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PBL publication number 500143004

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Abstract

The cultivation of energy crops on arable land may lead to the displacement of food crops and to indirect land-use change (ILUC). Some of the energy crops for biofuels deliver feed as by-products, and this will have an impact on the global feed market. These by-products could be a substitute for other crops cultivated for feed elsewhere. In those cases, the net land use for biofuel crops would be reduced substantially (for rapeseed and wheat by 50 to 100%, based on the substitution of soy meal).

Still, the impact of this land-use effect on the overall greenhouse gas emissions can be substantial, but sensitive to assumptions on yields and regional land-use change. In case land use in Europe (for wheat and rapeseed) is compared to land use in Latin America (for soy), regional differences in ILUC emissions strongly determine the overall emissions strongly.

1. Introduction

The production of many biofuel crops generates by-products (or co-products), such as compounds for animal feed. They might replace other feed products. In such cases, less land is required for feed production elsewhere. This means that net land-use for the biofuel is considerably less than the area needed for the cultivation of the energy crops. This positive effect has to be included in the impact assessment of biofuels.

An important issue in the sustainability assessment of biofuels from energy crops, which are cultivated on agricultural land, is indirect land-use change (ILUC). This is the shift of agricultural production for food to other locations. By-products also affect this indirect land-use change. When bio-energy crops generate feed as by-products and feed production elsewhere can be avoided, the indirect land-use change is smaller. By-products, therefore, are relevant in the analysis of indirect land-use effects.

Rapeseed (for biodiesel) and wheat (for ethanol) are important energy crops in Europe. Both generate by-products with high protein content, such as rapeseed meal and DDGS. These by-products can be a substitute for soy meal, which is the main protein commodity in the European feed production chain. This substitution may lead to less soybean cultivation and, thus, impacts the indirect land-use change from biofuel production. We analysed the contribution of this substitution to the indirect land-use effects and the overall greenhouse gas emission reduction from biofuel production.

2. How to assess the sustainability of biofuels, taking their by-products into account?

By-products cause interdependency between biofuel and feed production chains. This complicates the calculation of

Multi-product crops

Biofuel is not the only product made from energy crops such as rapeseed, wheat and soy.

Rapeseed: Rapeseed oil is used for biodiesel production (± 0.35 kg/kg of raw rapeseed) by esterification with methanol with the by-product glycerine (± 0.035 kg/kg). Rapeseed meal (± 0.5 kg/kg) is a protein-rich by-product. It can be used as feed or for process energy. Other possible by-products are honey and straw.

Wheat: Starch in wheat is the resource for ethanol production (± 0.3 kg/kg of wheat grains). DDGS (Dried Distillers Grains with Solubles, ± 0.3 kg/kg) is a protein-rich by-product of ethanol production, suitable for feed or process energy. Other by-products are bran and straw (used in stables).

Soy: Soy meal is the main product: ± 0.76 kg/kg of soy beans. From the soy oil ± 0.16 kg/kg of biodiesel can be produced with ± 0.016 kg/kg of glycerine as a by-product.

Methods for allocating environmental impacts (emissions, land use) of one process or production chain to the different products (such as biofuels and feed) **Table 1**

Method	Advantages	Disadvantages
Allocation based on the energy content of the products	Relatively simple Physical parameters are (quite) constant For biofuels, energy is the main quality aspect Producer controls the result	It does not simulate the actual processes Products with applications other than bio-energy are not valued in a proper way
Allocation based on the economic value of the products	Relatively simple All products are valued on an equal basis	Economic values fluctuate strongly Producer does not control the result It does not simulate the actual processes
Allocation based on substitution of one product by another	The best simulation of the actual impact All products are valued in a comparable way, based on their physical properties and applications Producer controls the result	A detailed analysis can be very complicated; simplification threatens to erode the first two advantages

Comparable systems (producing equivalent amounts of products) **Table 2**

Comparison	Reference system based on fossil oil and soy	Alternative bio-energy system
Rapeseed system	Fossil oil for diesel and glycerine Soy for biodiesel, feed and glycerine	Rapeseed for biodiesel, feed and glycerine
Wheat and rapeseed system	Fossil oil for petrol Soy for biodiesel, feed and glycerine	Wheat for ethanol (substituting petrol) and feed Rapeseed for biodiesel, feed and glycerine

greenhouse gas emission reductions and indirect land-use changes induced by bio-energy products, such as biofuels. There are three options to quantify this effect:

1. Integrated models could help in the assessment of the interactions between a new fuel–feed production chain and global economic and physical systems;
2. A simple life-cycle analysis (LCA) can be done, including a specification of overall impacts from biofuel production chains for energy products and by-products;
3. An extended life-cycle analysis (LCA) of the combined fuel and feed production chains can be done, including the substitution of animal-feed ingredients (e.g. soy meal) by biofuel by-products.

