CE Delft
Solutions for
environment,
economy and
technology

Oude Delft 180
2611 HH Delft
The Netherlands
tel: +31 15 2 150 150
fax: +31 15 2 150 151
e-mail: ce@ce.nl
website: www.ce.nl
KvK 27251086

Calculating greenhouse gas emissions of EU biofuels

An assessment of the EU methodology proposal for biofuels CO_2 calculations

Report

Delft, October 2008

Author(s): Harry Croezen
Bettina Kampman

Publication data

Harry Croezen, Bettina Kampman
An assessment of the EU methodology proposal for biofuels CO_2 calculations
Delft, CE Delft, October 2008

Greenhouse gasses / Emissions / Biofuels / Measuring system / LCA / EC / Policy

Publication number 08.3704.46

CE-publications are available from www.ce.nl.

Commissioned by: Greenpeace International.
Further information on this study can be obtained from the contact person Harry Croezen.

CE Delft
Solutions for environment, economy and technology

CE Delft is an independent research and consultancy organisation specialised in developing structural and innovative solutions to environmental problems. CE Delfts solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

For the latest information on CE Delft check out our website: www.ce.nl.

This report is printed on 100% recycled paper.

Contents

Summary

Early 2008, the European Commission published a proposal on renewable energy that included a biofuel target for 2020 and a methodology with which the sustainability of biofuels can be monitored - including a calculation methodology for determining net GHG emissions.

Greenpeace International is closely and critically following these developments and is strongly involved in the discussions regarding this proposal. To support this work, Greenpeace requested CE Delft to draft a report that analyses the GHG methodology proposed by the EC and proposes potential improvements. In addition, three case studies were carried out to illustrate the methodological issues.

We conclude that the GHG emission calculation methodology as proposed is more the start of the development of a methodology than a mature methodology:

- The available inventory of default values is insufficient to allow utilization of the methodology as a tool. Only a very limited number of default values for carbon stocks for ecosystems are available. No default values for GHG emissions related to production and utilization of energy carriers, fertilizers and other auxiliary substances are included.
- A calculation methodology for determining N_2O emissions from soils is lacking or is not specified.
- It is unclear if emissions due to changes in soil organic carbon stocks are taken into account in the EU methodology or how these should be included.
- Indirect land use change is not taken into account, despite increasing evidence that these effects are likely to occur and are very significant, and contrary to existing CDM methodology and future US methodology for determining net GHG emissions for biofuels.
- A questionable allocation methodology - allocation by energy content - is applied for allocation to by-products. This method does not provide insight in effects of by-product utilization on GHG emissions, and thus does not reward or penalize different types of by-products utilization. This may lead to significant errors in the results.
- Several other items that are included in IPCC methodology are not discussed and are probably lacking in the EU methodology proposal, e.g.
  - Way of removal of originally present vegetation in case of land use change (e.g. pile burning) and estimation of extra GHG-emissions resulting from removal (e.g. CH_4 from pile burning).
  - How carbon sequestered in perennial crops (e.g. oil palms, Jatropha trees) should be taken into account.

The proposal should be further developed with respect to the deficiencies mentioned above if it is to become a tool comparable in quality with the IPCC calculation methodology for GHG emissions and the UK and Netherlands GHG calculation tools for biofuels.

We furthermore conclude that a generic and relatively simple GHG emission calculation tool will probably always be too crude an instrument to produce a reasonably accurate estimation of GHG emissions. Uncertainties will always be significant.

Alternative policy options would be:

- A ‘no regret’ short list with respect to cultivation site, utilizable crops, cultivation practice, conversion technology, etc.
- A GHG calculation tool with a conservative approach to include intricately determinable emissions, such as indirect land use change.

No regret short lists could be for example:

- Only permanent grass lands, set aside land, degraded land and agricultural area previously taken out of production for economic reasons at specifically defined locations c.q. coordinates.
- Only second crop yield of cereals, cassave or sweet sorghum based double cropping systems.
- Only anaerobic digestion and comparable conversion processes that allow recirculation of nutrients and yield maximum energy efficiency in conversion.

Existing examples of reports containing a no regret short list are:

- The EEA report ‘How much bioenergy can Europe produce without harming the environment?[1]’.
- The Gallagher review.

A conservative approach in GHG calculation tools might be for example to always assume maximum GHG-emissions due to indirect land use change, unless one can prove the contrary.

---

[1] http://reports.eea.europa.eu/eea_report_2006_7/en/eea_report_7_2006.pdf

1 Introduction

1.1 Introduction

Early 2008, the European Commission published a proposal on renewable energy that contained, among other things, a proposal on a biofuel target for 2020 and a methodology aimed to monitor and ensure biofuels sustainability. The latter included a methodology proposal to calculate the greenhouse gas emissions of biofuels, defaults values of GHG emission savings for various biofuels and a requirement for a minimum GHG emission saving in order to count towards the target.

Greenpeace International is closely and critically following these developments and is strongly involved in the discussions regarding this proposal. To support this work, Greenpeace requested CE Delft to draft a report that analyses the GHG methodology proposed by the EC and proposes potential improvements. In addition, the methodological issues should be illustrated by applying LCA methodology on three specific biofuel cases that have so far not received much attention in the EU: biodiesel based on soy and palm oil and ethanol from maize.

1.2 Purpose of this report

The aim of this report is threefold.

- It should provide background knowledge on the LCA analysis of biofuels, explaining the various methodological choices and assumptions and illustrating their impact on results.
- It should assess the LCA methodology proposed by the EC, resulting in an overview of potential improvements.
- It should illustrate the issues of LCA methodologies with three specific cases: biodiesel based on soy and palm oil and ethanol from maize.

The first point is addressed in the next chapter, the second in chapter 3. The case studies are described in the annexes of this report.
Chapter 4 then provides a discussion on the potential role of LCA's in biofuels policy, followed by chapter 5 which contains conclusions and recommendations.

2 Determining GHG emissions the LCA-way

2.1 Introduction

The greenhouse gas (GHG) emissions of biofuels are generally calculated applying the methodology of Life Cycle Analysis (LCA), a methodology based on the ISO 14040 LCA standards.

The net GHG reduction per unit fuel is determined by comparing GHG emissions related to biofuels production and utilization with conventional diesel and gasoline production from mineral oil *and* the emissions related to reference land use. The LCA methodology gives rules:

- On what to compare (system definition).
- On default values to use for various processes and resources/products used, and a methodology on how to make emissions of different substances comparable and aggregatable under the same denominator[2].
- How to divide or otherwise manipulate emissions, e.g. when a process yields more than one product (calculation rules).

These three items are further discussed in the following.

2.2 System definition

2.2.1 Biofuel system

For biofuels, the system includes every process from crop cultivation to the final consumption of the derived transportation fuels in a car (seed-to-wheel).
Cultivation often gives the most important contributions to total system GHG emissions. Emissions related to cultivation include:

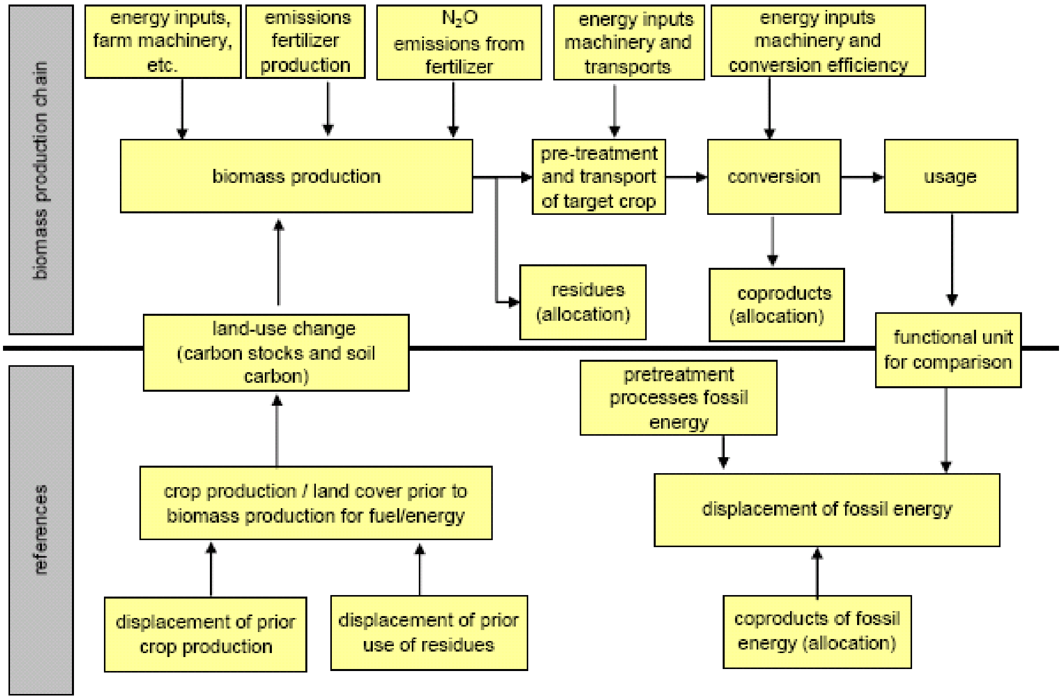
- N_2O from nutrients and manure.
- Net CO_2 (and N_2O) balance for oxidation of organic material in soil or on the contrary CO_2 fixation by build up of organic material in the soil due to changes in intensity of soil tillage compared to reference land use[3].
- If relevant, CO_2 fixation by build up of vegetation (in case of perennial crops, such as palm oil trees) or release of CO_2 by net removal of vegetation compared to reference land use.
- CO_2 from agricultural machinery.
- The emissions related to the production of fertilizers and other additives applied in cultivation.

---

[2] In the case of biofuels related GHG emissions, the various greenhouse gas emissions N_2O, CH_4, CO_2 are typically aggregated to one common denominator (CO_2 equivalents).

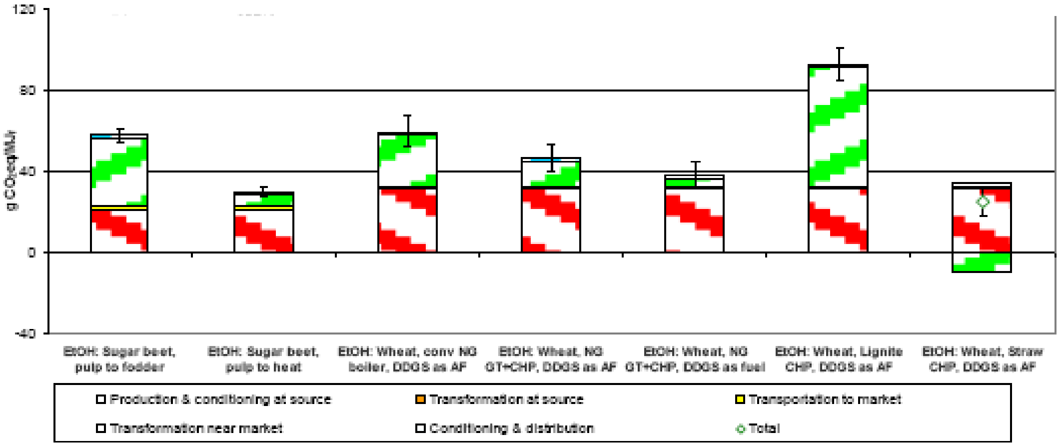
[3] Carbon stock decreases when vegetation is removed and previously undisturbed or extensively tilled soil is intensively tilled for biofuel feedstock crop cultivation (because more organic material in soil is exposed to air). Carbon stocks increase when extensivying tillage and when vegetation volume increases.

Figure 1 Bio-chain and fossil reference chain for GHG calculations



For ethanol the production of ethanol from the crop also gives high emissions due to fuel consumption in the production process.

Figure 2 Example of built up of GHG emissions related to ethanol production[4]



Source: JEC, 2007.

---

[4] Red bars = cultivation, green bars = fermentation and distillation.

2.2.2 Reference situation

The biofuel systems need to be compared to a realistic reference system, in which the biofuel would not be produced. The reference systems thus entail the fossil fuel system that is replaced by the biofuel.

For conventional, mineral oil based transportation fuels the system includes everything from pumping up the crude oil to the final consumption of the derived transportation fuels in a car. Hence the expression (oil) well-to-(car)-wheel analysis. Most important contribution to total GHG system emissions is the combustion emission from the gasoline or diesel itself (typically about 85% of the total emissions).

Because the land utilized for cultivation of biofuels feedstock crops was used for other purposes in the reference situation, emissions of CO_2 fixation from the original application will also have to be taken into account. This may be forest, idle land, natural grassland land, pasture, fields, etcetera. Emissions to be taken into account are CO_2 and N_2O emissions related to nutrients cycles. CO_2 and N_2O emissions from changes in vegetation and soil carbon stocks have already been mentioned.

The cases described in the annexes illustrate that the type of soil in the reference situation may have a strong impact on the results of the LCA, i.e., on the GHG emission savings achieved with a biofuel. Tropical rainforest, for example, contains large quantities of organic matter, both above and below ground, that are partly released as greenhouse gas when it is converted to a plantation. Set aside or grass land, on the other hand, will lead to much less emissions when converted to agricultural land for biomass production.

2.2.3 The issue of indirect land use change

A third item that - according to LCA ISO 1040 scientific standards - should also be taken into account is possible indirect land use change.

Biofuel feedstock crops could be cultivated on set aside land or land taken out of production because of overcapacity or because food or feed crop cultivation on this area was uncompetitive. These are likely scenarios for part of Europe’s biofuel feedstock cultivation.

Biofuel feedstock crops cultivation can however also take place on previously productive agricultural land.

Changing utilization of an agricultural field from food cultivation into biofuel feedstock crop cultivation does not mean requirement for food declines. The food production will merely be displaced to another area[5]. Unless existing agricultural production is enhanced proportionally, this may very well mean that the food is now cultivated on other land, possibly forest or grassland converted into agricultural land. This is called indirect land use change.

---

[5] Productive agricultural land becoming available due to increases in food and feed crop productivity are already mentioned in the previous paragraph (idle and set aside land).

The associated effect of indirect change from forest or grassland into agricultural land is release of CO_2, CH_4 and N_2O from vegetation removal and soil disturbance.

The emissions due indirect land use change can currently not be quantified reliably, although several attempts have been made recently (see for example Searchinger, 2007; Gallagher, 2008 or the German Risk Adder approach).

2.3 Calculation methodologies and defaults for standard processes

The LCA standards require determining a large set of emissions. Fortunately, defaults and standard calculation methodologies offer readily applicable and standardized information:

- The IPCC 2006 methodology can be applied for calculation of land use related GHG emissions (CO_2 and N_2O from soil, N_2O from nutrients, etcetera). It is the standard methodology used by all countries around the world for reporting national GHG emissions to the UN (more precisely, UNFCCC).
- The IPCC 2006 also provides default emission factors for fossil fuels.
- Soil related emissions (N_2O from fertilizer/manure and CO_2 and N_2O from oxidation of organic material in soil) can also be calculated applying biogeochemistry models for agricultultural ecosystems, such as DNDC, applied in JEC (2007).
- Most government initiated GHG calculation methodologies for biofuels include default emission factors for fossil fuels, standard processes and agricultural.

But it is free for every GHG balance conductor to use his own set of emission factors as long as the factors concur with LCA ISO 14040 standards.

2.4 Allocation of by-products

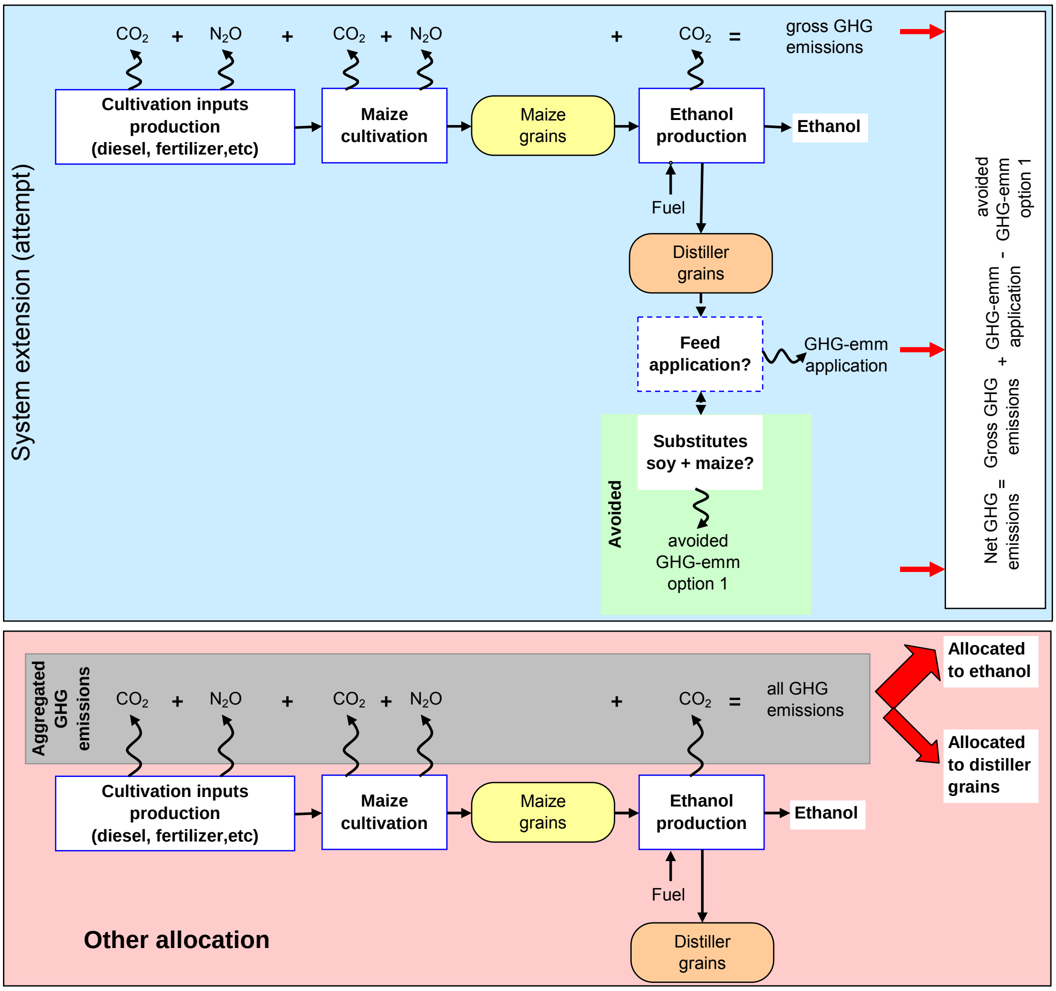
Crops are a complex combination of various components (sugars, proteins, fats) and physical or biological processing into biofuels often gives significant amounts of useful by-products, e.g. pulp from sugar beets or press cake from rape seeds.

