

Identifying the indirect effects of bio-energy production

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Identifying the indirect effects of bio-energy production

Abstract

By replacing fossil fuels bioenergy has the potential to reduce greenhouse gas (GHG) emissions, but indirect effects might partly or even completely eliminate this benefit. Production of bio-energy products, such as biofuels for transport, causes several indirect effects through their interactions with the global economic and physical systems. Indirect land-use change leads to GHG emissions – in some cases in the same order of magnitude as the fossil emissions – and loss of nature, but there are other relevant indirect effects as well. Intensification of agricultural production is another indirect effect and could be stimulated more to minimise the undesirable land conversion. However, intensification through increased fertiliser use can also lead to high GHG emissions. For preventing those indirect emissions, the focus in intensification should be on improvement of fertiliser use efficiency.

The direct effects of bioenergy are measurable and the responsibility of the producers. Indirect effects are less easy to quantify and more difficult to ascribe to producers or consumers. Therefore, in contrast to direct effects, indirect effects are neither included in present sustainability criteria of EU-policy, nor are they covered by other policy measures. A problem for including indirect effects in criteria is that these effects – opposite to direct effects – vary in space and time because global systems are dynamic and this variation is beyond producer control.

1. Introduction and objective of this brief report

The sustainability of bioenergy has been discussed widely in recent years. Sustainability criteria have been introduced, mainly focusing on direct effects of the production chain of bioenergy products. But the potential impact of bioenergy crops goes beyond that. It is recognized that bioenergy may cause significant indirect effects in other production systems too. Two indirect effects received much attention in public debate: indirect land use leading to GHG emissions and biodiversity loss, and indirect impact on food prices determining the availability of food for the poor. In the context of complex and scientifically uncertain issues, encompassed with political dilemmas, a policy discussion

takes place to create additional sustainability criteria to mitigate the impact of indirect effects.

Proper problem framing of the issue will help to facilitate discussion.

The objective of this brief report is to present an overview of the most important indirect effects of bioenergy products such as biofuels. We indicate the relationships between their production chains (with direct effects) and the indirect effects. Special attention is given to land use, biodiversity and GHG emissions. Although it is not our main goal in this brief report to present many data or results of calculations, the potential contribution of specific indirect effects to the overall impact is illustrated.

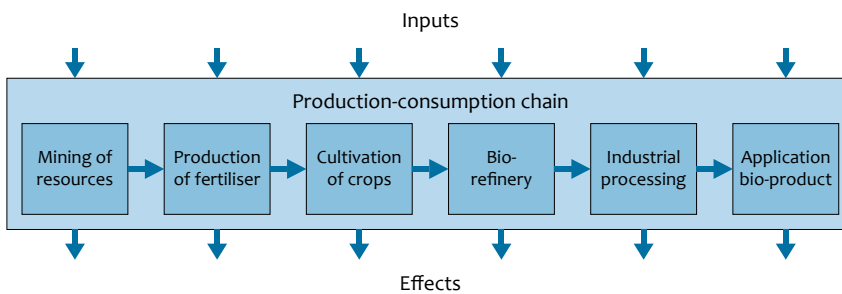
2. Policy context

In December 2008, the EU adopted a new policy on biofuels as part of a new Renewable Energy Directive (RED; EU 2009a), an ingredient of the EU Climate and Energy Package¹. This Directive details on the EU objective of a 20% overall share of energy from renewable sources by 2020 and includes 10% energy from renewable sources in transport. Bio-energy is an important option for meeting these goals, and specifically biofuels for transport.

The debate on the sustainability of biofuels set off relatively late during the process of political decision-making. This discussion also influenced the negotiations on the renewed Fuel Quality Directive (EU 2009b), which includes a 10% reduction target for greenhouse gas (GHG) emissions for 2020 for transport fuels. Under time pressure and in close cooperation between the European institutions it was decided to include a set of sustainability criteria for biofuels, both in the Renewable Energy Directive and the Fuel Quality Directive. But this set of criteria does not cover all issues and is no guarantee for sustainability.

