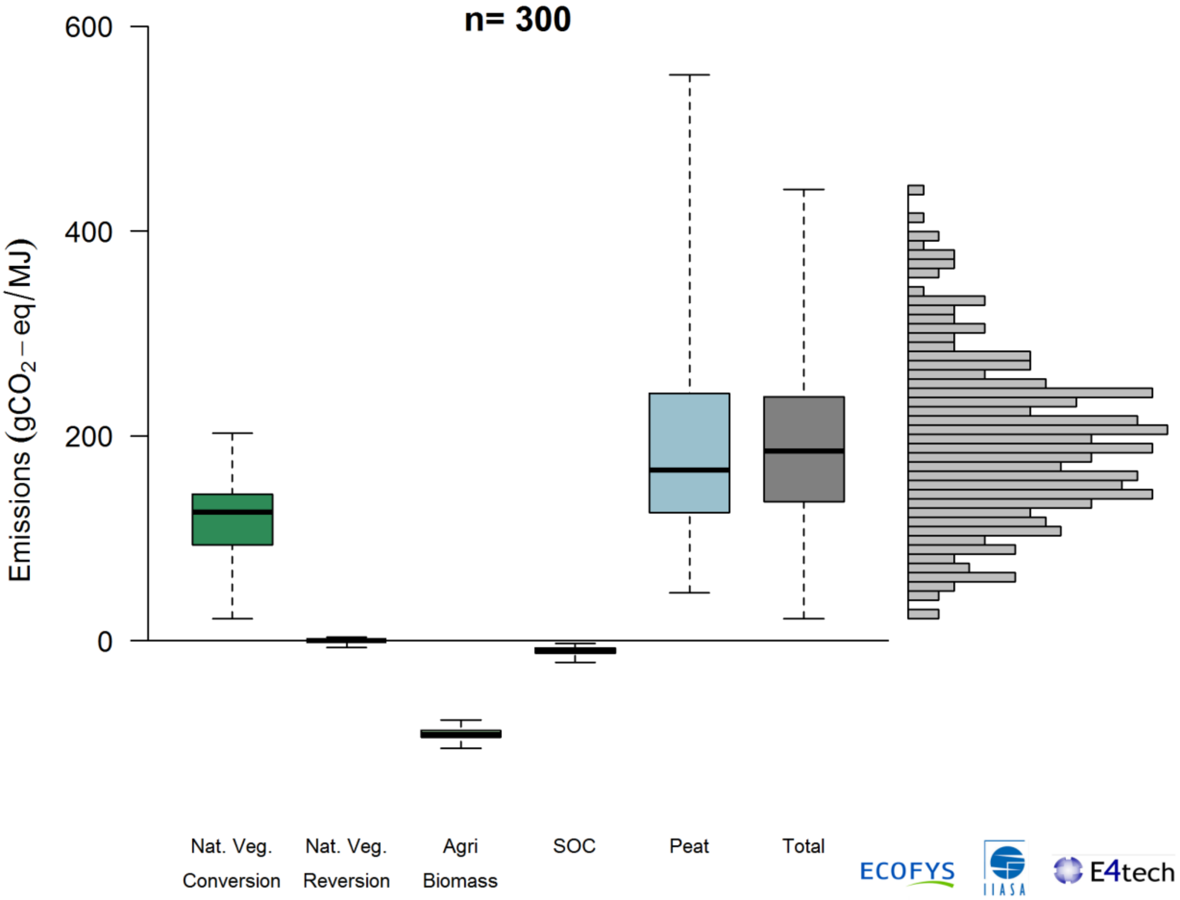
Like rapeseed, sunflower uncertainty is particularly strong for natural vegetation emissions and peatland emissions. Due a lower vegetable oil yield, the distribution is shifted up compared to rapeseed emissions, with a larger leakage to palm oil per unit of energy.