How to take by-products into account can differ in two aspects:

- The appraisal of these by-products, expressed in the applied methodology by which part of the environmental impact related to crop cultivation and biofuels production is allocated to these by-products.
- The considered application of these by-products.

The environmental impact of utilizing the by-products - and substituting primary products in the process - may be taken into account. This is called the system extension methodology. Alternatively, an allocation methodology can be applied in which the GHG emissions in the product chain are allocated to by-products and biofuel in accordance with some distribution formula.

Figure 3 How different allocation methodologies work



By-products? An example

If for example maize grains are used as a feedstock for ethanol production a by-product called distiller grains with solubles is also produced. Maize grains contain high percentages of starch, but also cellulose and hemicellulose, proteins, fats, ash, sugars and lignine.
In ethanol production the sugars and starch are extracted from the grains and converted into ethanol. The remainder of the grains is called distiller grains.

This by-product could be:

- Applied as feed.
- Converted into biogas and peat substituting digestate by anaerobic digestion.
- Or used as a solid fuel.

As a feed the distiller grains will compete with c.q. substitute protein rich oilseed meals such as soy meal. Biogas will be utilized as a fuel, substituting fossil fuels (probably natural gas) and the digestate will probably be applied as soil structure enhancer - an application for which in any case in the Netherlands imported peat is utilized. In utilization as a fuel the distiller grains are likely to substitute fossil fuels.

System extension

In system extension the distiller grains is followed and it is estimated what the most likely application would be. An assessment is made of what the by-product will substitute in the assumed application and the associated net GHG emissions related to that application are estimated.

Other forms of allocation

In other allocation methodologies the GHG emissions related to the cultivation of maize and the subsequent processing of the produced grains is simply divided between ethanol and by-product according to some distribution formula.

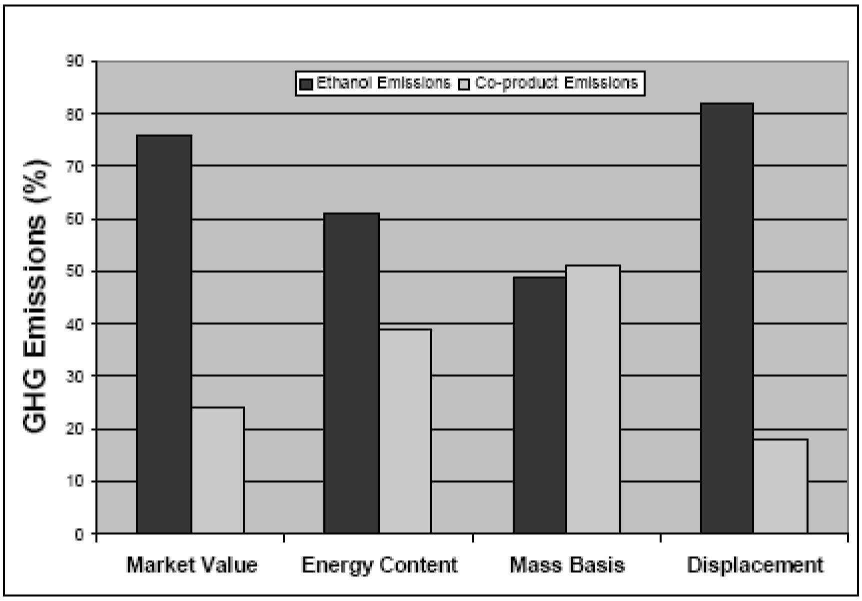
The distribution formula is generally based on physical or economic product characteristics such as energy content, mass or market value. Considering the latter as an example for how allocation works: if the financial value of the distiller grains is 30% of the total income (and ethanol would account for the remaining 70%), 30% of the GHG emissions related to maize cultivation and ethanol production is allocated to the by-product.

Comparison

System extension is generally considered to be the most accurate methodology (ISO 14040 standards). However, allocation is usually easier to implement, as the data required for this route are generally much easier to gather. Of the different possibilities for allocation economic allocation is considered the most representative (ISO 14040 standards).

Mass and energy based allocation tend to give quite different GHG emission reductions for biofuels than system extension and economic allocation as illustrated by Table 1 and Figure 4.

Figure 4 Example of the impact of different allocation methods



Source: ARB, 2007, for ethanol from dry milled maize.

The figures in Table 1 are taken from the proposal for the EU Renewable Energy Directive and give for system extension percentages for both feed application and application as energy source of by-products. In current practice the by-products are mainly applied as feed, this giving the highest extra income for the biofuels producer.

Table 1 Indicative GHG emission reductions for various biofuels systems (EU, 2008)

	Rapeseed biodiesel	Sunflower biodiesel	Sugar beet ethanol	Wheat ethanol, n.g.[6] boiler	Sugar cane ethanol
System extension, feed	38%	64%	31%	29%	
System extension, energy	69%	86%	65%	40%	88%
Mass allocation	60%	69%	60%	57%	77%
Energy allocation (EU proposal)	**44%**	**59%**	**49%**	**45%**	**77%**

Note that in these figures emissions due to indirect land use change - e.g. avoidance of land use change for primary feed cultivation - have not been included.

These examples show that energy content based allocation tends to allocate less GHG emissions to the main product than market value allocation, resulting in lower GHG emissions and thus higher GHG savings. System extension results depend quite strongly on the by product use, as can be seen in Table 1.

Effects of by product use on GHG emissions

System extension may be most desirable from a scientific point of view, it is also the most difficult methodology to apply because of the question for what purpose the considered by-products will be applied in practice and what exactly they will substitute in that application. This is not always straight forward.

The by-products of biofuel chains can often be used for various different applications, for example, for animal feed or for energy generation. These products then replace other products (e.g. grain or natural gas), that would have also caused GHG emissions. The emissions thus prevented by the by-products should be accounted for in the biofuel LCA. LCA results therefore depend on the assumed use of the by-products.

But even within a specific application there is a spread in the avoided environmental impact resulting from by-products utilization. For protein rich by-products applicable as feed and produced within the EU for example it is generally accepted within the LCA field that utilization as feed results in avoiding soy meal utilization.

But the question then becomes ‘what kind of soy meal is replaced, average or marginal’? Average meal refers to global soy meal production, both in the USA

---

[6] N.g. = natural gas.

and in Latin America[7]. Average meal is largely produced on existing agricultural area, e.g. long established agricultural land in the USA.
However, it could also be argued that the protein rich by-product competes exclusively with marginal soy meal, since it is ‘freshly’ being introduced on the feed market - thereby covering increased demand for protein feed. Marginal soy meal is soy meal being produced in Latin America on newly created agricultural fields: created by deforestation or on pasture becoming available because cattle farmers are moving into the remaining rain forest. The difference in environmental impact between average and marginal soy meal is therefore very significant[8].

2.5 Land use change emissions: years of allocation

As discussed before in section 2.1 and 2.2 greenhouse gas emissions can occur due to land use change (LUC), for example conversion of grass land or rain forest into agricultural land or a palm oil plantation. These LUC emissions can be due to both direct and indirect land use change, and LUC emissions may range from very significant (more than cancelling out any GHG emission savings of the biofuel) to negative, i.e., LUC may lead to carbon sequestration.

When these LUC emissions occur, it has to be decided how to include them in the LCA analysis of the biofuel. A significant part of these emissions may occur in a very short time span, when the existing vegetation is removed and the soil is prepared for its new crop. The remaining emissions may be released during the first years or perhaps decades of the new plantation, depending on the agricultural practice and the land type. An important issue is the question of how these emissions are allocated to the biofuels that are produced on this land.

IPCC chooses to allocate these LUC emissions to the biofuels production on that land in 20 years (irrespective of the question whether the land is indeed used for biofuels in that time period). In other words, 1/20th of the LUC emissions are to be added to the biomass harvest in one year. Different time periods are, however, also used by various researchers. Obviously, the longer the time period chosen, the lower the LUC emissions allocated per tonne or GJ biofuel.
Greenpeace demands application of a period of ten years. Applying such a period in combination with a high reduction target for GHG emissions compared to conventional automotive fuels is to be understood as a demand that utilization of biofuels does not result in significant degradation of vegetation and soil organic carbon stocks. With such a short period for distribution LUC related GHG emissions will render it very difficult to have a significant reduction in vegetation and soil organic carbon stock and still achieve a high reduction in GHG emissions.

---

[7] Though there are other regions where large amounts of soy are produced - e.g. China - the USA and Latin America are the sole exporters of soy beans and soy meal to third countries, including China.

[8] In JEC (2008) a similar example is given for marginal production of wheat and soy in Australia.

The choice of depreciation period can not readily be based on a scientific argument. 20 years could be considered typical for some plantations, but there is no guarantee that the land will indeed be used that long for biofuels production. One might argue that a longer time period would be realistic: looking at the deforestation in the EU in the past, we can see that the land is still used as agricultural land several centuries later. However, on the other hand, one can argue that large emissions in the short term will directly enhance the greenhouse effects in the coming decade, increasing the risk of negative effects in the coming decades. They will also make effective climate policy in the coming decades more difficult - emissions reductions need to be higher in order to reach a desired ppm level in the atmosphere - and more expensive.

2.6 Variations between biofuels

As many biofuel LCA studies show, there is a large variation between biofuel routes, even if they address the same type of biofuel. For example, bioethanol from maize may lead to very different GHG savings than from wheat, sugar beet or sugar cane. There can even be a large variation between biofuels from the same biomass source, depending on, for example, agricultural practice and region, process efficiencies and fuels and by product use.

The actual emissions from a relatively well defined biomass-to-biofuel route (such as ‘bioethanol from maize’) can thus vary significantly between different batches.

3 Assessing the EU methodology

3.1 The EU methodology in general

The GHG calculation methodology included in the EU renewable energy proposal concerns a proposal for a systematic way of calculating the net GHG emissions related to biofuels. It seems partly based on the well-to-wheel study conducted by Edwards et al., but it differs significantly in some aspects, primarily several methodological choices.

Our first impression of the current methodology included in the proposal is that it is more the start of the development than a fully developed methodology:

a The methodology includes only a limited number of the default values required to calculate GHG savings of biofuels. It only provides:
  - The average specific GHG emission related to the production and utilization of mineral oil based gasoline and diesel.
  - Global average and very rough sizes of carbon stocks in wet ecosystems (on peat soil), forest, grassland and agricultural area (686, 275, 181 and 82 tonnes C/ha respectively)[9].

  Other GHG emission factors and specific emissions for e.g. industrial processes, fuels and fertilizers are lacking.

b No calculation methodology is included for e.g. calculation of N_2O emissions, calculation of CO_2 and N_2O emissions from soils or net CO_2 emissions related to changes in vegetation. N_2O emissions should be taken into account (and we would expect that they are, in the GHG emission savings that are given in the proposal), but it is not clear how this should be done. Should one use IPCC methodology, apply the specialized DNDC biogeochemistry model or use some other methodology (see also next subparagraph)?

The current methodology as included in the EU renewable energy proposal therefore does not allow for the standardized and systematic calculation of net GHG emissions for biofuels. It furthermore does not provide sufficient information about the methodology used to calculate the biofuel default values that were proposed.

In comparison, the national GHG emission calculation tools for biofuels developed in the Netherlands, UK and Germany include an extensive set of default emission values and calculation methodologies. They also recognize the large variation in processes and emissions between various routes, and provide conservative, typical and best practice default values. Biofuel producers then

---

[9] Carbon stock default values in reality show a very large variation between different ecosystems belonging to the same category. For forests for example carbon stocks in aboveground vegetation range from 164 tonnes C/ha for tropical rainforests in insular Asia to 56 tonnes C/ha for average European forests (IPCC, 2006). Using the globalised average values provided in the methodology may thus result in significant errors (both positive or negative) in the results.

have to prove that they perform better than and are in their current shape far more applicable for GHG emission calculations than the currently proposed EU methodology.

3.2 Allocation

Next to this in the proposed EU methodology energy content based allocation for co-product appraisal is applied. Here, the methodology clearly deviates from the ISO 14040 standards preference and from the appraisal methodologies applied in the national GHG calculation methodologies developed in Netherlands, UK, Germany and USA (see ARB, 2007).

Energy content based allocation has the advantages that it is easily applicable, and provides results that do not change over time (as may happen in the case of substitution or market value allocation. However, energy content based appraisal is a scientifically less valued methodology, for the following reasons:

- Energy content based allocation tends to allocate less GHG emissions to biofuels than system extension, thereby giving 5-20% higher GHG emission reductions for biofuels than system extension methodology (see e.g. ARB, 2007). In a proper, peer reviewed LCA this discrepancy in results due to methodological choices would have to be explained thoroughly. As the complexity of system extension is not viewed as an obstacle for applicability in the USA and several EU member states, making the methodological choice by the EU less easily explainable and defendable (see e.g. ARB, 2007).
- Not considering by-products utilization also means loosing sight of and not being able to take future responsibility for part of the effects caused by EU biofuels policy. This approach is contrary to good stewardship.
  Note that these effects need not be negative by definition. For example, protein rich by-products from rape, sunflower and cereals (Distiller Grains) might compete on the feed market with marginal soy meal cultivation - an increase of by product availability will then reduce soy meal demand and thus reduce the current growth in soy production. In general an increase in soy production in Latin America (where most of the soy consumed in the EU originates from) is partly covered by creating more cropping area by deforestation. So increases in soy consumption within the EU is likely to partly result in deforestation in the Amazon region. By-products utilization within the EU livestock sector as protein source might in other words partly mitigate deforestation in the Amazon (CE, 2008).

3.3 Emissions of indirect land use change

A third, meanwhile often discussed issue is taking or not taking into account indirect land use change. As generally acknowledged indirect land use change in the shape of deforestation could result in GHG emissions that would nullify GHG emission reductions by biofuels, sometimes even leading to a significant increase of GHG emissions (see for example OECD, 2008; JRC, 2008; Gallagher, 2008).

In the EU methodology this is not considered an issue based on the argumentation that increased requirement for cropland from biofuels production will become available by the business as usual increased crop yields in food and feed production. This is however not very likely, as shown in various recent studies, such as Gallagher (2008) or MNP (2008). It is also a different approach compared to CDM and EPA:

- According to ARB (2007) taking indirect land use into account is compulsory for EPA under US law (EISA, 2007).
- BP and probably also other oil companies are planning to use large volumes of Jatropha, imported into the EU from Africa and Asia. For this kind of projects the CDM system would require an indirect land use change analysis. Given the fact that the EU methodology would allow for realization of Jatropha plantations in degraded forest area's - such as wood cut area's - and given the fact that several entrepreneurs are looking for possibilities of realizing Jatropha plantations on wood cut areas, there is a real possibility for indirect land use change by moving of the occupied wood cut area into unaffected or less affected forests.

It therefore seems a methodological flaw not to take indirect land use change into account.

3.4 Some other issues

The EC proposal indicates that the methodology and underlying data are largely based on or taken from the JEC well-to-wheel study[10]. However, parts are modified in response to the stakeholder consultation. As far as we can tell, it is not explicitly stated in the text that many of the default values and assumptions were taken from JEC (2007). The JEC study would at any rate provide default specific emissions for transportation, fossil fuels, fertilizer production and production of several chemicals. It would also provide a number of rules for calculation, e.g. a clear reference land use utilization (e.g., set aside land within the EU, etcetera). All these data are required to estimate the life cycle emissions of the biofuels.

However, even when the JEC default values were used, a number of questions remain.

Several issues are not elaborated in JEC (2007) because they were not part of the biofuel production systems considered in that study:

a Removal of originally present vegetation and GHG emissions related to the way it is removed (pile burning, natural decay, landfilling), e.g. combustion emissions. Should these be taken into account?

b Beneficial utilization of removed vegetation, e.g. application of removed trees for construction wood or as fuel wood: should GHG emissions be allocated to these beneficially utilized fractions of original vegetation?

c How to deal with the carbon stored in perennial crops, e.g. oil palms. Should this temporary storage be taken into the equation or should carbon

---

[10] See for example EU (2008), Annex 6.7.1.2 to the impact assessment.

sequestration in the oil palms be neglected because the trees may be cut down again after becoming too high?

All these factors can have a significant impact on total net GHG emission reduction. In the Jatropha biofuel system for example allocating to beneficially utilized removed vegetation makes a difference of approximately 10% points on the net GHG emission of the system. Taking into account the carbon stored in the Jatropha trees is even more important.

JEC (2007) does not provide a readily applicable calculation methodology for defining N_2O emissions related to nitrogen consumption as a nutrient. In JEC (2007) N_2O emissions were calculated with the DNDC biogeochemistry model for agricultural ecosystems. This kind of scientific model gives more reliable emission data for N_2O compared with the rough IPCC emission factors, but requires large amounts of detailed information and specific scientific knowledge of e.g. geochemistry for operation[11].