A simple LCA can be quite straightforward if all of these processes and their impacts are dedicated to biofuel only. However, when animal-feed components are involved, it is more complicated to determine the biofuel share in the total impact. Part of the impact can be dedicated to the feed. How greenhouse gas (GHG) emissions and land-use claims are divided over the various end products is a problem of allocation. Table 1 presents different approaches of this problem.

The EU Renewable Energy Directive (RED; EU, 2009) prescribes the allocation method for greenhouse gas emissions, based on energy content. For energy-related applications of all products, this is a relatively simple and straightforward method, and has been considered the most suitable for regulatory purposes. However, if the by-product is used as feed, then it is not the energy but the protein content that is its most important property. Therefore, the energy-based allocation method is not necessarily the most suitable for the allocation of land use.

Because an allocation based on substitution is regarded as a better approximation of reality, the EU directive also prefers this method for evaluation purposes. Such an application of the extended life-cycle analysis (LCA) method is very useful for obtaining a better understanding of the problem. It is more complicated than the energy-based allocation method, and also needs some simplification to prevent it from overextending. Nevertheless, this method is easier to apply than introducing this type of substitution in complicated integrated models. But allocation of land use or calculation of the net land use for biofuels is just the first step in the assessment of indirect effects. The integrated models are indispensable for covering other aspects of the complex issue of indirect effects on a global scale.

In this report, we present the results from an extended life-cycle analysis (allocation based on substitution) of estimating the net land use for biofuel crops. Such an approach involves all processes in the production-consumption chains of biofuels and feed. A sensitivity analysis has been executed for the indirect impact of this land use on greenhouse gas emission levels.

3. Combined biofuel and feed production

Two types of production systems are compared: one reference system based on fossil oil and soy, the current dominant resources for fuel and (proteins in) feed in Europe; the other an alternative system based on the energy crops rapeseed and wheat. In these comparisons, glycerine, a by-product in the production of biodiesel, is also taken into account. Table 2 gives the details on the systems in two significant comparisons. In the first alternative, rapeseed is used as a bio-energy crop; in the second, wheat is the main energy crop for ethanol, and rapeseed is added for biodiesel, to compensate for the (relatively small) amount of biodiesel by-product from soy production in the reference system.

The comparisons imply that equal amounts of fuel and feed are produced. For fuels, the produced amount of energy (Joules) has to be the same in both systems. The equivalency of feed is based on the protein content. Both systems have to

Yields and fertiliser use
Table 3

Rapeseed	Yield level	Yield (tonnes/ha.y)	N dose (kg/ha.y)
Rapeseed	High	4.5	175
	Low	4.0	100
Wheat	High	9.0	175
	Low	7.0	130
Soybeans	High	3.5	5
	Low	2.5	5

Greenhouse gas emissions and land use in the compared fuel and feed production systems
Table 4

Bio-energy system	GHG reduction* % (compared to reference system)	Increase in land use % (compared to reference system)	% of energy cropland allocated to feed based on the substitution method
rapeseed	35 - 55	15 - 80	55 - 85
wheat and rapeseed	30 - 40	0 - 70	60 - 100

* excluding land-use change emissions and other indirect emissions

produce the same amounts of proteins. Basic protein levels adopted in this analysis are 46% for soy meal, 32% for Dried Distillers Grains with Solubles (DDGS), and 31% for rapeseed meal. Data on direct emissions from the production chains are based on JRC/CONCAWE/EUCAR (2007) and Hamelinck and Hoogwijk (2007).

Crop production figures
In the analysis we used representative figures for the production of the crops (inputs, yields). The assumptions on crop yields and fertiliser doses in the cultivation step of the selected systems are based on an analysis of agricultural crop yield statistics, and on fertiliser use data (FAO, 2008; IFA 2006-2007). The figures used reflect the agro-ecological conditions and common management techniques (soybean cultivation in Latin America, and the cultivation of wheat and rapeseed in north-western Europe).