V.2.8 Soybean



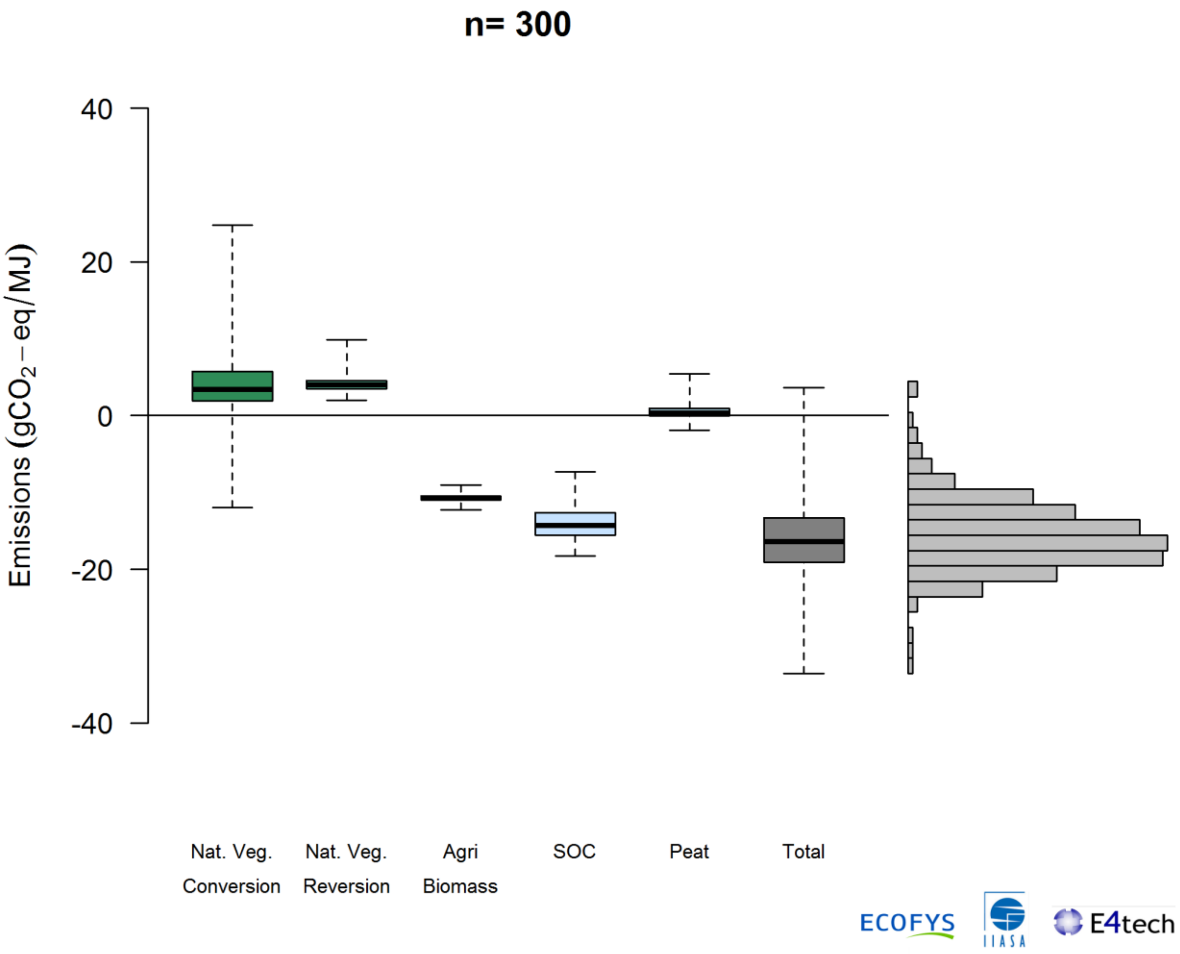
Soybean land use emissions are particularly uncertain on the natural vegetation conversion side. This is due to the various responses that land use can have in Latin America (e.g. from an expansion on the deforestation frontier to a large response through multi-cropping), but also to the low yield in vegetable oil of soybeans. Large uncertainty through palm oil leakage and peatland emissions also participate to a high dispersion of the results. Overall, the range of emissions lead to the central part of the distribution (second and third quartile) in the 50-150 gCO_2-eq range, with a high upper-tail of emissions up to almost 400 gCO_2-eq.