In JEC (2007) assumed reference land use utilization in Europe is set aside land, meaning biofuels would be produced solely on idle land. This is a questionable assumption to say the least:

- The assumption is contradicted in JEC (2008) in relation to palm oil biodiesel and sugar cane ethanol. In this study both production routes are said to be related to deforestation in tropical regions and conversion of unaffected Cerrado and ranchland.
- The argumentation is more or less contradicted by the text of the Commission staff working document (EU, 2008). As mentioned in the document (page 145) increases in vegetable oil production between 1980 and 2006 have come for approximately 30% from increases in cultivation area for vegetable oil producing crops.
  Given the fact that:
  - a The EU 2020 biofuels target would mean an increase of 20% compared to the business as usual 2020 vegetable oil consumption forecast.
  - b Business as usual increase in vegetable oil demand has already resulted in deforestation or other kinds of land use change.

  It would seem very likely that fulfilling the proposed EU biodiesel demand would result in land use change of land with high carbon stocks into crop land and not just utilization of set aside land.

In JEC (2007) CO_2 emissions (and N_2O emissions) from further decline of organic soil matter in agricultural soil are not considered. In the study the carbon content of agricultural soils is assumed to be constant. There are however indications that this is not the case and that the carbon content in the EU-15 still decreases steadily at a rate of 0,84 tonne C/ha/a (Freibauer, 2004). This gives a GHG emission comparable to the N_2O contributions to net GHG emission balance, i.e. in the order of tens of kg CO_2 eq./GJ biofuel.

---

[11] A more sophisticated approach that does not require the specialized knowledge and large amount of data required for scientific models such as DNDC would be the methodology developed by Stehfest and Bouwman (see Stehfest, 2006). Maybe this would be an alternative applicable within the EU GHG calculation methodology.

Summarizing the issues described above, the JEC study (JEC, 2007) would not provide a complete calculation methodology for every relevant biofuel production route and also contains at least one questionable assumption.

3.5 Conclusions

Summarizing the discussion in previous sections a fair conclusion would be that the EU methodology proposal concerns a rough and incomplete approach for analyzing such complex systems as production of biofuels.

4 The potential role of biofuel LCA's in policy

4.1 Introduction

The EC renewable energy proposal aims to ensure that only biofuels with sufficient GHG emission savings (more than 35% in the current proposal) are promoted. In addition, it sets rules about what type of soil can be used, in order to prevent too high land use change emissions and loss of biodiversity. In addition, the Fuel Quality Directive proposal aims to promote biofuels with higher GHG savings more than those with lower savings.

The LCA methodology and default factors that are used for these policies are crucial for the effectiveness and fairness of these policies. If they result in over or underestimation of the actual GHG savings, the policies will not have the desired result.

In the following, we try to assess this approach, in view of the methodological discussions and omissions in the previous chapter.

4.2 Can biofuel LCA's be accurate enough?

In our view, many significant contributions to the GHG emission balance of a biofuel system cannot be calculated accurately with a relatively simple LCA methodology, especially not those concerning agriculture (e.g. N_2O emissions), land use changes and emissions from soil. Some of these contributions can be calculated only with sufficient accuracy applying a specialized bio geological chemistry computer model, such as DNDC or Century. Such programmes are well suited to provide accurate estimates of the (direct) effects of specific biomass to biofuel routes. However, they are complex and detailed and therefore seem less suited for large scale application by industrial entrepreneurs and farmers. It may even turn out to be impossible to accurately incorporate some macro effects such as indirect land use changes in a LCA methodology.

Therefore, even though we certainly see the value of LCA calculations for biofuels, we doubt whether it will be possible to develop a methodology that is both usable on a large scale (i.e., for all biofuel producers and suppliers in the EU) and accurate. Some of the current omissions in the methodology can not be easily mended, and the errors that they might cause in the results can be very significant. As the errors mainly seem to result in an underestimation of the GHG savings of part of the biofuels on the market, they will undermine the effectiveness of the biofuel policy. The risk that the biofuels policy will rather increase than decrease global GHG emissions then remains.

In the longer term, it might be feasible to elaborate the current methodology, and incorporate a more detailed bio chemistry model, for example by developing a detailed (and computerized) reporting and calculation tool. The indirect effects, however, may prove difficult to incorporate. This would, however, require additional research.

4.3 Policy options

With this at the back of the mind we would see that the following policy options may result in biofuel policies that effectively reduce GHG emissions:

1 A short list approach, somewhat comparable to the advice in the Gallagher report:
   - No regret approach for indirect land use change, e.g. only low value organic residues as feedstock, only cultivation on marginal land or cultivation of coverage crops as second yield crops on existing arable land.
   - Only cultivation in certain specific regions, with soil producing minimal N_2O emissions.
   - Only cultivation of certain high yield crops, requiring little water, nutrients, pesticides, etcetera (see also EEA report from 2006).
   - Only best environmental practice in cultivation (e.g. no till operation) and conversion (e.g. optimal heat integration, natural gas or biomass as fuel).
   - A large default database accessible for entrepreneurs for estimating N_2O emissions for specific locations and specific crops.

2 A further development of the GHG calculation methodologies, with a conservative approach. In this case the omissions in the methodology are repaired, ensuring that all effects are incorporated (including the indirect effects). In the short term, some of these effects can only be included roughly and we would propose to use conservative default values in these cases. Further research should then be aimed at the further development of these values, hopefully resulting in improvements to the LCA methodology in the coming years.

5 Conclusions and recommendations

5.1 Conclusions

The GHG calculation methodology for biofuels that has been proposed by the European Commission adheres to a large part to the standard LCA methodology as defined in ISO 1040 standards. However, we conclude that:

- Some important issues that should be included are neglected (namely indirect land use change).
- Some issues that are included contain choices that seem to lack a solid (scientific and transparent) basis.
- Some issues that are included are not further elaborated on (such as the default GHG savings values).

Regarding the latter two points, in our opinion, the GHG methodologies recently developed in the Netherlands and in the UK are much more transparent and complete.

Regarding the omission of indirect land use change effects, we think that there is by now enough evidence to conclude that these effects are likely to occur and that they may be so large that they may lead to a net increase of GHG emissions with many of the biofuels on the market. Not taking into account these effects may therefore lead to a significant overestimation of the GHG savings in some, perhaps even many biofuels on the market.

We therefore conclude that the methodology as proposed is more the start of a development than a mature methodology. The proposal should be further developed as follows:

- Indirect land use change emissions should be included. This requires further research into these effects, but that should not be a reason not to include them as they may be very significant. In the meantime, one should consider following the recommendations brought forward in the Gallagher review (RFA, 2008), such as slowing down the growth of biofuels and implement policies that ensure that biofuels production occurs on idle or marginal land.
- The calculation methodology of agricultural emissions from soils (N_2O and CO_2) and the emissions (or carbon sequestration) related to changes in vegetation should be made more transparent.
- The calculations of the default and typical values should be made transparent.
- Default and typical values should not only be provided for a limited number of routes and land use changes. As these values may depend strongly on the regional conditions, soil types and specific processes, much more values should be provided.
- Default and typical values should also be provided for biodiesel from soy routes.

- The by-product allocation by energy content may have practical advantages, it also tends to result in (sometimes significantly) higher GHG savings than substitution, which is considered to provide the most realistic result. It also means loosing sight of the GHG effects of by product use, which may be very significant with some biofuels. This again may lead to significant errors in the GHG savings that are calculated (the actual savings may be underestimated by about 20-50% in the cases of biofuels from rape, sunflower and cereals).

5.2 Recommendations

Summarizing the issues described above, the EU methodology proposal does not provide a complete calculation methodology for every relevant biofuel production route. It also contains at least two questionable methodological choices, namely the choice for allocation based on energy content, and the lack of indirect land use change effects.

To become a usable methodology, the following subjects should be added:
- A list of default values for chemicals, fertilizers, transports and other additives and minor processes.
- A more detailed list of default values for aspects such as carbon stocks.
- A clear calculation methodology for determining N_2O emissions.
- A calculation methodology for calculation of GHG emissions due to changes in carbon stocks.
- A calculation methodology for the indirect land use change effects.

Regarding improvements of the proposed LCA methodology, we would recommend the methodological choices as outlined in Table 2.

Table 2 Recommended methodological choices

Item	Options	Proposal
Direct land use change	Include or not	Include, in line with IPCC methodology
Indirect landuse change and allocation methodology	• Ignore • Include requirements regarding 'save' cultivation soils and regions (in line with the Gallagher review) • Model the effects accurately	Develop and incorporate methodology for the calculation of ILUC effect for different biofuels.
Variation in calculation methodologies and uncertainty in calculated N_2O emissions	• Ignore • IPCC methodology • Stehfest and Bouwman • DNDC, etc. - complex models	IPCC as a minimum, but preferably Stehfest and Bouwman.
Variations in cultivation practices	• Assume conservative defaults • Let biofuel suppliers fill in real data	Assume a conservative approach/defaults (biofuel suppliers may provide real data).
Variations in conversion process lay outs and energy supply to conversion processes (fuels applied).	• Assume conservative defaults Let biofuel suppliers fill in real data.	Assume a conservative approach/defaults (biofuel suppliers may provide real data).
'Depreciation methodology'	10-20 years or more	20, in line with IPCC
By-product treatment	• System expansion • Economical allocation • Mass allocation • Energy allocation	Energy allocation, with a realistic correction for the land use emissions saved if the by product is used as feed.

Alternatively, if these improvements are considered to be too complex or otherwise impossible (for example, due to lack of data), it should be considered to distinguish between biofuels with 'good' and 'bad' environmental performance using a short list approach, as for example proposed by the Gallagher review.

References

ARB, 2007
A. Prabhu, Ch. Pham
Low carbon fuel standard LCA working group 1 meeting of California EPA
S.I. : Air Resources Board, 2007
http://www.arb.ca.gov/fuels/lcfs/111607wg1.pdf

CE, 2008
H.J. Croezen, F. Brouwer
Potential impacts of by-products utilization
Delft : CE Delft, 2008

Claasen, 2007
Frans Claasen
Responsible Soy : Challenges and Opportunities
Berlin : S.n. 2007
http://assets.panda.org/downloads/claassensoyaberlinfebruary282007.pdf

EC, 2008
Commission staff working document, annex to the impact assessment (provisional) of the 'package of implementation relating to the EU's objectives on climate change and renewable energy for 2020' : Proposals for Directive of the European Parliament of the Council amending.
Directive 2003/87/EC so as to improve and extend the EU greenhouse gas emission allowance trading system.
Decision of the European Parliament and of the Council on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.
Directive of the European Parliament and of the Council on the promotion of use of renewable energy sources, (COM(2008) 16),(COM(2008) 17),(COM(2008) 19)
Brussels : European Commission, 2008

Ensus, 2008
Indirect effects of biofuels ; Study by the Renewable Fuels Agency
Yarm : Ensus Limited, 2008

Freibauer, 2004
A Freibauer et al.
Carbon sequestration in the agricultural soils of Europe
In : Geoderma 122 (2004); p. 1 - 23.

GHGenius, 2008
www.ghgenius.ca/

IGES, 2006
S. Eggleston, et al.
2006 IPCC Guidelines for National Greenhouse gas Inventories
S.I. : The Institute for Global Environmental Strategies (IGES), 2006

JRC, 2007
R. Edwards, J-F. Larivé, V. Mahieu, P. Rouveirolles
Well-To-Wheels analysis of future automotive fuels and powertrains on the European context', Well-to-Wheels Report
S.I. : Institute for environment and sustainability of the European commission's Joint Research Centre JRC/IES : European Council for Automotive R&D EUCAR, CONCAWE, 2007

JRC, 2008
G. De Santi, et al.
Biofuels in the European context : Facts and uncertainties
S.I. : JRC, 2008

Parkhomenko, 2004
S. Parkhomenko
International competitiveness of soybean, rapeseed and palm oil production in major producing regions (Sonderheft 267)
Braunschweig : Federal Agricultural Research Centre (FAL), 2004

RFA, 2008
Ed Callagher
The Gallagher Review of the indirect effects of biofuels production
S.I. : Renewable Fuels Agency (RFA), 2008

Stehfest, 2006
E. Stehfest, L. Bouwman
N_2O and NO emisisons from agricultural fields and soils under natural vegetation: summarizing available measurement data and modelling of global annual emissions
In : Nutrient Cycling in Agrosystems, vol. 74, (2006); p. 207-228

CE Delft
Solutions for environment, economy and technology

Oude Delft 180
2611 HH Delft
The Netherlands
tel: +31 15 2 150 150
fax: +31 15 2 150 151
e-mail: ce@ce.nl
website: www.ce.nl
KvK 27251086

Calculating greenhouse gas emissions of EU biofuels

An assessment of the EU methodology proposal for biofuels CO_2 calculations

Annexes

Report

Delft, October 2008

Author(s): Harry Croezen
Bettina Kampman

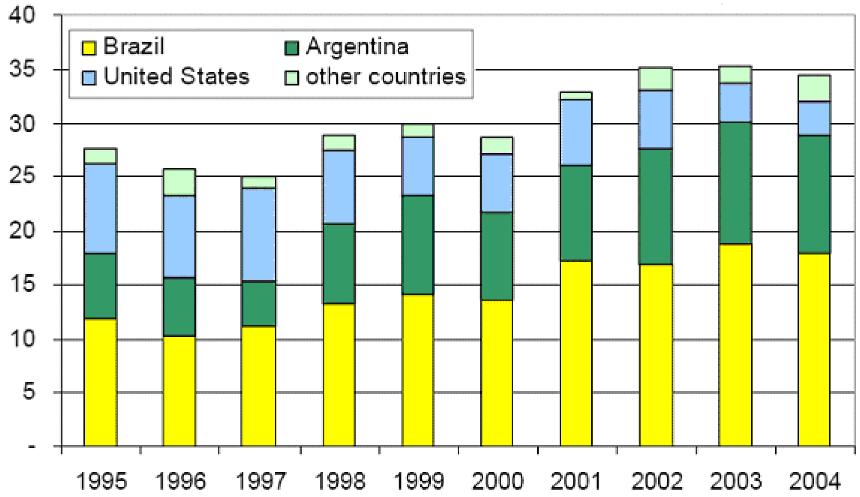
A Case study no. 1: EU biodiesel from soy

A.1 Chain and direct GHG emissions

Soy is cultivated for the meal, which is globally the primary protein source in livestock breeding. The oil is a valuable by-product of high quality. In terms of quality the oil competes with and can be replaced by rapeseed oil and sunflower oil. In terms of volume soybean oil competes with palm oil, which can be produced at lower costs. Palm oil is applied in consumer products up to levels allowed by its quality.

Soy meal and soy beans consumed within the EU are primarily imported from Argentina and Brazil (LMC, 2006) because of the cultivation of GM soybean varieties in the USA.

Figure 5 Soybean and soybean meal imports by EU, in soybean meal equivalents[12]



Source: Claassen, 2007.

Yields from soybean cultivation in these countries amount to 2.7 tonne/ha and 2.3 tonne/ha respectively. In both countries soy beans are rotated with corn, in Argentina also with wheat.

In case the oil is too applied as biodiesel feedstock the beans will be dried from 15 to 13% moisture and will be subsequently crushed. The crude soy oil will be degummed and refined and esterified, yielding free fatty acids and raw glycerine as by-products

Mass balance and specific consumptions are given in Figure 6[13]. The total GHG emission related to consumptions of energy and additives, transportations and N_2O emissions are also given, in kg CO_2 eq./ha.

---

[12] http://assets.panda.org/downloads/claassensoyaberlinfebruary282007.pdf.

Emissions related to consumptions of energy and additives and to transportations can be calculated by combining the given consumptions with the specific GHG emissions given in Annex D.
It must be noted that the applied specific emissions for additives, energy carriers and transportation refer to a EU setting, while in this scan activities in Latin America are considered. This is however common practice in most LCA’s - see e.g. JEC (2007).