Table 3 summarises the assumptions, with the distinction of two situations for each crop/biofuel combination to enable an assessment of the impact of the cultivation step. For the N_2O emissions from land use (due to the use of fertilisers), the IPCC emission factor was used.

4. Greenhouse gas emissions and land use in bio-energy systems

Bio-energy systems based on energy crops, such as rapeseed and wheat, require land. Using by-products to substitute soy meal means a reduction in land use for soy cultivation. Therefore, the increase is limited and dependent on the assumptions about the yields (reflected in the ranges in Table 4). It should be noted that land in Europe and land in Latin-America are not equal in all respects. However, if this method is applied for allocation, about 50 to 100% of the land needed for the energy crops rapeseed and wheat is allocated to by-products used for feed (allocation based on energy results in 40 to 50%).

Table 4 presents only the direct greenhouse gas emission reduction. The impact of by-products on net land use for biofuel products is substantial. Still, there is an increase in land-use in the alternative bio-energy systems and thus, indirect land-use change emissions remain an issue. Indirect emissions should also be included in overall emission effects.

5. Overall greenhouse gas emission reductions including indirect emissions: a sensitivity analysis

An extended life-cycle analysis (LCA) is not suitable for the calculation of emissions from indirect land-use change (ILUC), because these emissions are related to global system dynamics. For these ILUC emissions, there are no undisputed data at this moment. They strongly depend on the ratio of intensification and land conversion for the necessary increase in agricultural production, on specific yields and on the types of land converted. Furthermore, they can be different for different world regions. For this brief report, a sensitivity analysis has been executed, using potential ILUC emissions.

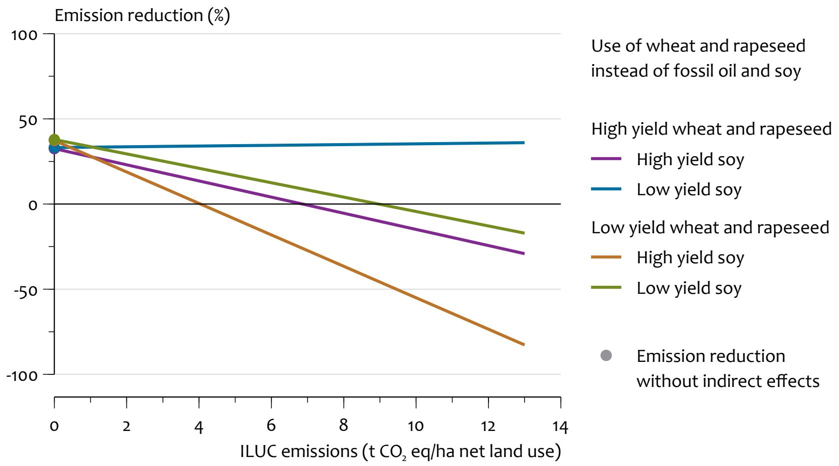
What is the order of magnitude for ILUC emissions? Based on several studies (Ecofys, 2009; California EPA, 2009; Fritsche, 2009), we concluded that, for biofuels, indirect emissions are most likely to be in the range of 4 to 13 tonnes CO_2 eq/ha per year (on average over a period of 30 years and neglecting indirect emissions from intensification).

This number is only an indication. In actual practice, ILUC emission levels are not constant. They depend on many different circumstances and vary over time. In our comparisons, we calculated with ILUC emissions from biofuel production, varying from 0 to 13 tonnes CO_2 per hectare.

Sensitivity for yields
For the system based on wheat and rapeseed, Figure 1 shows how the overall greenhouse gas emission reductions depend on the ILUC emissions, if we apply them to the net land-use change based on the substitution method. In this case, for the reference system and the alternative bio-energy system, we assumed that the ILUC emissions per hectare of land use are the same in Europe and Latin-America. The different lines in Figure 1 reflect different situations with high and low yields.