V.2.9 Palm oil



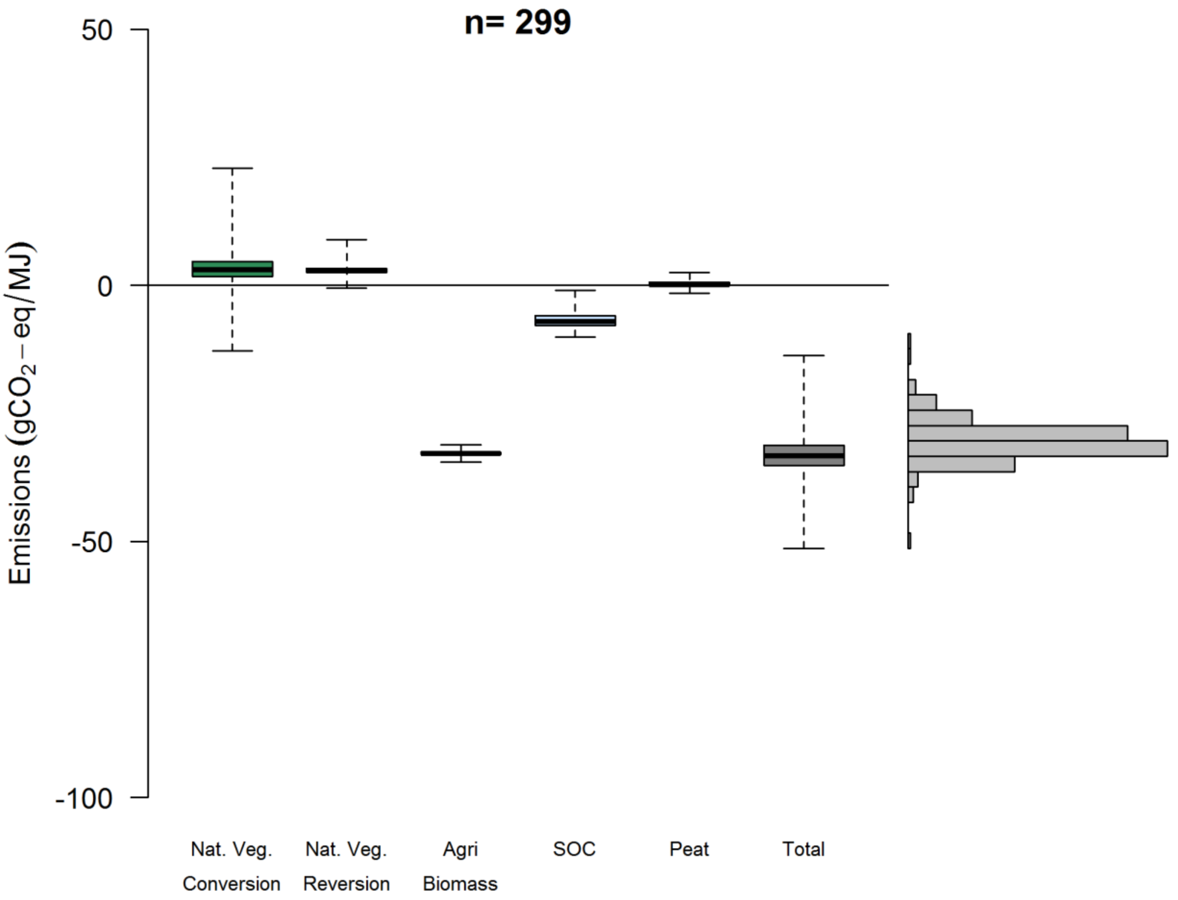
Palm oil emission uncertainty is for a large part associated to peatland emissions, whereas natural vegetation emission uncertainty is found of relatively lower magnitude. This can be explained by the relatively high yield of palm plantations and the fact that not all plantation expansion necessarily lead to deforestation. The final distribution of palm oil emissions therefore directly compares to the one found for peatland emissions in Indonesia and Malaysia. The range is relatively large, from values close to zero to around 500 gCO_2-eq.