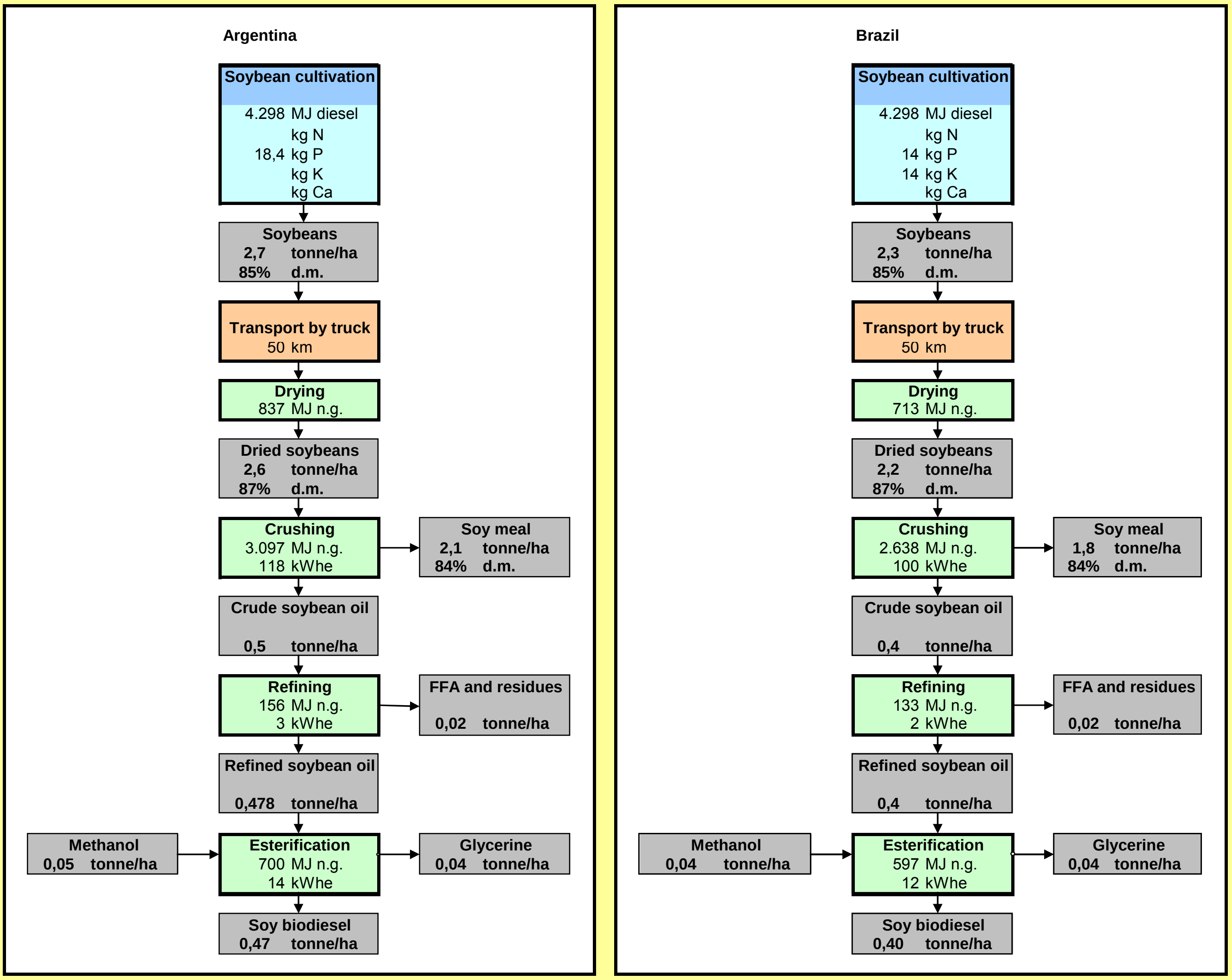
Emissions of N_2O have been taken from JEC (2007) and GHGenius (2008). These emissions are not related to nitrogen fertilizer application. Because it is a N-fixing crop soy does not require N-fertilization. The given N_2O emission (of 1.25-1.28 kg N_2O/ha) is applied as a default value in both studies and is based on dozens of emission measurements on soy fields.

The ‘Effects from residue’ category refers to the benefits brought about by the crop residue (roots, stalks, leaves, etc). As a N-fixing crop soy fixes nitrogen in both beans and other crop fractions - which after beans harvesting become residues. The residues remain on the field, are ploughed under and decay and mineralize, making the stored nitrogen available for successive crops - probably maize.
The residue is however a less efficient nitrogen source than fertilizer (so substitution ratio is < 1) and gives a higher total N_2O emission. This has been taken into account.

---

[13] Sources: CE, 2006; FAO, 2004; Parkhomenko, 2004; JEC, 2007.

Figure 6 Soy biodiesel production chain and its mass balance and direct GHG emissions



	total emission kg CO2-eq/ha	
Diesel in agriculture	385	
Fertilizers	19	
N2O directly from soil	379	
Effects from residue	-288	
Transportation	11	
Drying	50	
Crushing	240	
Refining	11	
Esterification	48	
Methanol production	100	
	955	Gros GHG-emission

	total emission kg CO2-eq/ha	
Diesel in agriculture	385	
Fertilizers	22	
N2O directly from soil	379	
Effects from residue	-246	
Transportation	10	
Drying	43	
Crushing	204	
Refining	9	
Esterification	41	
Methanol production	85	
	933	Gros GHG-emission

Contribution to EU consumption	
Argentina	40%
Brazil	60%

A.2 Land use change, direct and indirect

A.2.1 General picture

As stated soy for the European market is mainly produced in Brazil and Argentina. Historically cultivation has taken place on land that was previously Cerrado (Latin American variety of Savannah) but in the last decade soy cultivation has expanded into the Amazon rain forest area. Increase in production between 1992-2005 is estimated to have been achieved for 70% by land area change, converting natural area into cropland.
The picture is now changing a little because high yield varieties of soybean have been developed that have allowed for an increase in Brazilian production between 2004/2005 and 2007/2008 of 10 Mtonnes to a total of 60 Mtonnes annually, despite of a drop in planted area of 2 Mha to a total area of 21 Mha.

This still lets unimpeded that soy cultivation has resulted in large areas of natural habitat that have been converted into cropland in the past. Estimated contributions of different land uses that have been converted into soy crop land are:

- 20% other crop land.
- 30% grassland - pastures for cattle breeding.
- 50% forest land.

Changed crop land does not solely refer to a change in type of cultivated crop, a situation that occurs when it becomes economically more attractive to cultivate crop instead of the previously cultivated crop. It also refers to the mechanism in which large industrial soy farmers force small farmers and cattle breeders from their land, who subsequently try to carve out a new existence by creating a new farm at the expense of Amazon rain forest.
This means that direct and indirect land use change related environmental effects can be comparable - albeit the latter is often much harder to prove.

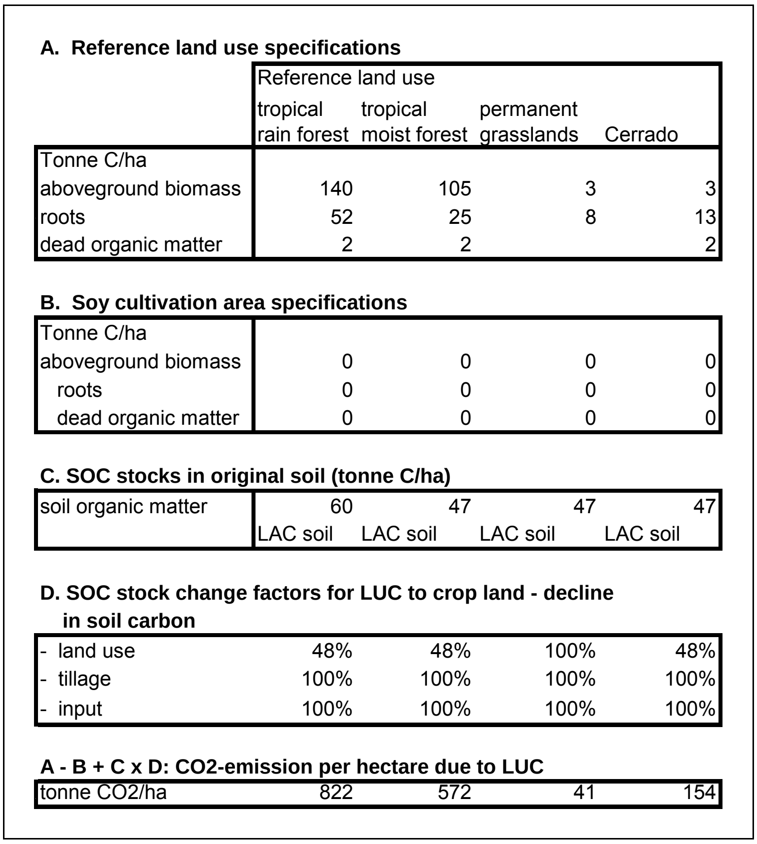
A.2.2 Calculation

These emissions due to land use change are shown in Table 3 and Figure 7.
Because of the very different possible reference situations and associated greenhouse gas emissions we did not try to give an average GHG emission due to land use change for soy cultivation.
Instead we have calculated total GHG emission due to LUC for the four possible references mentioned above. All references occur both in Brazil and in Argentina, rain forest included[14].
Calculation of the resulting GHG emissions are visualized below.

---

[14] See http://tropicalconservationscience.mongabay.com/content/v1/08-06-09-editorial.html

Figure 7 GHG emissions from direct LUC for extension of soy cultivation and for crop yield increase and existing cultivation



A. Reference land use specifications

	Reference land use			
	tropical rain forest	tropical moist forest	permanent grasslands	Cerrado
Tonne C/ha				
aboveground biomass	140	105	3	3
roots	52	25	8	13
dead organic matter	2	2		2

B. Soy cultivation area specifications

Tonne C/ha				
aboveground biomass	0	0	0	0
roots	0	0	0	0
dead organic matter	0	0	0	0

C. SOC stocks in original soil (tonne C/ha)

soil organic matter	60	47	47	47
	LAC soil	LAC soil	LAC soil	LAC soil

D. SOC stock change factors for LUC to crop land - decline in soil carbon

- land use	48%	48%	100%	48%
- tillage	100%	100%	100%	100%
- input	100%	100%	100%	100%

A - B + C x D: CO2-emission per hectare due to LUC

tonne CO2/ha	822	572	41	154

The net GHG emission arising from LUC is caused by:

- Change in aboveground vegetation and associated roots and dead organic matter (fallen leaves, branches, fruits, etcetera).
- Change in carbon stocks in soil.
- Change in N_2O emissions from soil.

Changes in vegetation

The change in the aboveground vegetation can be deducted by comparing and subtracting the amount of carbon stored in the soy area (rows under category B) from the amounts of carbon stored in the vegetation originally present (rows under category A[15]). Multiplying changes in carbon stocks with 44/12 gives the concurrent CO_2 emissions.

Dead organic matter refers to fallen leaves and twigs and other vegetative debris. In case of palm oil plantation this also refers to the empty fruit bunches and other fruit residues returned to the plantation. For natural forests it refers the mentioned twigs, leaves and to fruits, nuts and anything else up to dead trees.
Amount of dead organic matter will change when vegetation changes.

---

[15] Carbon in soil and vegetation has been derived from IPC (2006) except for the data for vegetation on Cerrado, this being derived from GAIA.

Changes in carbon stored in soils

Change in soil carbon stocks can be calculated by multiplying the carbon stock originally present with the three change factors:

$$SOC_2 = SOC_1 \cdot f_{\text{land use}} \cdot f_{\text{tillage}} \cdot f_{\text{input}}$$

These factors indicate the effects of different mechanisms on soil carbon content. Tillage and annual cropping mean disturbance of the soil structure and exposure of soil organic matter to oxygen and results in oxidation and degradation of the soil organic matter, releasing the carbon stored in the organic matter as CO_2.
On the other hand returning crop residues to the soil and application of manure and green manure all mean organic material is added to the soil organic matter. A small part of the organic material added to the soil will not be degraded and will instead accumulate in the soil, thus resulting in soil generation.

The term LAC soil refers to Low Activity Clay and refers to a highly weathered with a relative low concentration of nutrients because these have been leached from the soil under influence of precipitation and temperature.

N_2O emissions

Changes in vegetation will also result in changes in N_2O emissions. Agricultural soils have a different soil hydrology, receive different amounts of organic and inorganic nitrogen and different amounts of carbon material. As a result the soil chemical reactions producing N_2O also occur with different reaction rate and volume of produced N_2O per unit of time.

N_2O emissions for reference situation and soy cultivation are compared in Table 3.

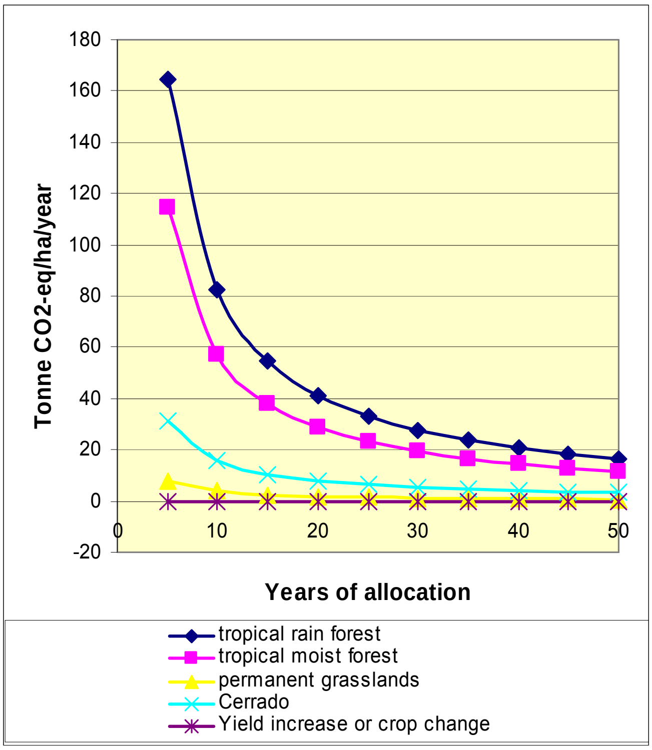
Table 3 N_2O emissions for soy cultivation and reference landuses

	Tropical rain forest	Tropical moist forest	Permanent grasslands	Cerrado
N_2O-N kg/ha/y				
Reference land use	0.8	0.8	2.0	0.5
Biofuel system	1.25	1.25	1.25	1.25

Resulting annual emissions and optimization opportunities

We have visualized the net GHG emissions due to LUC as a function of the number of years of allocation - the period of time the once-only LUC related GHG emissions are divided by 20 years is the standard defined by IPCC, but other time periods are used as well in the literature. Clearly, the longer the period, the lower the LUC emissions allocated to a given volume of soy oil produced.

Figure 8 LUC related GHG emissions for soy bean cultivation as a function of the number of years of allocation



Note that a number of (agricultural) possibilities to reduce these land use change emissions have been identified (Volpi, 2008).

- There is 30 Mha of degraded pasture that could be applied for soy cultivation expansion.
- Cattle ranching could be intensified, releasing land for soy cultivation expansion.
- Soy could be rotated with cattle in an integrated crop livestock zero tillage system, giving possibilities for actually releasing land from livestock breeding and farming activities.

These options have not been further assessed here.

Slash and burn and resulting GHG emissions

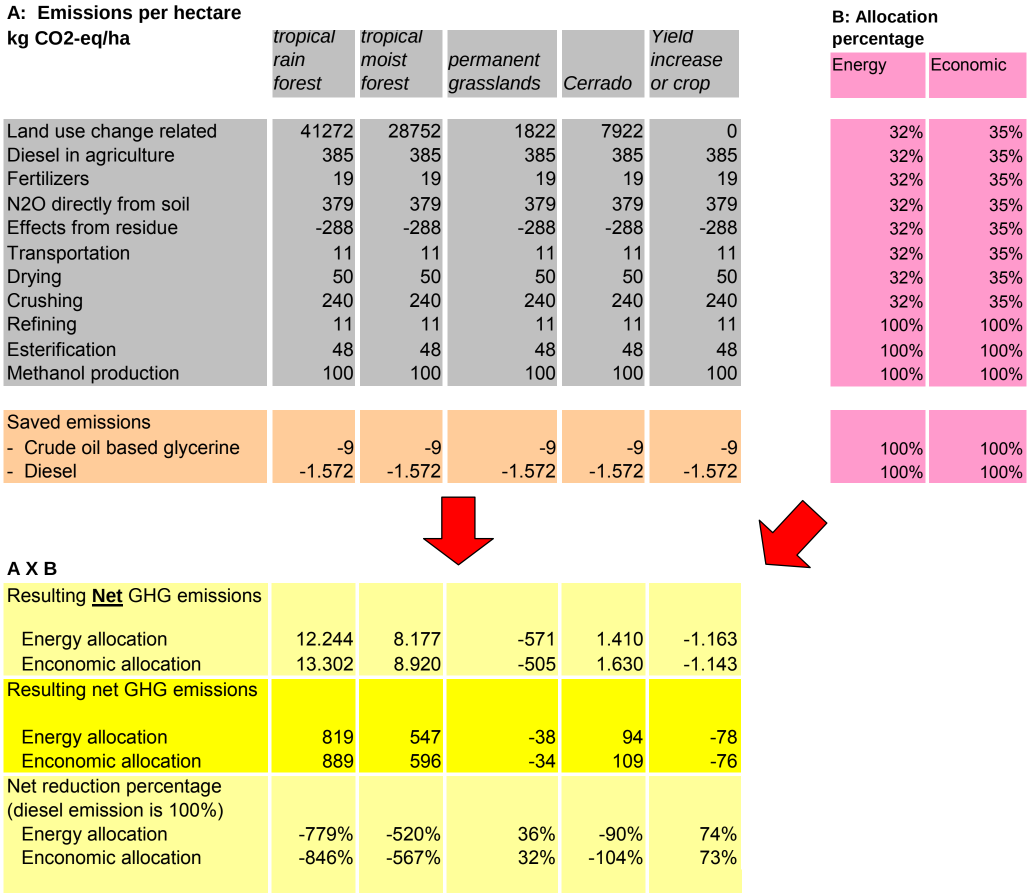
Removal of vegetation by slash and burn might yield extra emissions of CH_4 and N_2O due to incomplete combustion of the removed/slashed vegetation in piles. Contributions to climate change of these emissions are however limited. Total contribution for slash and burn of Cerrado would amount to 3,600 kg CO_2 eq./ha, while emissions due to changes in vegetation and soil carbon stock are at least ten times higher.

A.3 Allocation

Since soy is the main protein source in cattle breeding and soy will be cultivated for the meal and not for the oil system, extension as allocation methodology is not applicable.

That leaves allocation based on market value or energy content as options. Application of both methodologies is visualized in Figure 9.