The issue of indirect land-use changes (ILUC) of biofuels, which was put on the agenda by several researchers and

¹ climate and energy proposals by the European Commission released on 23 January 2008



Production-consumption chain of a bio-energy product with inputs (resources such as energy, labour, fertiliser) and outputs (e.g. emissions and products).

institutes (Gallagher, 2008; Eickhout et al., 2008; Searchinger et al., 2008; Fargione et al., 2008), played an important role in the debate on the sustainability of biofuels. However, because of difficulties to define indirect land-use changes in a legal policy context, scientific uncertainties to quantify the impacts, and because of time constraints, it was decided to keep the effects of ILUC out of the sustainability criteria included in the Directives. However, the Directives require that the European Commission submits a report to the European Parliament and Council by the end of 2010, reviewing impacts of indirect land use change on GHG emissions and addressing ways to minimise that impact.

The Commission started the work on the impacts of indirect land-use changes with a pre-consultation in June and July 2009, putting several options on the table. Some of the options focused on adapting the criteria to include the indirect GHG emissions for which the introduction of an ILUC emission factor was the most prominent. Although this option received broad fundamental support in most reactions, the ILUC emission factor was criticised for lacking a proper scientific foundation. Other options pointed towards the reinforcement of policy, protecting land and/or regulating products and crops (most indirect land-use effects of biofuels are caused by direct effects on food and feed crops). Several

reactions emphasised that implementation would require more time, and that such an approach would not be sufficient to prevent negative effects in the short term.

3. Definitions and framing of direct and indirect effects

The term *indirect effects* is used in policy discussions without a clear definition. To make a clear distinction between direct and indirect effects definitions are needed. Therefore, we propose definitions that focus on the most relevant differences in this policy context.

Direct effects

Direct effects are the effects that can be directly and exclusively linked to the production-consumption chain of the bio-energy product.

During the entire life cycle (production and consumption chain, see Figure 1) of a product resources are used, emissions occur, services or goods are delivered and people are working. The changes in these pools or resources are all regarded as direct effects.

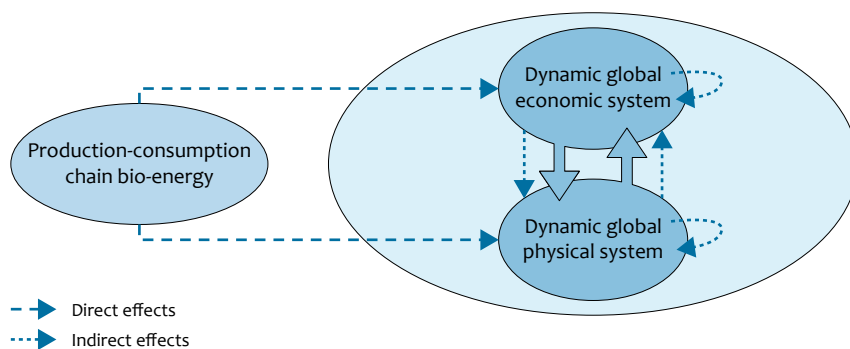
Box 1: Sustainability criteria in the EU Directive: for which bio-energy products?

The focus of the sustainability criteria in the EU Directive is on biofuels for transport, particularly liquid biofuels, such as ethanol or biodiesel, and gaseous fuels, such as biomethane. Furthermore, the criteria also apply to bioliquids, generally used in other applications such as for heating, cooling and electricity. The criteria in the directive do not apply to biomass as a resource for the chemical industry. Not all bio-energy products are included. The criteria do not concern solids (i.e. solid biomass) in general and gaseous products used in other applications than for transport.

Biomass is converted into many intermediate and end products. Usually, the first processing step converts the biomass into products which are easier to handle than conventional

feedstocks. Examples are pellets, vegetable oils, pyrolysis oil, ethanol, syngas (CO and H₂), and biomethane. Some of them are end products themselves (e.g. bioethanol), others are converted further into products such as biodiesel, bio-ETBE (additive for transport fuel), biohydrogen, bioplastics, green gas, and bio-electricity. In many cases the state of the product (solid, liquid or gaseous) changes.

Many of the products have more than one application; for example, biomethane or green gas, which is used for transport and for heating. Another example is the use of ethanol for transport and in the chemical industry. In both examples, the EU criteria only hold for the transport application.