V.2.10 Perennials



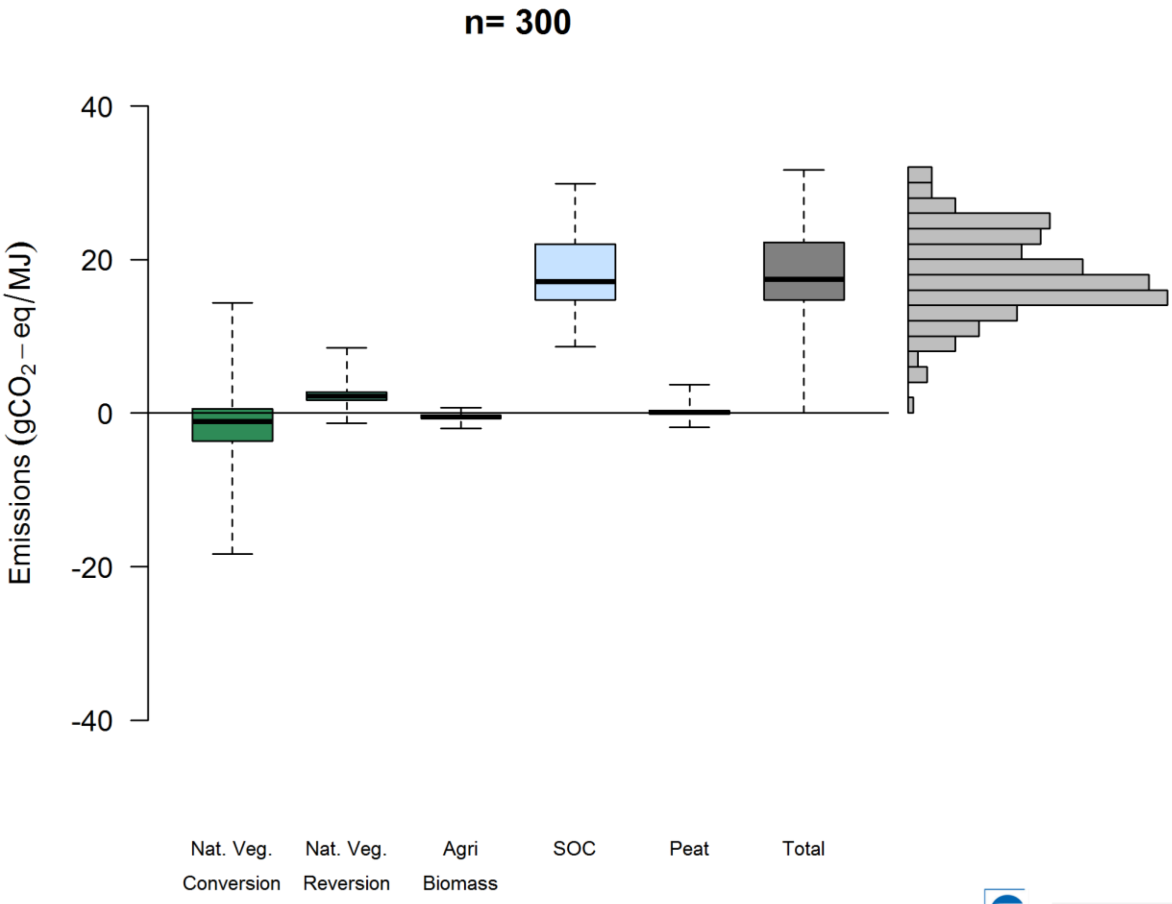
Uncertainty in the case of perennials appears mainly associated to natural vegetation emissions; however this source only has a secondary impact on the final distribution of the results, more impacted by the effect of agricultural biomass and soil organic carbon. Overall results are found to follow distribution with mostly negative values, with minimum around -30gCO_2-eq.