Figure 9 Calculation of net GHG emissions for soy biodiesel produced in Argentina, LUC related emissions included and depreciated over 20 years



A: Emissions per hectare **kg CO2-eq/ha**	*tropical rain forest*	*tropical moist forest*	*permanent grasslands*	*Cerrado*	*Yield increase or crop*		**B: Allocation percentage** Energy	Economic
Land use change related	41272	28752	1822	7922	0		32%	35%
Diesel in agriculture	385	385	385	385	385		32%	35%
Fertilizers	19	19	19	19	19		32%	35%
N2O directly from soil	379	379	379	379	379		32%	35%
Effects from residue	-288	-288	-288	-288	-288		32%	35%
Transportation	11	11	11	11	11		32%	35%
Drying	50	50	50	50	50		32%	35%
Crushing	240	240	240	240	240		32%	35%
Refining	11	11	11	11	11		100%	100%
Esterification	48	48	48	48	48		100%	100%
Methanol production	100	100	100	100	100		100%	100%
Saved emissions								
- Crude oil based glycerine	-9	-9	-9	-9	-9		100%	100%
- Diesel	-1.572	-1.572	-1.572	-1.572	-1.572		100%	100%

A X B

Resulting **Net** GHG emissions					
Energy allocation	12.244	8.177	-571	1.410	-1.163
Enconomic allocation	13.302	8.920	-505	1.630	-1.143
Resulting net GHG emissions					
Energy allocation	819	547	-38	94	-78
Enconomic allocation	889	596	-34	109	-76
Net reduction percentage (diesel emission is 100%)					
Energy allocation	-779%	-520%	36%	-90%	74%
Enconomic allocation	-846%	-567%	32%	-104%	73%

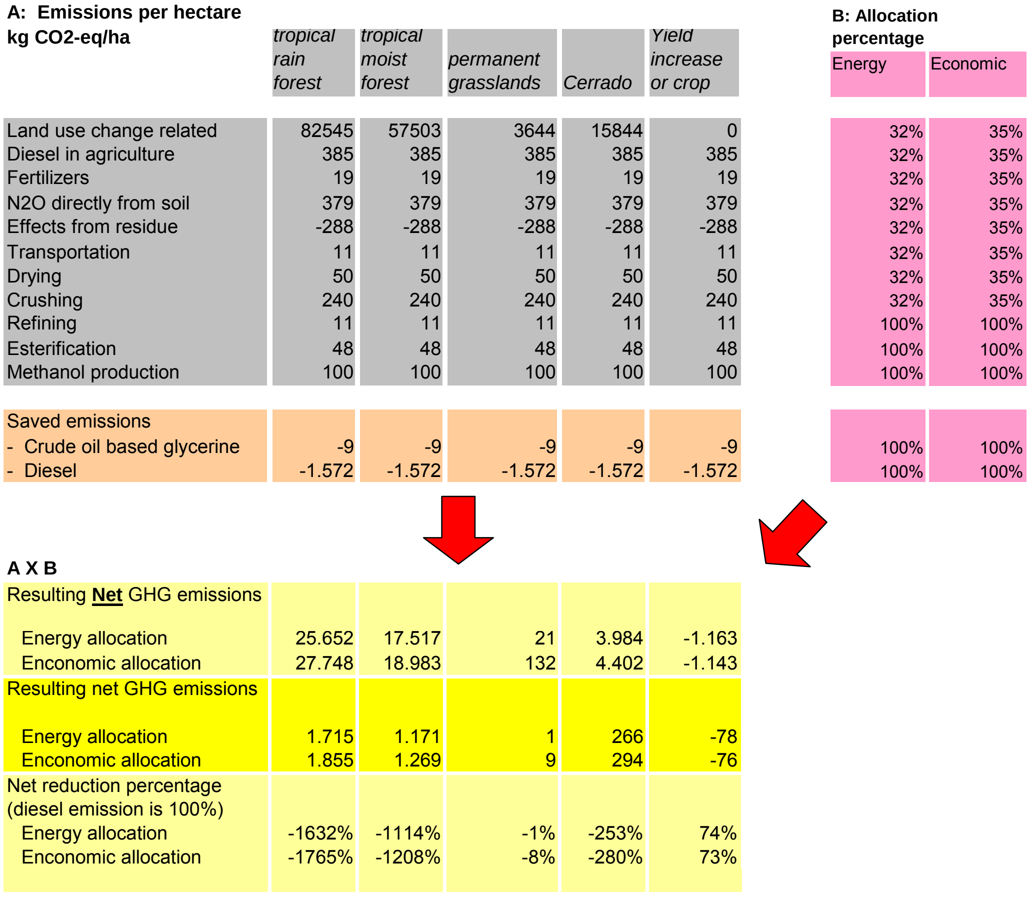
For LUC related GHG emissions we used 20 years of allocation, in accordance with IPCC methodology. Other periods are of course also possible, but these will make the results incomparable with those of studies like JEC (2007) and GHGenius.

Our estimation is that the net GHG emission per GJ of soy biodiesel amounts to -80 kg CO_2 eq. to 900 kg CO_2 eq. GHG emissions can be saved compared with conventional diesel when:

- Soy produced by yield increase is applied.
- Soy is cultivated on what historically already was cropland and no indirect deforestation occurs.
- Soy is cultivated on what historically was grassland or pasture and no indirect deforestation occurs.

For ten years depreciation time the results are as illustrated in Figure 10.

Figure 10 Calculation of net GHG emissions for soy biodiesel produced in Argentina, LUC related emissions included and depreciated over ten years



A: Emissions per hectare **kg CO2-eq/ha**	*tropical rain forest*	*tropical moist forest*	*permanent grasslands*	*Cerrado*	*Yield increase or crop*	**B: Allocation percentage** Energy	Economic
Land use change related	82545	57503	3644	15844	0	32%	35%
Diesel in agriculture	385	385	385	385	385	32%	35%
Fertilizers	19	19	19	19	19	32%	35%
N2O directly from soil	379	379	379	379	379	32%	35%
Effects from residue	-288	-288	-288	-288	-288	32%	35%
Transportation	11	11	11	11	11	32%	35%
Drying	50	50	50	50	50	32%	35%
Crushing	240	240	240	240	240	32%	35%
Refining	11	11	11	11	11	100%	100%
Esterification	48	48	48	48	48	100%	100%
Methanol production	100	100	100	100	100	100%	100%
Saved emissions							
- Crude oil based glycerine	-9	-9	-9	-9	-9	100%	100%
- Diesel	-1.572	-1.572	-1.572	-1.572	-1.572	100%	100%

A X B

Resulting **Net** GHG emissions					
Energy allocation	25.652	17.517	21	3.984	-1.163
Enconomic allocation	27.748	18.983	132	4.402	-1.143
Resulting net GHG emissions					
Energy allocation	1.715	1.171	1	266	-78
Enconomic allocation	1.855	1.269	9	294	-76
Net reduction percentage (diesel emission is 100%)					
Energy allocation	-1632%	-1114%	-1%	-253%	74%
Enconomic allocation	-1765%	-1208%	-8%	-280%	73%

One uncertainty not included in the analysis is the fate of the vegetation originally present. This may be slashed and burned, giving extra GHG emissions from the combustion. However, as indicated in section A.2, the contribution will be relative unimportant.

In case of a largely of completely undisturbed forest it is likely to very likely that part of the trees are utilized and sold as construction wood, pulp wood or fuel wood. In that case LCA methodology requires that part of the land use change related GHG emissions are allocated to the usefully applied part of the vegetation originally present.

B Case study no. 2: Palm oil biodiesel

B.1 Description of the chain

Approximately 85% of global palm oil production takes place in Malaysia and Indonesia. Cultivation takes place partly on drained peat soils that as a consequence partly oxidate, releasing large amounts of CO_2 and N_2O. In some cases the drained land disappears beneath the water level within some decades.

Oil palm cultivation in itself has a high possibility for recycling of nutrients and organic material. Empty fruit bunches (EFB), POME[16] and other residues can and often are being returned to the plantation. Shells and other rigid residues are often applied as fuel in the milling process with the ash subsequently returned to the plantation as fertilizer. As with sugar cane processing the amount of residue is large enough to allow for generation of (far) more electricity than required by the palm oil mill. The plantation itself could yield raw materials such as wood.
However, in practice these opportunities are not always exploited, in Malaysia probably more than in Indonesia.

In the chain the fruit bunches are harvested by hand, and cooked as soon as possible. The crude palm oil (CPO) is subsequently pressed from the fruits. The fruit kernel is crushed and kernel meal and oil are separated as valuable products. In this scan we assumed for convenience that the kernel oil is also processed into biodiesel.

Electricity and heat are often produced by combustion of residues in a CHP boiler. Effluent from the palm oil mill cooking process (POME) is directed to lagoons for decomposition of the organic material present in the effluent. In practice decomposition is partly anaerobic, resulting in methane formation. If not collected and flared or utilized as a fuel the methane will be emitted to the atmosphere - current practice at most mills - and will contribute to the enhancement of the greenhouse gas effect.

The rest of the chain consists of oil refining and esterification, the same processes as for production of soy biodiesel.

B.2 Direct GHG emissions

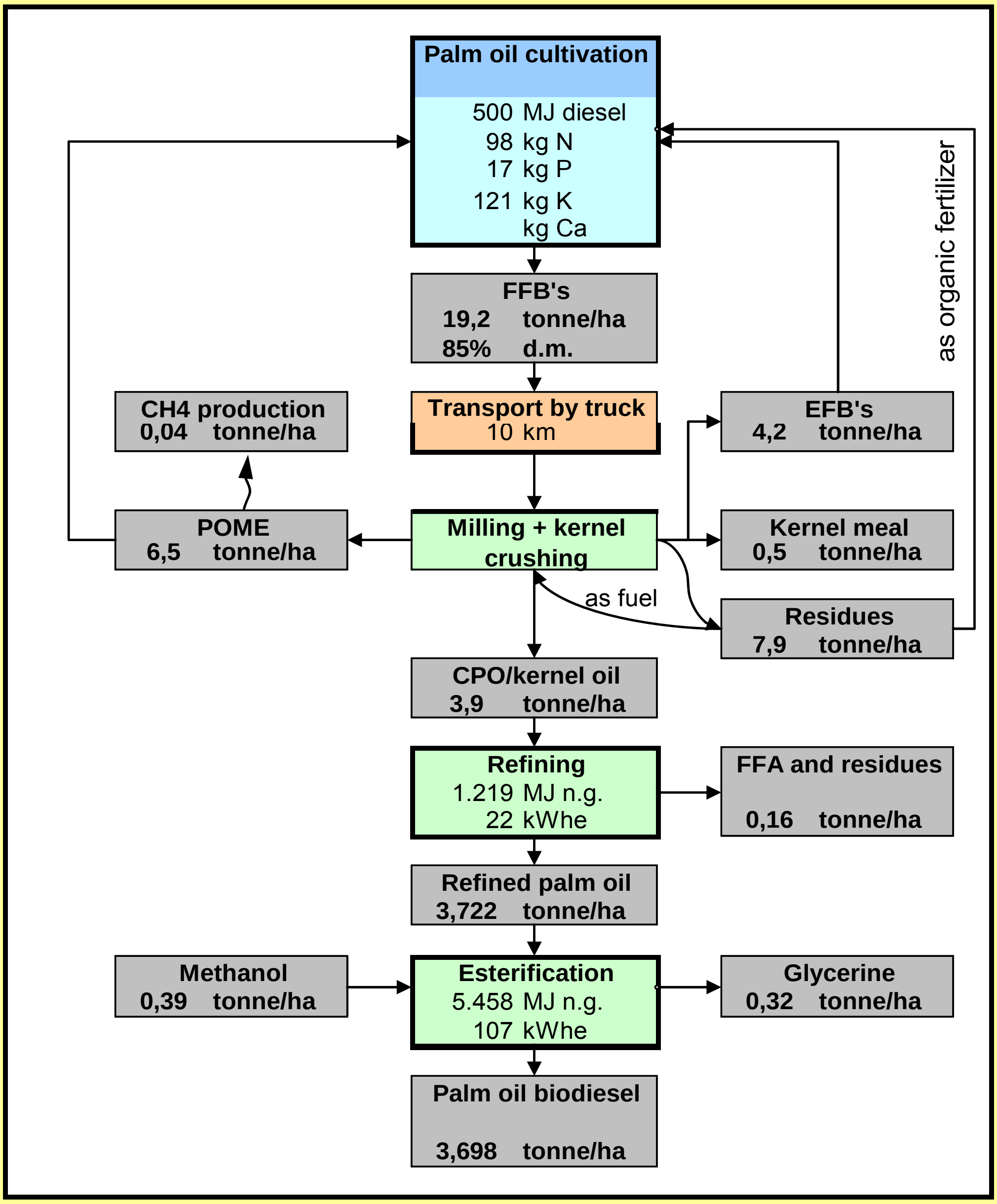
Mass balance and specific consumptions are given in Figure 11[17]. The total GHG emission related to consumptions of energy and additives, transportations and N_2O emissions are also given, in kg CO_2 eq./ha.

---

[16] Palm Oil Mill Effluent.

[17] Sources: CE, 2006; FAO, 2004; Parkhomenko, 2004; JEC, 2007.

Figure 11 Palm oil biodiesel production chain and its mass balance and direct GHG emissions (all figures per ha/year)



	total emission kg CO2-eq/ha typical	best case
Diesel in agriculture	45	45
Fertilizers	682	682
N2O	604	604
POME digestion	839	
Refining	85	85
Esterification	384	384
Methanol production	779	779
Gros GHG-emission	**3417**	**2578**

In this case specific GHG emissions for the Malaysian electricity production plants were applied. For all other additives and energy carriers again defaults for the EU region were applied.

The given N_2O emission refers to fertilizer application in a wet environment. This means that approximately 30% of the fertilizer is leached as NO_3 and 10% evaporates as NH_3. Both substances are also partly converted into N_2O in the environment (indirect N_2O emissions).
The given N_2O emission is an underestimation of the total emission. The recirculated residues also contain a significant amount of nitrogen part of which will also be emitted as N_2O. We were however unfortunately not able to find data on the recirculated amounts of nitrogen in residues.

B.3 Land use change, direct and indirect

Production of palm oil biodiesel will result in an equivalent increase in palm oil demand and hence an increase in plantation area. As indicated by JRC (2008) new plantation area is primarily created at the expense of tropical forest area. This forest may be on peat soil, that will be drained in case of oil palm cultivation and will subsequently partly oxidize.
Within the scope of LCA methodology it is irrelevant whether the plantation on the new area is used for palm oil for food applications or for biodiesel generation. The net effect of biodiesel production is deforestation.

However, we know from literature that oil palm plantations have also partly replaced rubber plantations because palm oil cultivation has become economically more viable than rubber production. Plantations have also been realized on lands partly or completely deforested by the wood industry previously. There thirdly is a significant potential in yield improvement. Current average palm oil and palm kernel oil yield is something of 3.7 tonnes/ha as indicated in Figure 11. The potential maximum yield is something of 7-8 tonnes/ha and at very good managed plantations already yields of 6 tonnes/ha are being realized.

We are not aware of any other kind of indirect land use change as a result of oil palm plantation realization.

Calculation of the resulting GHG emissions is visualized below. A description of the nature c.q. methodology of the performed calculations can be found in previous appendix.

Figure 12 GHG emissions from oil palm cultivation

A. Reference land use specifications

	Reference land use			
	tropical rain forest			
	mineral soil	peat	permanent grasslands	Rubber plantation
Tonne C/ha				
aboveground biomass	166	166	3	85
roots	62	62	8	25
dead organic matter	2	2		2

B. Palm oil plantation specifications

Tonne C/ha				
aboveground biomass	60	60	60	60
roots	18	18	18	18
dead organic matter	6	6	6	6

C. SOC stocks in original soil (tonne C/ha)

soil organic matter	44 HAC soil	peat	44 HAC soil	44 HAC soil

D. SOC stocks change factors for LUC to crop land - decline in soil carbon

- land use	100%		100%	100%
- tillage	100%		100%	100%
- input	111%		111%	111%

A - B + C x D: CO2-emission per hectare due to LUC

tonne CO2/ha	518	536	-284	86

Because the oil palm plantation itself accumulates a lot of biomass during its 25-30 years life emissions are lower than for soy cultivation. If the plantation is preserved after its economical life it might even be deemed a forestation project in case it has been realized on former grassland.

That is, in accordance with IGES (2006). In this methodology time horizon stretches up to 20 years and not beyond. The question is if the oil palm trees will be preserved after the trees have become too high for harvesting and after yields have started to reduce. It seems that this is currently the common practice and that after the old plantation has become unviable the new plantations is simply realized on previously undisturbed land or on slashed forest area.

But if the plantation is slashed after becoming unviable the carbon sequestered in the palms should in fact not be taken into account. On the other hand, reusing the same area prevents land use change.

HAC refers to Highly Active Clay soils and means soils only slightly weathered and still containing high concentrations of nutrients.