Direct and indirect effects of a (new) bio-energy product.

The most important direct effects are:

- Land use (changes in land cover or land management)
- GHG emissions
- Water use
- Jobs (change in labour market, impact on health of workers)
- Profits.

In the policy context, the key to the definition is that the direct effects can be directly linked to and therefore controlled by the actors in the production chain. This makes criteria and regulations for direct effects (potentially) effective. The present EU criteria include direct GHG emissions and direct effects of land use.

Direct GHG emissions have been subject of intense discussion, resulting in the restriction that, to be included in the 10% target, GHG emission savings from the use of biofuels and bioliquids should be at least 35%. For biofuels in transport the most common boundary of the life cycle is from the well (the biomass growth) to the wheel (application of the fuel). This well-to-wheel method is applied to determine direct GHG emissions.

Forests and wetlands are excluded for feedstock production, as are other high carbon or high biodiversity land use types (Article 17 of the RED; EU, 2009a).

Indirect effects

Indirect effects are the effects that are caused by the introduction of a bio-energy product, but cannot be directly linked to the production chain.

Imagine a world with and a world without biofuels. Apart from the direct effects of the biofuels production chains, there would be many other differences between these two worlds. These differences are the indirect effects. They comprise all effects in all sectors with all their consequential effects. This shows that for the analysis of indirect effect a systems approach is indispensable.

The production chain of a bio-energy product is just one of many production–consumption chains. These chains interact with dynamic, often global, systems, such as the

economic system, the climate system, ecosystems and, more specifically, the agricultural system. The interaction between the bio-energy subsystem and the larger systems leads to all kinds of small and somewhat bigger changes in these global systems (Figure 2): the indirect effects. Examples are higher prices for (non-biofuel) food products, nature conversion for food production, lower feed and oil prices. The numerous interactions imply that every indirect effect in its part is a cause of other effects and so on, although the impact is becoming smaller and smaller. However, a final equilibrium is often not reached, because these dynamic systems are changing continuously and so are the indirect effects.

4. How to quantify indirect effects?

Monitoring indirect effects

How can these indirect effects be quantified? As we do not have two worlds available (one with and one without bio-energy products) to compare the indirect effects cannot be measured unequivocally. A lot of developments and effects can be monitored, both on the biofuels and within global systems. But how can they be related to each other? Only by adopting a set of assumptions, for example on indirect land-use changes, monitoring data can be used to estimate historic indirect effects of bio-energy production (see box 2). Such a set of assumptions can be regarded as a modelling approach.

Modelling indirect effects

Besides using monitoring data, modelling approaches can be helpful in evaluating systems with and without bio-energy. One should realise that all models are an imperfect simulation of a complex reality; because of assumptions and data restrictions they portray a simplified representation of reality. However, models can be very useful for understanding the mechanisms leading to indirect effects of bio-energy, especially when comparing the results from different models with a different representation of the system. For the assessment of indirect effects of bio-energy modelling on a global scale is required.

The models describe the interaction of a new bioenergy production system with global dynamic systems. The result is dependent on the changing states in these global systems.

Therefore, the indirect effects vary in time and they are no fixed characteristics of the biofuel alone.

5 The importance of different indirect effects

The indirect effects of bio-energy products are caused by direct effects within the life cycle of those products or the introduction of the products themselves. So, the direct effects and the new products are the starting point of a variety of cause-and-effect chains leading to indirect effects. These indirect effects can be ecological, environmental, social or economic. Social and economic effects are not discussed in this report. Table 1 summarises the indirect effects that have great impact on GHG emissions and biodiversity.

Table 1 shows that indirect land use change (ILUC) is not the only indirect effect that counts. Other effects may contribute significantly to GHG-emissions and biodiversity loss as well.

Many integral models calculate the combined impact of several types of indirect effects, in most cases not only the ILUC-emission, unless all the other effects are explicitly fixed at zero.

In the following part of this report, the most important cause-and-effect chains are described simply and separately, while realising that they are all interconnected. First, a short discussion on land use (the starting point for the indirect effects a. and b.) is given, followed by the details of all the separate effects of Table 1.