Effect of indirect land use on reduction in greenhouse gas emissions from biofuels **Figure 1**

Sensitivity to yield assumptions



Greenhouse gas emission reduction regarding different ILUC emission factors for land use in Europe and Latin America (system B: wheat/rapeseed) **Table 5**

	ILUC in EU 5 tonnes/ha ILUC in LA 5 tonnes/ha	ILUC in EU 3 tonnes/ha ILUC in LA 7 tonnes/ha	ILUC in EU 7 tonnes/ha ILUC in LA 3 tonnes/ha
wheat and rapeseed	- 10 to 30%	60 to 90%	-70 to -35%

The overall emission reduction depends on yields, which determine net land use. The slopes of the lines in Figure 1 indicate the net land use for biofuel crops, which strongly dependents on assumptions on yields. In a situation of high wheat and rapeseed yields and low soy yields there is no extra land use, because the area of land used in soybean production is similar to that used in wheat/rapeseed production. In such a rather exceptional case, ILUC emissions would not have a relevant impact on the greenhouse gas emission balance.

In most other cases, overall reduction in greenhouse gas emissions gradually decreases with increasing ILUC emission factors. Even though the indirect land use for biofuels is reduced by more than 50% as a result of the extra feed products, the overall emission reduction is expected to go down, substantially, in many cases. Negative emission reductions cannot be excluded.

Sensitivity to by-product characteristics

Figure 2 shows the sensitivity of the calculated overall emission reduction of the biofuel to the protein content of the by-products. When the protein content is 20% lower, less soy can be substituted and net land use of the biofuels is significantly higher. It is reflected in the impact of ILUC emissions on the overall emission reduction. The proteins in Dried Distillers Grains with Solubles (DDGS) and rapeseed meal are not the same as the proteins in soy meal. This fact may also lead to a lower substitution potential.

What would be the situation, if by-products are not applied as feed? Instead, they could be used as an energy source in biofuel production. The direct emission reduction would be larger, because less fossil fuel would be burned in the process. But, so would the net land use and, therefore, the overall emissions very strongly depend on the ILUC emission factor (Figure 2).

Sensitivity to regional differences in ILUC emissions

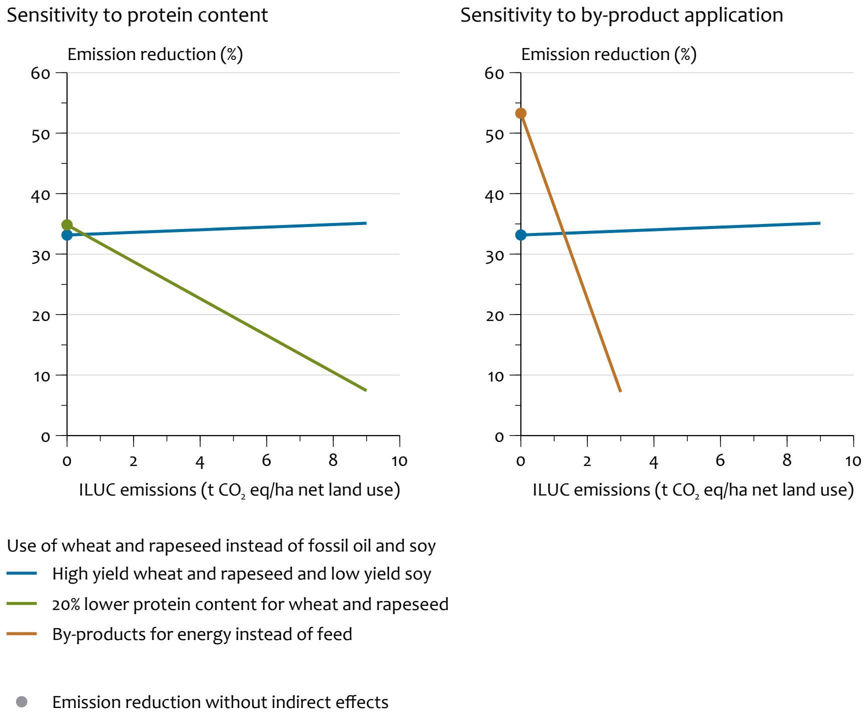
A specific new (energy) crop grown on agricultural land in a specific region causes indirect land-use change on a global scale. Still, the indirect effects per hectare of land used in Latin America and Europe may be different. In the case of relatively high ILUC emissions from crops in Latin America, due to a large share in forest conversion, substituting these crops would have an important positive impact. However, relatively high ILUC emissions related to European land use might lead to strongly negative emissions. This could be the case if high productivity levels within Europe require more land to be used elsewhere, in a shift in production.

We examined the sensitivity of the overall emission reduction, for different assumptions on ILUC emissions (Table 5). The overall results show that the differences in ILUC emission factors strongly determine the overall emission reductions from biofuel production.