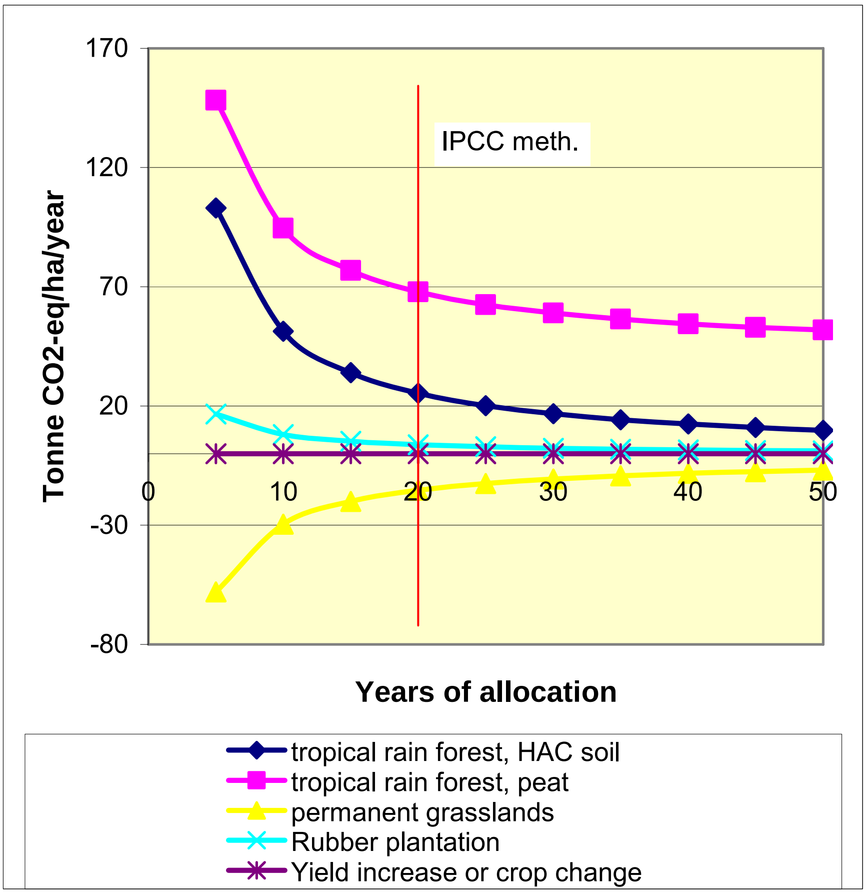
For peat no carbon stock in soil for the reference situation is given. That is because peat is completely made up of organic matter.

For the drained peat soil we also have to take the oxidation of the peat in account. This emission amounts to approximately 10.7 tonnes C/ha/yr according to IGES (2006).

We thirdly have to take into account that the former land coverage also produced N_2O emissions: 1.8 kg N_2O-N/ha/yr for rain forest and rubber plantation and approximately 4 kg N_2O-N/ha/yr for grassland.

Combining the three emission categories gives the following relation of annual emissions as a function of the number of years of allocation.

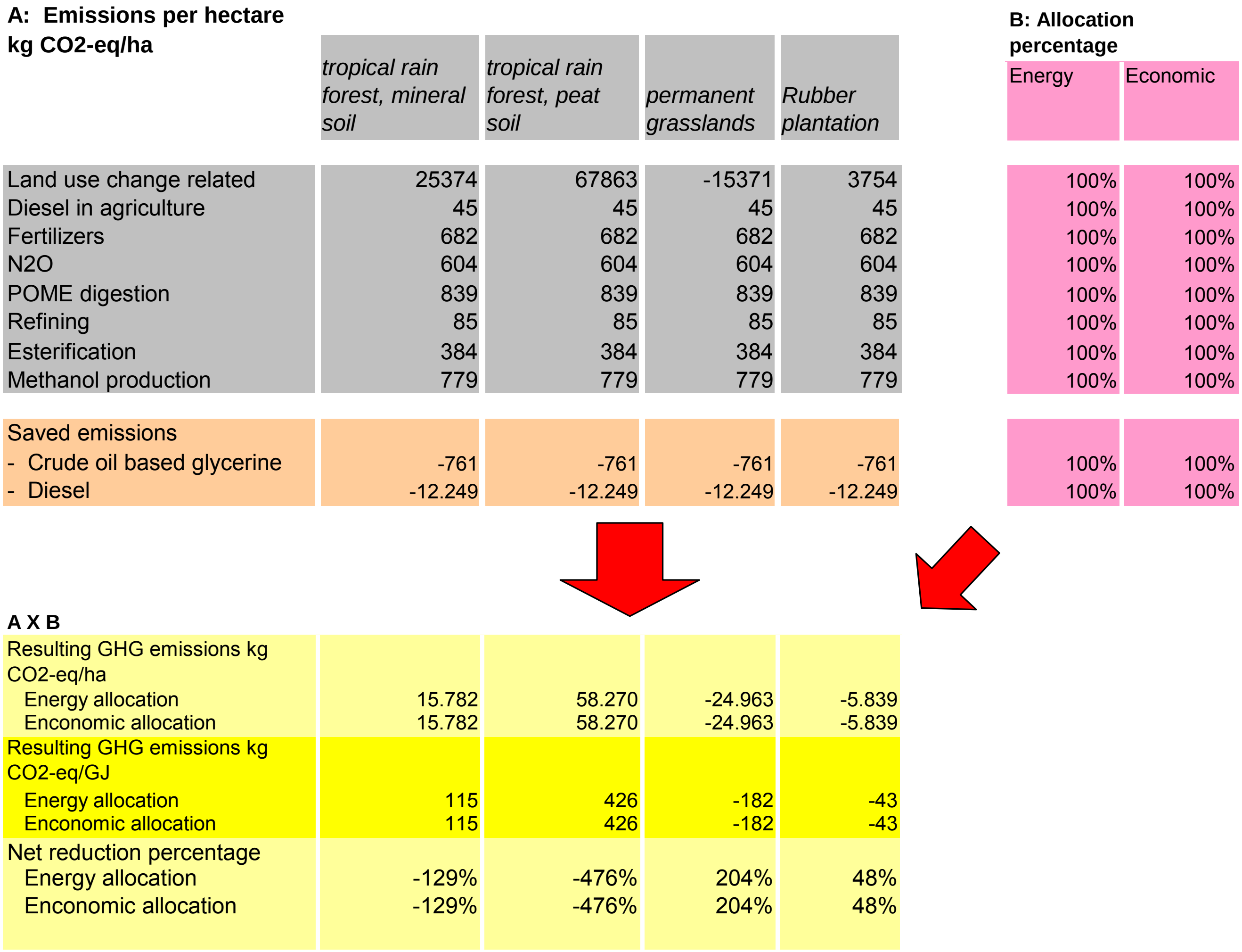
Figure 13 LUC related GHG emissions for oil palm cultivation as a function of the number of years of allocation



B.4 Allocation

As with soy, system extension is not applicable as allocation methodology. In this case both allocation methodologies are not applicable because palm oil is the main product on the market. You either produce it or you don’t.
Palm kernel as a by-product is such as small fraction compared to the amount of oil produced that it is not worth while to allocate to it or consider system extension. As a consequence the analysis is straight forward, as are the results (see Figure 5).

Figure 14 Palm oil biodiesel net GHG emissions, 20 years depreciation of (I)LUC emissions



A: Emissions per hectare kg CO2-eq/ha

B: Allocation percentage

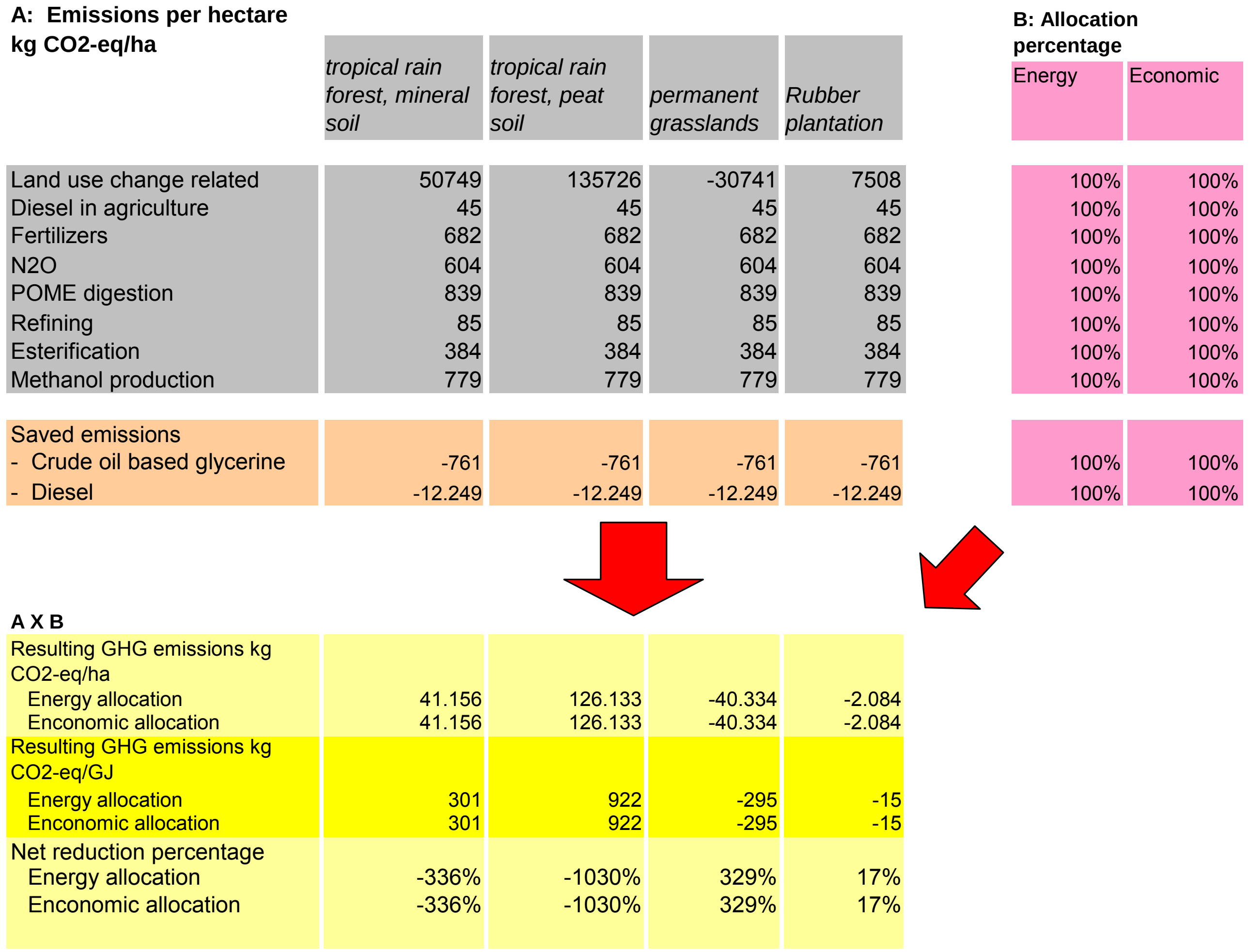
	tropical rain forest, mineral soil	*tropical rain forest, peat soil*	*permanent grasslands*	*Rubber plantation*	Energy	Economic
Land use change related	25374	67863	-15371	3754	100%	100%
Diesel in agriculture	45	45	45	45	100%	100%
Fertilizers	682	682	682	682	100%	100%
N2O	604	604	604	604	100%	100%
POME digestion	839	839	839	839	100%	100%
Refining	85	85	85	85	100%	100%
Esterification	384	384	384	384	100%	100%
Methanol production	779	779	779	779	100%	100%
Saved emissions						
- Crude oil based glycerine	-761	-761	-761	-761	100%	100%
- Diesel	-12.249	-12.249	-12.249	-12.249	100%	100%

A X B

Resulting GHG emissions kg CO2-eq/ha				
Energy allocation	15.782	58.270	-24.963	-5.839
Enconomic allocation	15.782	58.270	-24.963	-5.839
Resulting GHG emissions kg CO2-eq/GJ				
Energy allocation	115	426	-182	-43
Enconomic allocation	115	426	-182	-43
Net reduction percentage				
Energy allocation	-129%	-476%	204%	48%
Enconomic allocation	-129%	-476%	204%	48%

For ten years depreciation the results are as given in Figure 15.

Figure 15 Palm oil biodiesel net GHG emissions, 10 years depreciation of (I)LUC emissions



A: Emissions per hectare
kg CO2-eq/ha

B: Allocation percentage

	tropical rain forest, mineral soil	*tropical rain forest, peat soil*	*permanent grasslands*	*Rubber plantation*	Energy	Economic
Land use change related	50749	135726	-30741	7508	100%	100%
Diesel in agriculture	45	45	45	45	100%	100%
Fertilizers	682	682	682	682	100%	100%
N2O	604	604	604	604	100%	100%
POME digestion	839	839	839	839	100%	100%
Refining	85	85	85	85	100%	100%
Esterification	384	384	384	384	100%	100%
Methanol production	779	779	779	779	100%	100%
Saved emissions						
- Crude oil based glycerine	-761	-761	-761	-761	100%	100%
- Diesel	-12.249	-12.249	-12.249	-12.249	100%	100%

A X B

Resulting GHG emissions kg CO2-eq/ha				
Energy allocation	41.156	126.133	-40.334	-2.084
Enconomic allocation	41.156	126.133	-40.334	-2.084
Resulting GHG emissions kg CO2-eq/GJ				
Energy allocation	301	922	-295	-15
Enconomic allocation	301	922	-295	-15
Net reduction percentage				
Energy allocation	-336%	-1030%	329%	17%
Enconomic allocation	-336%	-1030%	329%	17%

C Case study no. 3: Ethanol from maize

C.1 Chain

The ethanol from maize biofuel chain is fairly straight:

- Maize is cultivated yielding 7,5 tonnes - 12,5 tonnes of wet maize grains (85% d.s.) per hectare. Associated amounts of cobs and stalks amount to 15-25 tonnes/ha. The cobs and stalks are left on the field and are eventually ploughed under.
- Grains are transported to the ethanol plant.
- The grains are applied as feedstock in conventional ethanol production technology - in which only C_6 sugars are converted into ethanol and CO_2 by yeast.

In the ethanol production process starch is hydrolyzed by boiling the feedstock in water. The hydrolyzed sugars - the beer - are then fermented into CO_2 and ethanol by yeast, after which ethanol is isolated by distillation.

Distillation technology and technology for production of the steam utilized in hydrolysis and distillation may differ significantly, resulting in a wide range in specific energy consumption.
For this case study we considered two extremes:

- Conventional technology:
  - Dilute fermentation producing a beer of 10 vol% ethanol.
  - Distillation technology with minimum heat integration requiring 5 MJ/l ethanol.
  - A conventional lignite fueled boiler with 90% thermal efficiency.
- State of the art technology:
  - Fermentation producing strong beer (16 vol% ethanol).
  - State of the art distillation technology with maximum heat recovery requiring 3 MJ/l ethanol.
  - Steam production in a gasturbine CHP plant with 35% electric and 50% thermal efficiency → electricity is supplied to grid, heat cocombustion factor of 0,7 $GJ_{n.g.}/GJ_{th}$

The other hydrocarbons, fats and proteins present in the maize grains are separated out as distiller grain and solubles. This by-product - Distiller Grains with Solubles (DGS) - is either dried (Dry DGS or DDGS) and applied as livestock feed or is supplied directly to farmers as cattle feed (Wet DGS or WDGS). In the USA a large part of the distiller grains and solubles seems to be supplied as wet product. Wet supply means a lot of fuel is saved, as water removal requires at least 2.7 GJ/tonne water removed.

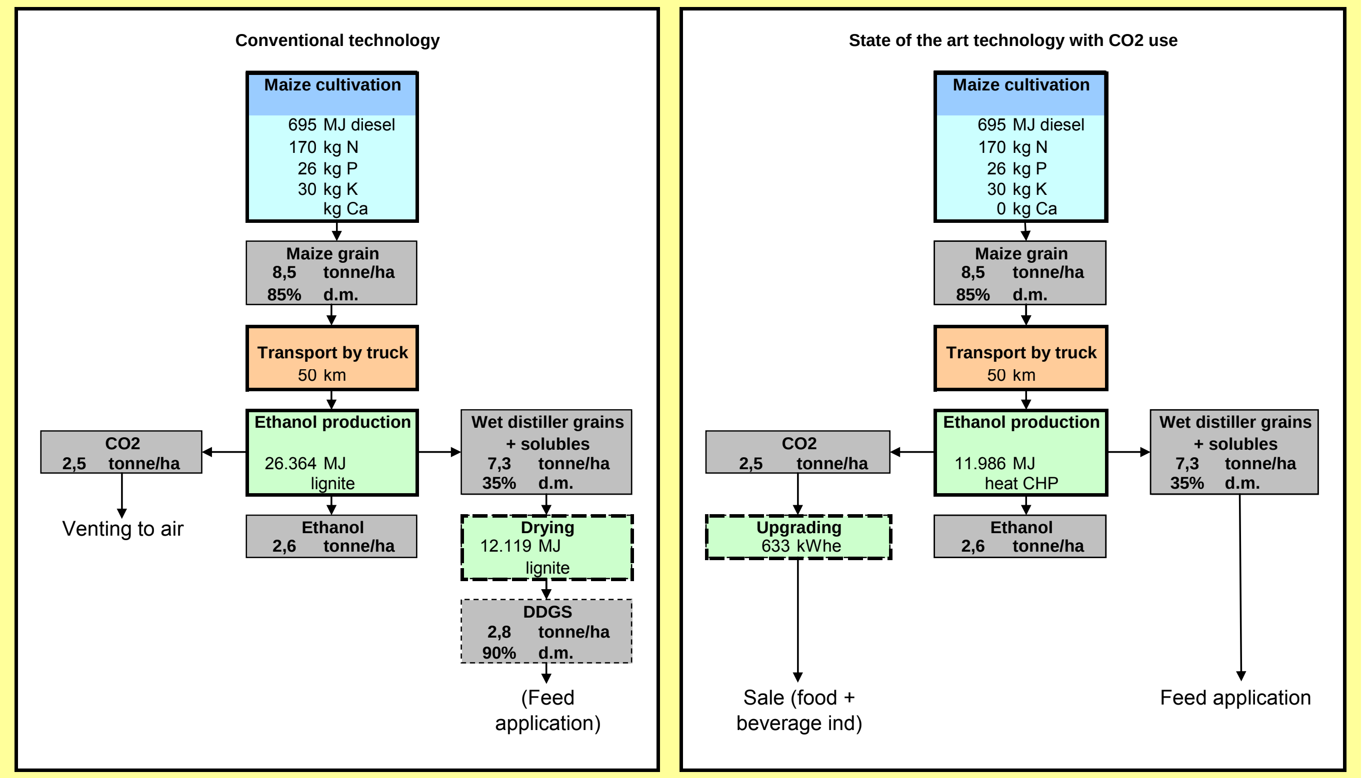
The distiller grains and solubles are consumed by cattle as a high protein feed, capable of substituting a mixture of soy meal and feed maize. As a result marginal land use change due to extension of soy cultivation can be avoided. Based on digestable protein content and metabolic energy content of DGS we estimate that 1 tonne of DDGS (90% d.s.) or 2.6 tonnes of WDGS (35% d.s.) can substitute 0.6 tonne of soybean meal and 0.4 tonnes of feed maize because of its high protein content and energy content.