Indirect effects of the use of agricultural land

The cultivation of energy crops requires land. In case agricultural land is used, it replaces other crops, which is the starting point of several cause-effect chains. Figure 3 shows the possible options for growing feedstocks to produce bio-energy: Use of currently productive land and the conversion of unproductive land. These are direct land-use effects. In

Box 2 Emission reduction of current biofuel use

The actual emission reduction of currently used biomass includes direct and indirect emissions. Indirect land use change (ILUC) emissions as a result of biofuel production cannot be measured directly. However, under certain assumptions and using monitoring data on land use and agricultural production emission reduction as a result of biofuel use including indirect land use change emissions can be assessed. The example below calculates emissions for current biofuel use in the EU (i.e. 2007). The calculation includes the following steps, including the main assumptions and ranges for sensitivity analysis:

1. Monitoring data on consumption and imports of specific biofuels are combined with specific yields to calculate the area needed for the production of the feedstocks needed to produce the biofuels.
2. Since no exact monitoring data are available on the application of by-products we assume that 80% of protein-rich by-products is applied for the use as feed. So, part of direct land use is assigned to the feed and not to the biofuel. More extreme situations (100% feed and 0% feed combined with 50% used as process energy) were also considered in the sensitivity analysis.
3. All land use for the actual cultivation of biofuel crops is assumed to occur on currently productive lands and, therefore, the former production has to be compensated elsewhere. Based on FAO-data (2009) we derived that, globally, 31% of production increase is due to expansion of agricultural land during the past 10 years, 69% is due to increasing yields (this intensification may lead to extra emissions, but this is neglected in this calculation).
4. Biofuels from different regions might lead to different ILUCs compared to the global average of 31%. For example, in South America and especially South-East Asia ILUC is higher than the global average. In the EU set aside land is used. We assume no ILUC-emissions there. The extreme situations, 100% of ILUC is

regional and 100% global values, have been used in the sensitivity analysis.

5. For the actual emissions from land use conversions due to ILUC regional and global averages (for the 2 situations under 4.) have been used (van Minnen 2008, CDB 2009). These are based on monitoring data on which land conversions have taken place combined with emission factors for each type of conversion. Two time periods are included in the calculation to average the peak emission from the land conversion: 20 and 50 years. This is a conservative assumption, because the biofuel use has been increasing strongly, so most of the ILUC-emissions are still in the peak.
6. The calculated ILUC-emissions are added to the direct emissions (from literature) for the specific biofuels used. Total biofuel emissions are related to the emissions of fossil transport fuels.

Using the calculations from the sensitivity analysis to estimate a range of possible outcomes results in a GHG-emission reduction between -156% (higher emissions than fossil) to 13% (actual reductions) for the calculation with 20 years and -34% to 35% for the calculation with 50 years. The above figures can also be translated into a pay-back time: the period with an overall net emission reduction of zero. This is equivalent to a pay-back time for current biofuel use in the EU of 15 - 86 years.

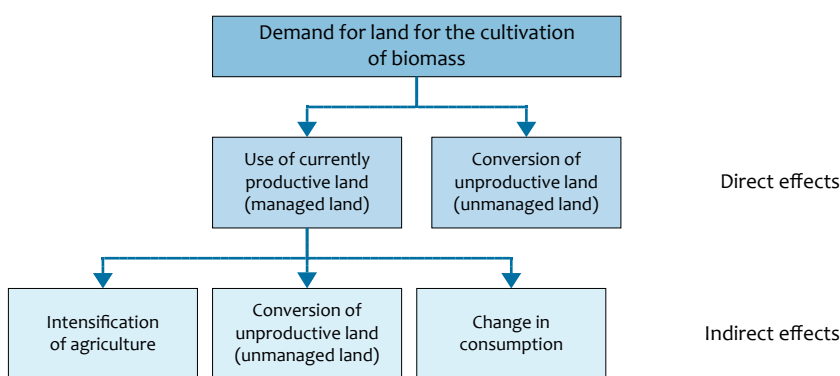
Under the assumptions that 80% of the by-products is used as feed and an average ILUC of 31%, and using the average conversion emissions from Van Minnen (2008) the GHG-emission reduction is -28% (28% higher emissions than fossil) for the calculation with 20 years and 19% (actual reductions) for the calculation with 50 years. For current biofuel use under the above assumptions the pay-back time is 31 years. It should be realized ILUC-emissions are temporarily for the largest part because of the short term peak due to land conversion.