6. The potential of soy meal substitution by biofuel by-products

The above analysis is based on the assumption that soy meal is substituted by biofuel by-products. How real is this assumption? A main driver, of course, is the soy meal price and that of its potential substitutes. In this brief report, we

Effect of indirect land use on reduction in greenhouse gas emissions from biofuels **Figure 2**



focus on the technical aspects. By-products, such as rapeseed meal and Dried Distillers Grains with Solubles (DDGS), could replace soy meal, but this begs the question of whether the potential production of first-generation biofuels, within Europe, would generate too many of these by-products?

If, by 2020, 5% of transport fuels in Europe are biofuels (about 1.5 EJ/year), and the production of feed components consists of about 0.04 kg per MJ of produced biofuels, then the total EU production of feed components from biofuels would amount to 60 Mt/year.

Present feedstuff consumption in Europe is 450 Mt/year (Fefac, 2006). The total application of oil cakes and meal in Europe for cattle feed is 52 Mt/year – 34 of which are derived from imported soybean meal. On the assumption that one unit of soybean meal is equivalent to about 1.5 units of non-soybean meal (considering the difference in protein content and protein types), the feedstuff market in Europe might be able to absorb about 50 Mt/year of non-soybean meal. This amount may be a conservative estimate, because of expert judgments that the percentage of meal and cakes in the animal diet might increase further. Therefore, the potential for substitution is large.

In actual practice, rapeseed meal and DDGS are being used as animal feed, but no data are available to assess the extent to which this application has already become common practice, in combination with biofuel production. Some of the by-products may be used for process energy.

Substitution of soy meal by other products is only partly a matter of the protein content. The quality of the proteins and other components are relevant, as well. Changing the composition of animal feed is more than simply substituting one protein source for another. Differences in many other aspects of feed quality also determine the potential of soy meal substitution. Present quality of rapeseed meal and DDGS does impose some restrictions on their application. However, for any potential market, research is expected to focus on quality improvement.

7. Other aspects of biofuels and feed

Sustainability of feed

The impact of soy meal substitution on net land use and greenhouse gas emissions from biofuels, based on crops such as rapeseed and wheat, is no indication of the sustainability of the feed itself. In an extended life-cycle assessment (LCA) approach, the impact of soy meal production is deduced from the impact of the bio-energy system. In general, this approach implicitly assumes sustainability of the soy meal and feed. Monitoring shows that global feed production is one of the important drivers of land-use changes and all associated impacts (biodiversity loss, greenhouse gas emissions). Therefore, allocating part of the land use to feed crops in a sustainability assessment is questionable.

Indirect effects of meat consumption

By-products of biofuels entering the market as feed components may have an impact on feed prices in general. An increased supply of feed would decrease feed prices, which, in turn, might increase meat production and consumption. This dietary shift could lead to additional greenhouse gas emissions, taking away some of the positive effects by-products may have.

ILUC effects of waste streams for energy

It should be noted that there is another interaction between bio-energy and feed, with opposite effects from those described for by-products. Waste streams from the agro-food industry can be a resource for energy as well as for feed. Once a feed resource is turned into an energy resource, the feed would have to be produced another way. This might require land and, therefore, indirect land-use changes cannot be excluded in cases where waste streams are used for bio-energy.

8. Conclusions

- Bio-energy products based on rapeseed and wheat have by-products that are used for feed. If they substitute soy meal, the land use for soy cultivation can be reduced by 50 to 100% compared to the land used for the cultivation of the rapeseed and/or wheat (based on the protein content). Therefore, by-products used for feed may substantially change indirect effects of land-use change and overall greenhouse gas emission reductions from biofuel production.
- The net land use for bio-energy from rapeseed and wheat is strongly dependent on the assumptions about agricultural yields and protein content.
- Land in Europe is not the same as land in Latin America. The overall emission reductions from biofuel production are quite sensitive to assumptions on ILUC emissions from new crops grown on agricultural land in different world regions. This impact can be either positive or negative.
- Although the potential market for protein-rich feed in Europe allows for wider application of products, such as rapeseed meal and DDGS from wheat, their future application might be limited for reasons of quality. In case the same by-products are used to generate energy, the direct emissions are somewhat lower (and the reduction higher), but indirect emissions are likely to be much higher.

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Colophon

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