C.2 GHG emissions

Mass balance and specific consumptions are given in Figure 16[18]. The total GHG emission related to consumptions of energy and additives, transportations and N_2O emissions are also given, in kg CO_2 eq./ha.

GHG emissions related to DGS drying are included, but would in case of energy content based allocation and economic value based allocation not have to be taken into account because this step is part of the DGS chain, not of the ethanol chain.

Figure 16 Maize ethanol production chain and its mass balance and direct GHG emissions



	total emission kg CO2-eq/ha
Diesel in agriculture	62
Fertilizers	1075
N2O directly from soil	667
Effects from residue	-495
Transportation	36
Ethanol production	2768
Gros GHG-emission	4113

	total emission kg CO2-eq/ha
Diesel in agriculture	62
Fertilizers	1075
N2O directly from soil	667
Effects from residue	-495
Transportation	36
Drying	719
Gros GHG-emission	2064

---

[18] Sources: CE, 2006; FAO, 2004; Parkhomenko, 2004; JEC, 2007.

C.3 Reference system and direct and indirect land use change

The maize ethanol chain is a good example of the potentially very different net GHG emission balances for different regions and different regional agricultural systems for the same biofuel. For illustrating this we considered both production in the EU and production in the USA.

C.3.1 Production in the EU

The EU is a very regulated agricultural system, imposing maximum production levels on a large number of crops cultivated within the Union. As a result large areas of land have been set aside and temporarily or finally taken out of production.
In accordance with this Ensus (2008) and JEC (2007) indicate that the most realistic reference land uses for maize cultivation for biofuels production in the EU are:

- Set aside land in Western Europe.
- Land having become available due to yield increases in cultivation in East European countries.
- Land that has previously been taken out of production in East European countries.

In all these cases land use change will not result in indirect land use changes and will probably only result in a very modest change in soil carbon stocks.

Figure 17 GHG emissions from direct LUC for maize cultivation

A. Reference land use specifications

	Reference land use		
	Set aside land	Pasture	Formerly out of production
Tonne C/ha			
aboveground biomass		2	
roots		14	
dead organic matter			

B. Maize cultivation

aboveground biomass			
roots			
dead organic matter			

C. SOC stocks

soil organic matter	78	95	78

**D. SOC stocks change factors for LUC to crop land
- decline in soil carbon**

- land use	84%	69%	84%
- tillage	100%	100%	100%
- input	100%	100%	100%

A - B + C x D: CO2-emission per hectare due to LUC

tonne CO2/ha	45	167	45

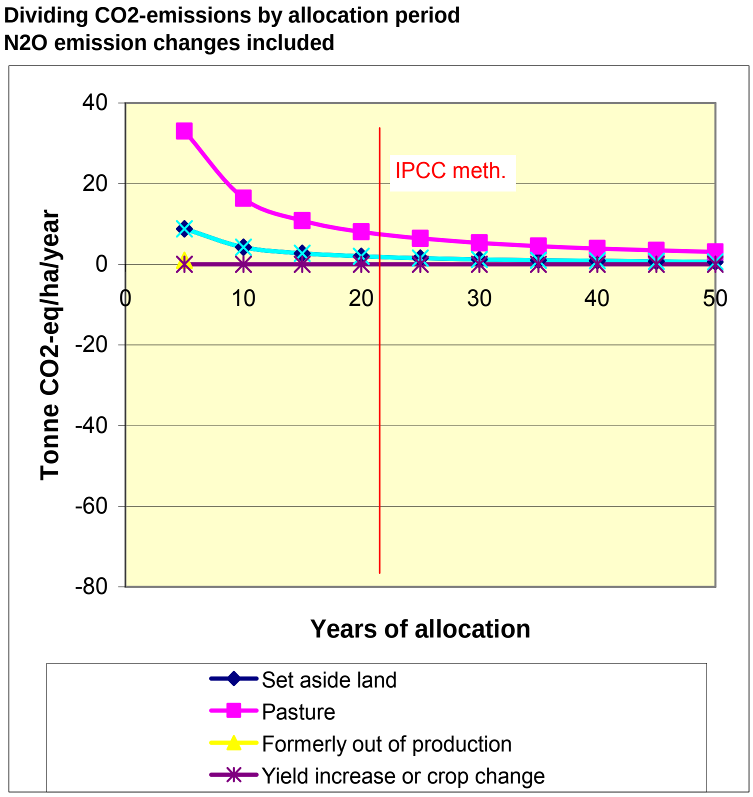
Since a field cultivated with annual crops has no permanent vegetation and associated dead litter, section B contains no figures. The same applies to set aside land and agricultural land previously taken out of production.
Permanent pastures have permanent vegetation cover, the carbon sequestered in it being released when the land is utilized for crop cultivation.

Set aside land and land previously taken out of production might accumulate some carbon in the soil because the soil is no longer disturbed. Tilling for maize cultivation will again result in enhanced soil organic matter oxidation and will reduce the soil carbon content down to its former level.

Emissions of N_2O related to maize cultivation have already been taken into account in Figure 16. The reference grass covered land however also produces N_2O emissions. The difference in N_2O emissions per hectare per year is estimated at 1 kg/ha/year in accordance with JEC (2007).

As a function of the years of allocation annual emissions can vary as illustrated below. In the emission figures an avoided N_2O emission of 1 kg N_2O/ha/year (JEC, 2007) is included.

Figure 18 Variation of annual LUC related emissions for maize cultivation as a function of the number of years of allocation



There may also be a possibility that land previously used for cultivation of export crops (cereals) is used for maize biofuel feedstock. In that case indirect deforestation may occur in case the crop is now cultivated on area outside the EU created by converting forest land into cropland. This is however not a certainty. Other possibilities are for example

- Cultivation of export cereals in Ukraine or other former Eastern Bloc on land previously set aside or taken out of production - as is happening with rapeseed[19].
- Increased production in Australia, in fact.

As stated in JEC (2007) the change and resulting effect is very difficult to quantify without global market analyses of the probabilities of this scenario in different regions and has therefore not taken into account.

Economic and Energy content based allocation

In this biofuel production chain there is at least one relevant by-product to which one can allocate part of the emissions related to the cultivation of maize and the subsequent production of ethanol: DGS.

There is also a possibility that the produced CO_2 can be sold. In North America part of the CO_2 produced is sold to food and beverage industry, which prefer CO_2 from sources such as ethanol production because of its biological origins. The CO_2, which is produced as a very concentrated gasflow (≥ 80 vol% CO_2), could also be sequestrated geologically after gas treatment.

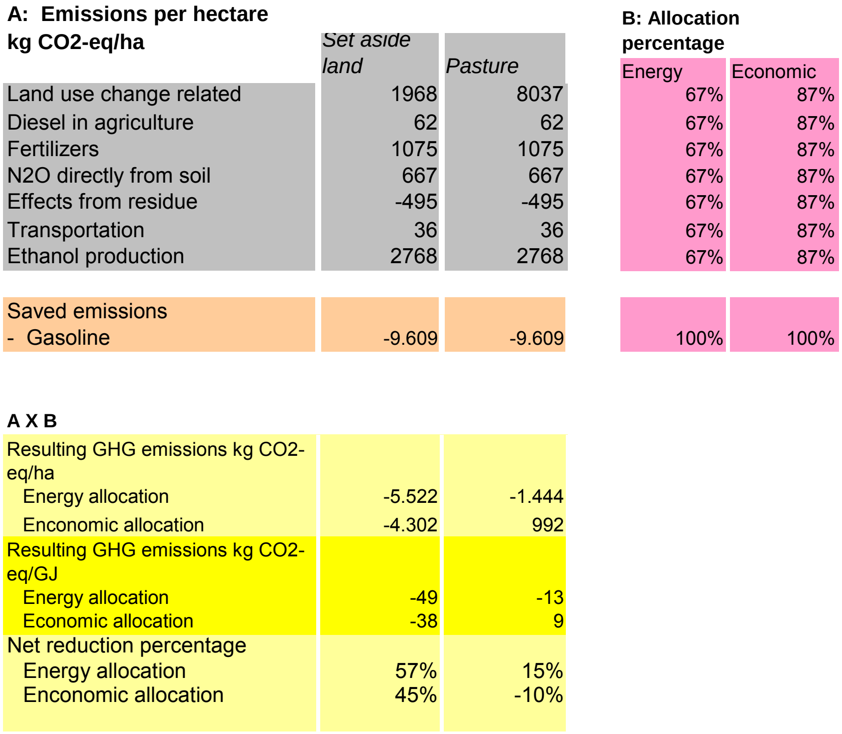
In energy based allocation no environmental impacts will be allocated to the CO_2 stream because its enthalpy is zero.

Resulting net GHG emissions are given in Figure 19 and Figure 20 for conventional and state of the art technology.

---

[19] Diversion of rapeseed cultivated in Europe for biodiesel production has not resulted primarily in expansion of palm oil area as was predicted, but in extension of rapeseed cultivation in Canada, Ukraine and Kazachstan.

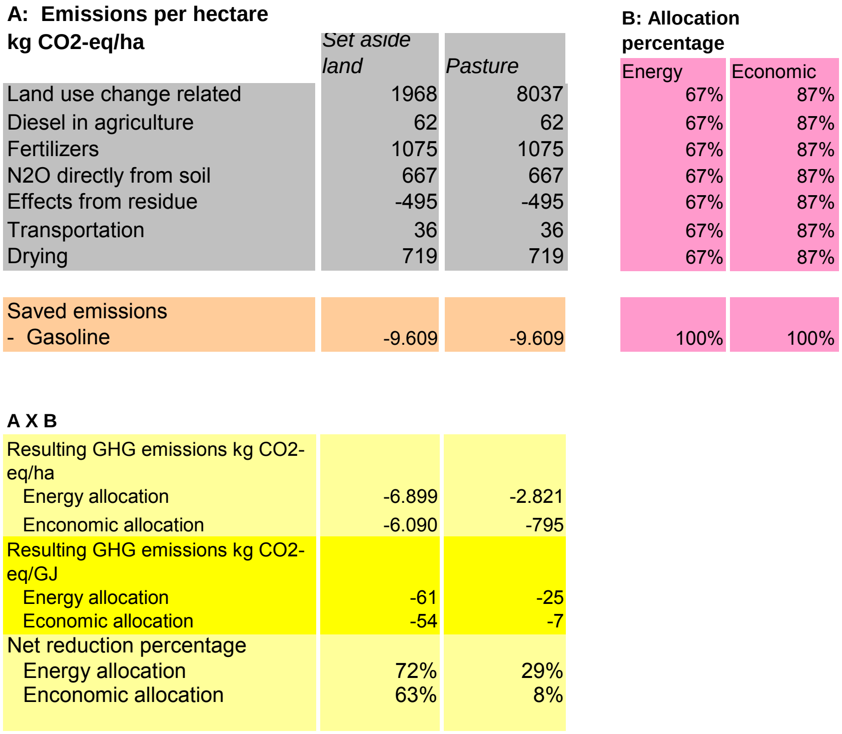
Figure 19 Net GHG emissions for maize ethanol for conventional production technology



A: Emissions per hectare **kg CO2-eq/ha**	*Set aside land*	*Pasture*	**B: Allocation percentage** Energy	Economic
Land use change related	1968	8037	67%	87%
Diesel in agriculture	62	62	67%	87%
Fertilizers	1075	1075	67%	87%
N2O directly from soil	667	667	67%	87%
Effects from residue	-495	-495	67%	87%
Transportation	36	36	67%	87%
Ethanol production	2768	2768	67%	87%
Saved emissions - Gasoline	-9.609	-9.609	100%	100%

A X B		
Resulting GHG emissions kg CO2-eq/ha		
Energy allocation	-5.522	-1.444
Enconomic allocation	-4.302	992
Resulting GHG emissions kg CO2-eq/GJ		
Energy allocation	-49	-13
Economic allocation	-38	9
Net reduction percentage		
Energy allocation	57%	15%
Enconomic allocation	45%	-10%

Figure 20 Net GHG emissions for maize ethanol for state of the art production technology



A: Emissions per hectare **kg CO2-eq/ha**	*Set aside land*	*Pasture*	**B: Allocation percentage** Energy	Economic
Land use change related	1968	8037	67%	87%
Diesel in agriculture	62	62	67%	87%
Fertilizers	1075	1075	67%	87%
N2O directly from soil	667	667	67%	87%
Effects from residue	-495	-495	67%	87%
Transportation	36	36	67%	87%
Drying	719	719	67%	87%
Saved emissions - Gasoline	-9.609	-9.609	100%	100%

A X B		
Resulting GHG emissions kg CO2-eq/ha		
Energy allocation	-6.899	-2.821
Enconomic allocation	-6.090	-795
Resulting GHG emissions kg CO2-eq/GJ		
Energy allocation	-61	-25
Economic allocation	-54	-7
Net reduction percentage		
Energy allocation	72%	29%
Enconomic allocation	63%	8%

System expansion

In system extension methodology utilization of DDGS and CO_2 and the products substituted by them are also taken into account.

Utilization of DGS as feed will very probably substitute soy and maize. Substituting primary maize will give reduced net land requirement for maize cultivation in the EU. Soy substitution may result in avoiding deforestation in Cerrado and Amazonian rain forest.
However, substituting soy meal will indirectly mean reduced production of vegetable oil. This reduction will probably require extra production of palm oil, the cheapest alternative.

The calculation of the net resulting GHG emissions is illustrated in Figure 21. Figures stem from both previous paragraphs.

Figure 21 Calculation of net GHG emissions related to utilization of DGS as feed

	worst soy, worst palm	best soy, best palm	best soy, worst palm
Ratio to soybean meal	0,60	0,60	0,60
Ratio DDGS (90% d.s.) to maize	0,40	0,40	0,40
Product per tonne maize grain (a.r.)	0,33	0,33	0,33
So in case of system extension reduction ratio in maize cultivation with	13%	13%	13%
Soy cultivation gives GHG-emission of (kg CO2-eq)	42.079	807	807
for tonnes of soy meal	1,9	1,9	1,9
for tonnes of soy oil (refined)	0,4	0,4	0,4
Per tonne of soy bean meal			
kg CO2-eq	21.579	414	414
palm oil requirement	0,2	0,2	0,2
palm oil (refined)			
kg CO2-eq	27.629	-13.955	27.629
for tonnes of palm oil:	3,7	3,7	3,7
kg CO2-eq/tonne ref palm oil	7.423	-3.749	7.423
Net GHG-emission			
avoided soy cultivation and processing	-4.316	-83	-83
extra GHG-emissions from palm oil production	1.657	-837	1.657
	-2.659	**-919**	**1.574**

The calculation illustrates that soybean meal substitution with DGS can result in reduction in GHG emissions as long as the oil palms required for substituting the missing soybean oil is cultivated on former grasslands (best palm).
The most realistic scenario is probably the one in which deforestation in the Amazone or Cerrado is avoided (worst soy), but the required extra oil palm area is created on former rain forest in South East Asia (worst palm). This scenario also yields a significant reduction in GHG emissions.
The DGS also substitutes maize as energy component in feed (see Figure 22).

Separation and upgrading of CO_2 into dry and pure gas requires 250 kWhe/ tonne, according to figures for the beer industry. Beer production, spirits production and ethanol production are basically all comparable production processes with regard to hydrolysation and fermentation, including production and potential treatment and separation of CO_2.
The upgraded CO_2 may substitute CO_2 produced from geological CO_2 accumulations such as the Montmiral gasfield or CO_2 stemming from industrial processes, such as ammonia production. In any case, the substituted CO_2 is of fossil origins.
Total resulting GHG emissions amount to the figures given below.