V.2.11 Short rotation plantations



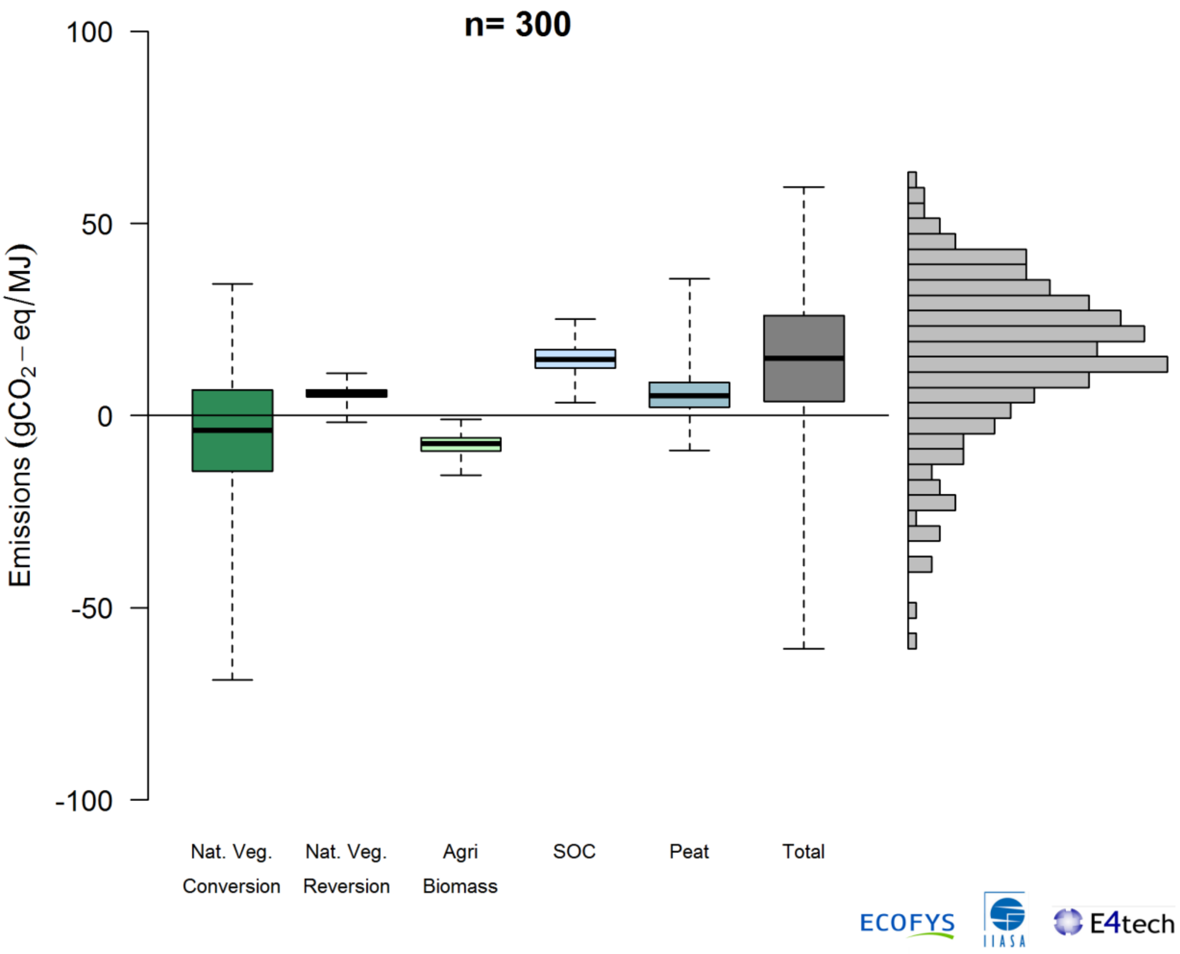
Uncertainty for short rotation plantation is associated mainly to natural vegetation emissions, driven by different patterns of LUC. These however play a secondary role compared to sequestration of carbon in the plantation biomass. Overall, the distribution of results remain negative, with a limited range of results from -40 to -10 gCO_2-eq.