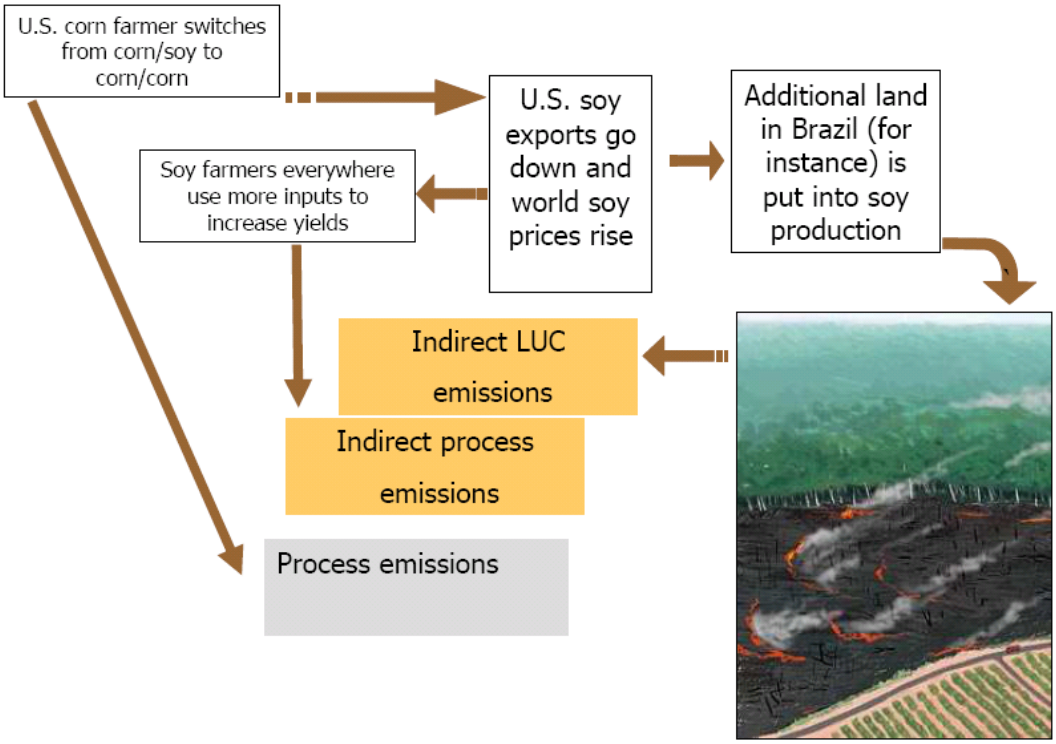
Figure 22 Net GHG emissions for maize ethanol, applying system extension allocation methodology

	Conventional technology		State of the art technology	
	Set aside	*Pasture*	*Set aside*	*Pasture*
Land use change related	1.968	8.037	1.968	8.037
Diesel in agriculture	62	62	62	62
Fertilizers	1.075	1.075	1.075	1.075
N2O directly from soil	667	667	667	667
Effects from residue	-495	-495	-495	-495
Transportation	36	36	36	36
Ethanol production	2.768	2.768	719	719
WDGS drying	1.273	1.273		
CO2 upgrading			291	291
Saved emissions				
- gasoline	-9.609	-9.609	-9.609	-9.609
- Fossil CO2			-2.532	-2.532
- Maize cultivation	-437	-437	-437	-437
- Soy cultivation	-2.659	-2.659	-2.659	-2.659
Total GHG-emissions				
kg CO2-eq/ha	-5.351	718	-10.913	-4.845
kg CO2-eq/GJ	-47	6	-96	-43
Net reduction percentage	56%	-7%	114%	50%

C.3.2 Maize cultivation in the USA

Maize based ethanol production in the USA is comparable with maize based ethanol production in the EU.
However, land use change aspects differ between both regions. Maize cultivated in the USA seems to be cultivated primarily at the expense of soy. In that case there is a possibility that indirect land use change at the expense of natural areas in Latin America will occur - as illustrated by Berkeley.

Figure 23 Land use change as a result of maize cultivation for bioethanol production in the USA[20]



However, in that case too the DGS by-product will partly substitute soy and maize cultivation for feed applications. Given following ratio's:

- A substitution ratio of 0.6 tonnes of soy bean meal and 0.40 tonnes of maize per tonne of DDGS.
- A production ratio of 2.8 tonnes of DDGS per hectare of maize.
- A production ratio of 0.33 tonnes of DDGS per tonne of maize.
- A substitution ratio of (0.4 x 0.33) = 0.13 tonnes of maize per tonne of maize.

One hectare of maize for bioethanol production will net substitute

$$(2.8 \times 0.6) \div (1 - 13\%)^{21} = 1.96 \text{ tonnes}$$

of soy bean meal. This is equivalent to 1.96 ÷ 80% = 2.47 tonnes of soy bean.

---

[20] See http://www.arb.ca.gov/fuels/lcfs/011708UCBLUCcolor.pdf.

[21] This fraction of 1-13% = 87% represents the reduction in area required for fodder maize cultivation. The area thus becoming available may also be applied for cultivation of bioethanol feedstock maize.

Soy yield per hectare in the USA amounts to 2.9 tonnes/ha. Given the estimate that DGS can substitute the equivalent of 2.5 tonnes of soy bean as protein source, the DGS produced almost completely compensates for the decrease of local soy production. Only a relative small amount of 0.4 tonnes of soy beans has to be produced abroad.

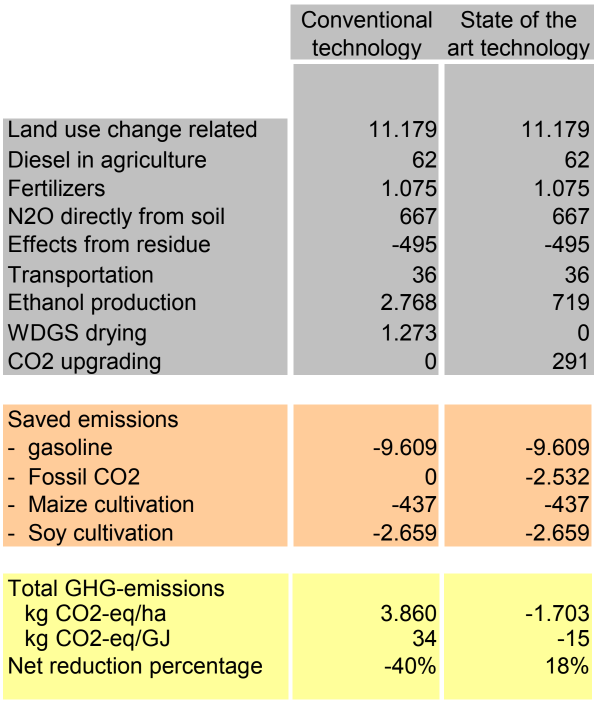
Substituting soy cultivation will however also avoid soy oil production of 2.5 x 0.2 = 0.5 tonnes per hectare of maize. The avoided oil production will have to be compensated by extra vegetable oil production from other sources. Most likely alternative source is palm oil.
Assuming that both cultivation of extra soy abroad and production of extra palm oil will result in indirect deforestation in Latin America and South Asia - worst case approach - the indirect land use change effects result in an extra GHG emission of 11,180 kg CO_2 eq./hectare of maize.

Table 4 Estimating GHG emissions related to extra soy bean and oil palm cultivation

	Tonne/ha maize	kg CO_2 eq./tonne product	kg CO_2 eq./ha maize
Extra soy beans	0.4	17,642	7,505
Extra palm oil	0.5	7,423	3,674
			11,179

This indirect emission will counterbalance the GHG emission reduction related to bioethanol utilization in case of conventional technology. In case of state of the art technology utilization of CO_2 in food industry results in a small net reduction of GHG emissions compared with the reference system.

Figure 24 Net GHG emissions for bioethanol from maize cultivated in the USA - worst case approach for ILUC



	Conventional technology	State of the art technology
Land use change related	11.179	11.179
Diesel in agriculture	62	62
Fertilizers	1.075	1.075
N2O directly from soil	667	667
Effects from residue	-495	-495
Transportation	36	36
Ethanol production	2.768	719
WDGS drying	1.273	0
CO2 upgrading	0	291
Saved emissions		
- gasoline	-9.609	-9.609
- Fossil CO2	0	-2.532
- Maize cultivation	-437	-437
- Soy cultivation	-2.659	-2.659
Total GHG-emissions		
kg CO2-eq/ha	3.860	-1.703
kg CO2-eq/GJ	34	-15
Net reduction percentage	-40%	18%

D Defaults

Fuel_defaults		
Diesel1)	0,090	kg CO2-eq/MJ
Gasoline	0,084	kg CO2-eq/MJ
Fuel oil2)	0,087	kg CO2-eq/MJ
Natural gas2)	0,060	kg CO2-eq/MJ
kolen		kg CO2-eq/MJ
Industrial heat		kg CO2-eq/MJ

Elec_defaults		
Netherlands		kg CO2-eq/MJ$_e$
Europe	0,128	kg CO2-eq/MJ$_e$
Africa		kg CO2-eq/MJ$_e$
Asia	0,147	kg CO2-eq/MJ$_e$
Latin America		kg CO2-eq/MJ$_e$
North America		kg CO2-eq/MJ$_e$

Fertilizers		
N_fertilizer_defaults	6,065	kg CO2-eq/kg N
Urea	2,330	kg CO2-eq/kg N
KAS	7,480	kg CO2-eq/kg N
P_fertilizer_defaults	1,018	kg CO2-eq/kg P
K_fertilizer_defaults	0,583	kg CO2-eq/kg K
Ca_fertilizer_defaults	0,124	kg CO2-eq/kg Ca
Pesticides	17,258	kg CO2-eq/kg pest

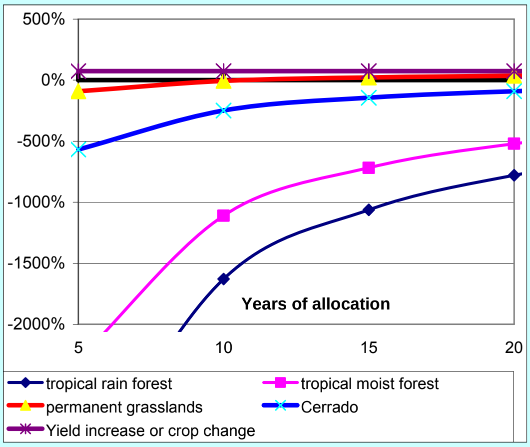
Transport_defaults		
Tractor		kg CO2-eq/tonne·km
Truck	0,085	kg CO2-eq/tonne·km
Barge	0,038	kg CO2-eq/tonne·km
Seaship	0,018	kg CO2-eq/tonne·km
Train	0,027	kg CO2-eq/tonne·km

E Factsheets

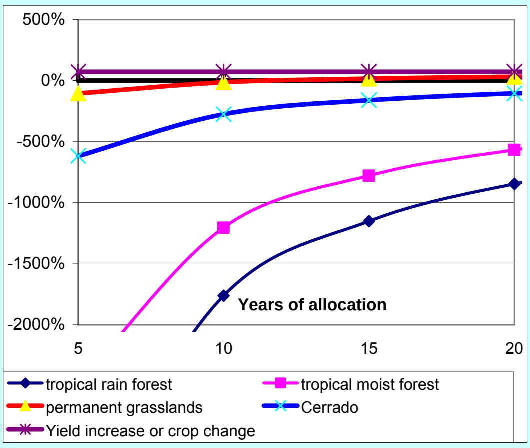
E.1 Soy bean oil based biodiesel

Net GHG emission reduction compared to diesel

Energy allocation



Economic allocation



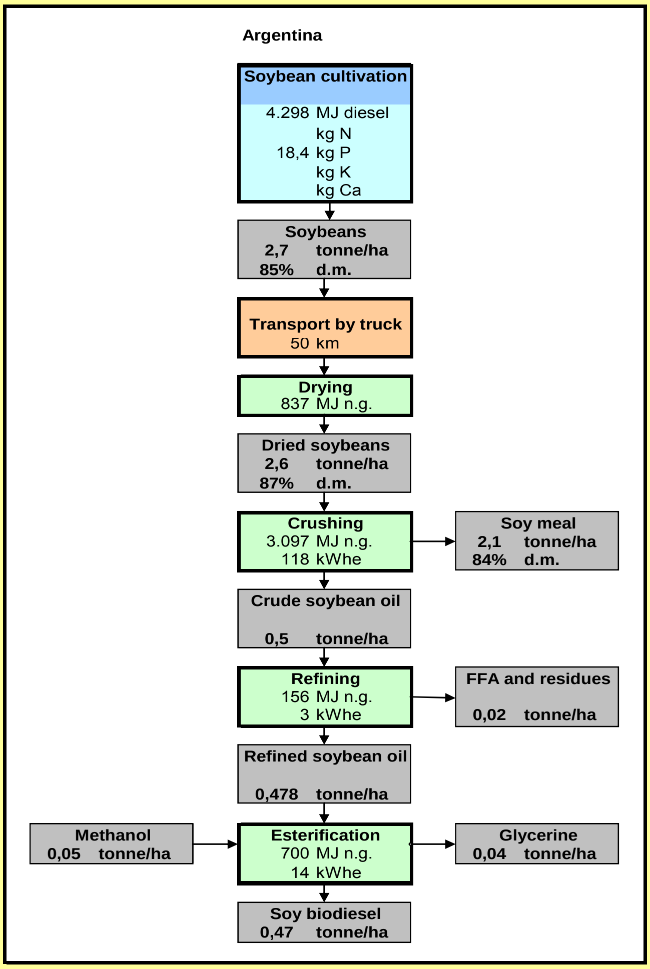
System extension

Not relevant

Methodological aspects

Location	Argentina
Period	Short term
Forms of land use for cultivation	Tropical rain forest Tropical moist forest Permanent tropical grass lands Cerrado Crop yield increase
Indirect market and land use effects?	Can occur, when soy cultivation replaces cattle breeders and smal farmers
Impact applied technology	Marginal, little differences in technology

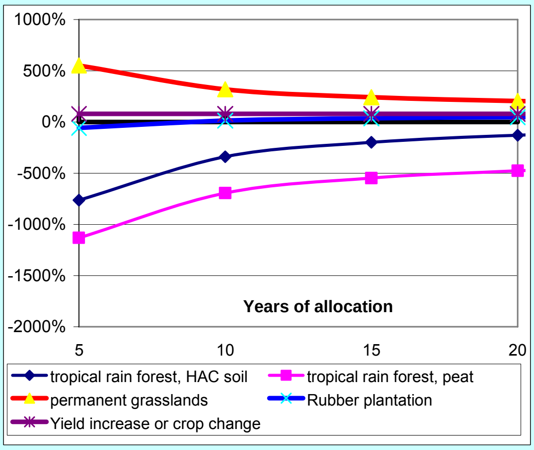
Mass balance and direct GHG emissions



E.2 Palm oil based biodiesel

Net GHG emission reduction compared to diesel

Energy allocation



Economic allocation

Same as for Energy based allocation

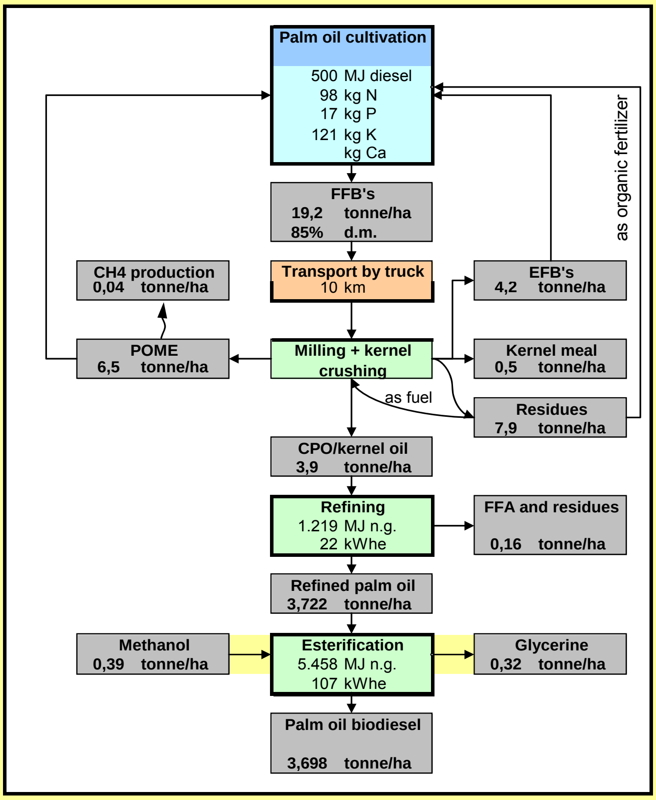
System extension

Not relevant

Methodological aspects

Location	Malaysia, Indonesia
Period	Short term
Forms of land use for cultivation	Tropical rain forest Tropical moist forest Permanent tropical grass lands Rubber plantations Crop yield increase
Indirect market and land use effects?	Marginal, palm oil plantations realized in previously intact jungle or replacing uneconomic rubber plantations.
Impact applied technology	Generally small differences in technology. However fate CH4 from POME has high impact on net GHG emmissions.

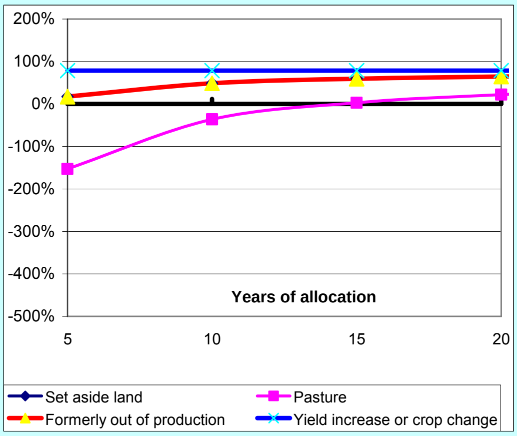
Mass balance and direct GHG emissions



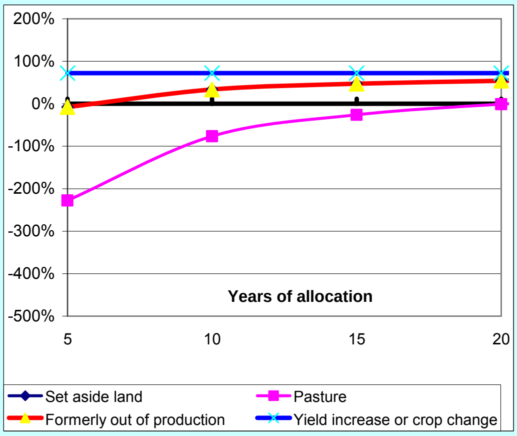
E.3 Maize based ethanol

Net GHG emission reduction compared to diesel

Energy allocation



Economic allocation



System extension

Methodological aspects

Location	USA and EU
Period	Short term
Forms of land use for cultivation	Set aside land Pastures Soy fields Fields previously out of production
Indirect market and land use effects?	When replacing existing economic viable cultivation, that cultivation probably relocated, affecting nature
Impact applied technology	Large range in technologies, modern heat-integrated with CO2 utilization to old with high fuel consumption

Mass balance and direct GHG emissions, modern