V.2.12 Cereal straw



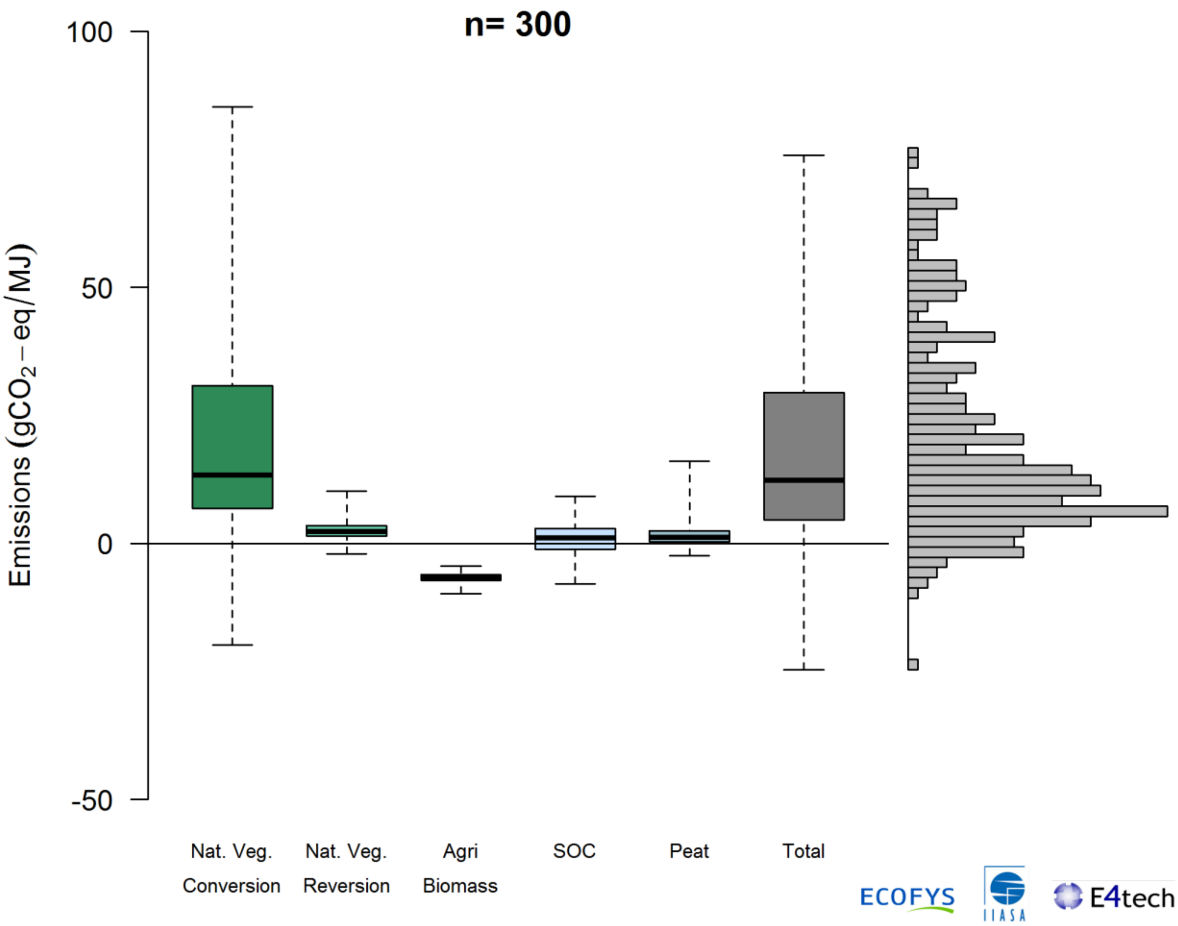
Yield impact also leads to some reallocation of land use with uneven implications for natural vegetation emissions. The largest part of emissions is in the range 0-20 gCO_2-eq.

V.2.13 Starch group



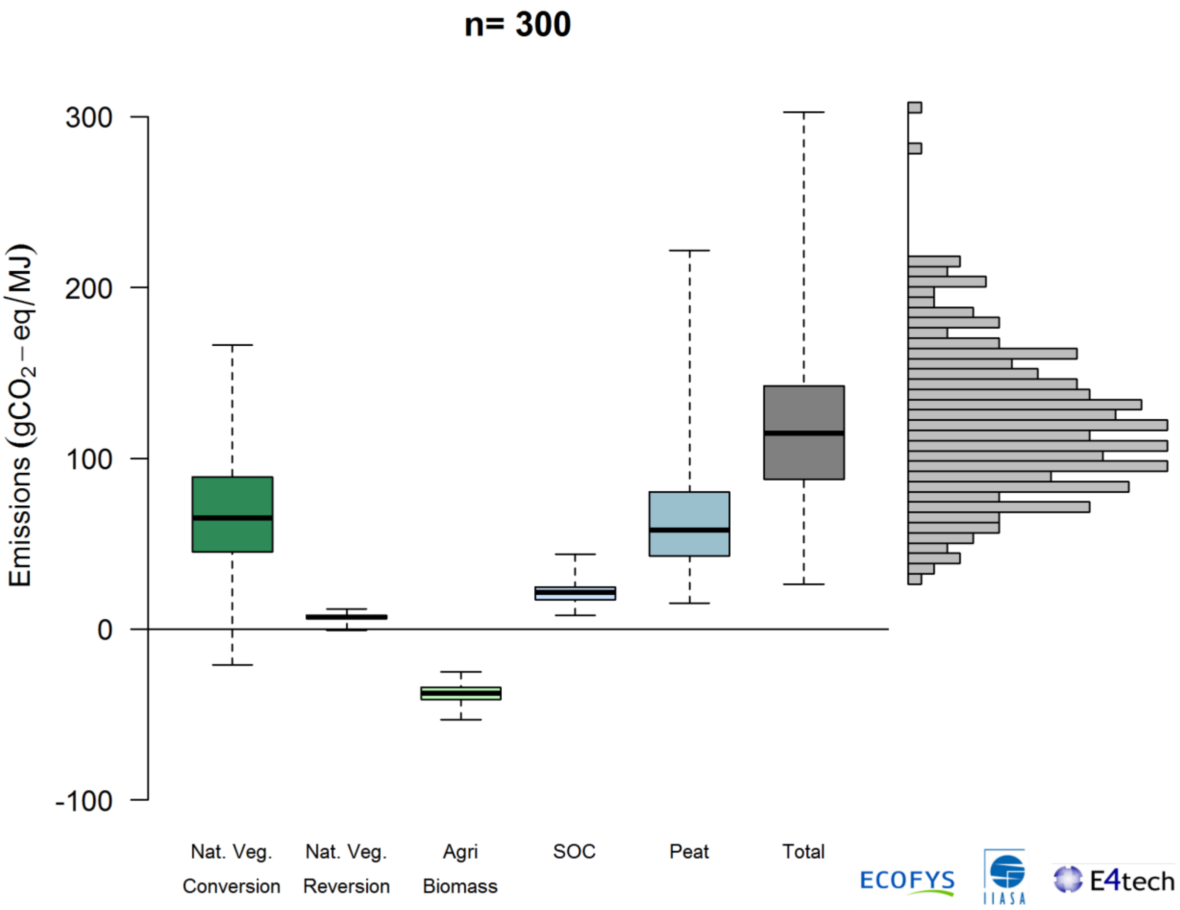
For starchy crops, the largest uncertainty comes from land conversion emissions. Impact of other source participates to the overall level of emission levels, but with lower dispersion. Overall, the second and third quartile of emissions are located in the range 0-30 gCO_2-eq, whereas some negative values can appear for the first quartile of values.

V.2.14 Sugar group



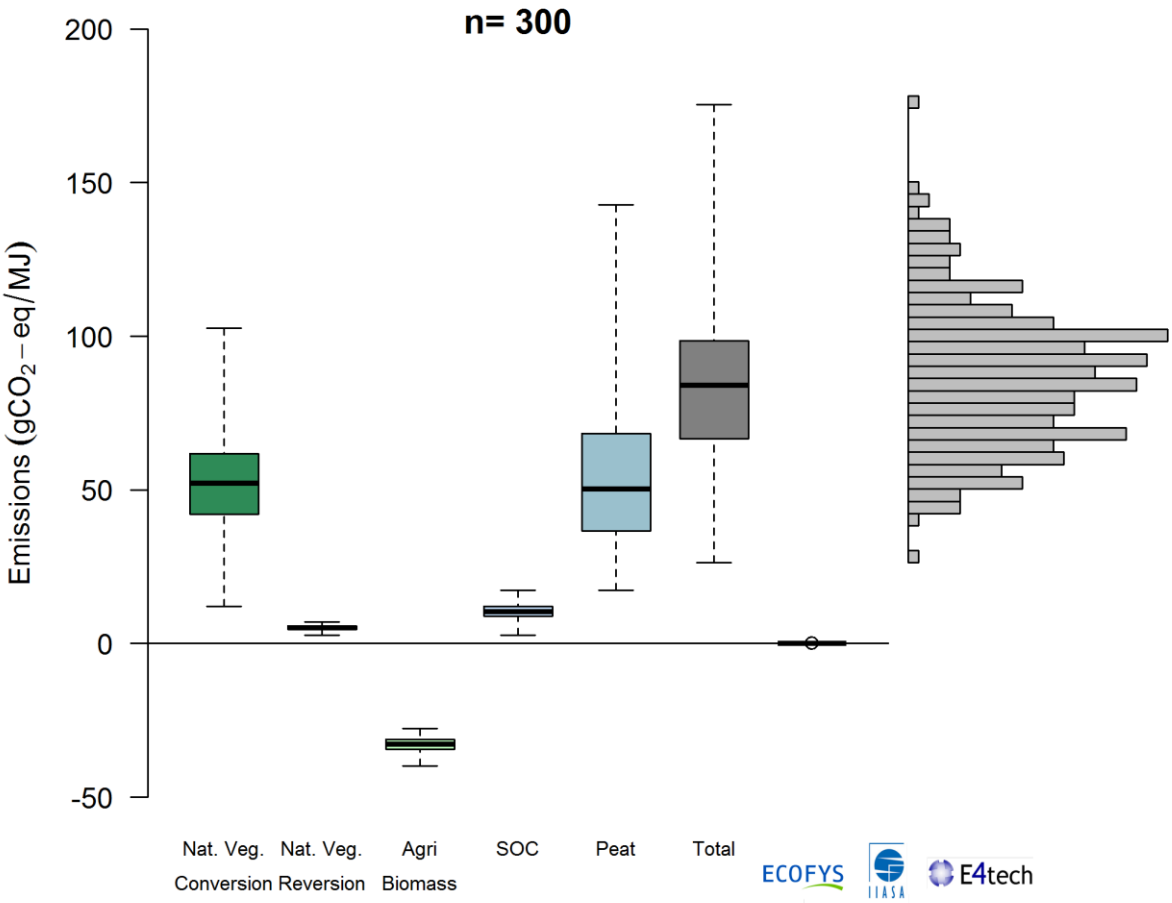
In the case of sugar crops, the results are significantly shaped by the little dispersion of sugar beet emissions, with most of the distribution in the 15-35 gCO_2-eq range. However, due to uncertainty on land use conversion emissions from sugar cane, a upper-tail is found with some possible values close to 100 gCO_2-eq.

V.2.15 Vegetable oil group



Vegetable oil emissions are strongly influenced by the high values found for palm oil and soybean oil. In particular, large uncertainties appear that are related to land use conversion emissions, but also with significant magnitude to peatland emissions. The overall dispersion of the vegetable oil group is therefore relatively high, with most of the distribution higher than 50 gCO_2-eq and some values higher than 200 gCO_2-eq.

V.2.16 EU 2020 biofuel mix scenario



For the EU 2020 biofuel mix scenario, sources of uncertainty come mainly from natural vegetation biomass and peatland emissions, in particular due to the contribution of vegetable oil for biodiesel. The final distribution of effects is quite large, with values ranging from 20 to 150g CO_2-eq.

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