Indirect effect	Impact on GHG emissions	Impact on biodiversity *
a. Indirect land-use change (ILUC): conversion of land	Loss of carbon from vegetation and soils can be substantial, sometimes of the same order of magnitude as direct reductions	Immediate loss of natural area, more infrastructural barriers
b. Intensification of agricultural production	Emissions from nitrogen fertiliser use, very sensitive to management practices (worst case emissions equal to ILUC emissions);	Emissions of nitrogen compounds and pesticides affect terrestrial and aquatic life
c. Substitution of traditional feed-stocks with by-products	Can reduce potential ILUC emission, considerably	Can reduce indirect land-use change and loss in natural area, considerably
d. Excess in production of animal feed	Effects unclear, both positive and negative; effects mainly via the land-use system	Effects unclear, both positive and negative; effects mainly via the land-use system
e. Impact on oil prices (leading to lower oil prices and higher oil consumption)	The indirect emissions can be in the order of 10-40% the emissions of the fossil fuels	Increase in environmental pressure of many economic activities
f. Impact of climate change on agricultural production	Regional differences: positive and negative effects on yields	Regional differences: positive and negative effects mainly via the land-use and water systems

* the consequential effect of GHG emissions on biodiversity is relevant too, but not explicitly mentioned in this column. (i.e. climate change will impact biodiversity in the long term).

Direct land use for bio-energy and its indirect effects

Figure 3



Direct land use for bio-energy and its indirect effects.

case of the conversion of unproductive land (here we mean land without any agricultural or forestry production, such as nature areas) all effects are direct effects, since there is a one to one relation between the feedstock production and the land use changes and its related emissions and no additional land use effect regarding productive land is assumed to occur here. In case of cultivation on currently productive land (e.g. agricultural land, formerly used for crop production for food, feed and fibre, including forest production), the original crop would have to be produced elsewhere or our consumption habits must change. This is the starting point for the indirect effects a. and b. in Table 1. The ‘displacement’ of agricultural production has been discussed extensively in the literature over the last two years (Searchinger et al, 2008, Fargione et al, 2008), and is generally called the indirect land-use change effect. Where Searchinger and Fargione mainly report on land-cover conversions, additional crop production can also be achieved by changes in land management (e.g. intensification).

The mechanisms that determine the contribution from intensification, land conversion or changes in consumption, depend on many parameters, which can vary between countries and regions. These parameters, for example, are price elasticity’s, availability of suitable land, national policies favouring either the use of inputs or the cultivation of land,

the economic ability of farmers to buy inputs or invest in technologies, and the possibility of hiring labour. Integrated models include some, many or all of these parameters. These models are very important tools in the assessment of indirect effects of bio-energy products, especially the overall contribution of several types of land conversion in different regions of the world.

a. Indirect land-use change (ILUC): conversion of land

Direct effect that cause indirect effects:

- Cause-and-effect relationships

Cause-and-effect relationships:

- Displacement of food/feed crops (commodity in general)
- Changes in prices of food/feed
- Agricultural expansion: conversion of natural areas into agricultural land to grow food/feed crops elsewhere
- Possible effects: change in carbon content of vegetation and soil resulting in CO₂ emissions;

Land contains carbon stored in the vegetation and the soil. The amount of carbon depends on the type of vegetation (forests/trees are high in carbon) and soil (high for peat land). In general agricultural land contains less carbon than natural land, even grassland. The carbon in the vegetation is lost with

the conversion. In soil the carbon content slowly changes to a new equilibrium, which can be reached after several decades. Carbon disappears into the air in the form of CO₂. These emissions decrease over time. In many cases these ILUC emissions are calculated as average yearly values over periods of 20 (EU Directive for direct emissions) to 50 years.

Typical emission values over the whole period are on average 300 to 1600 ton CO₂ equivalent /ha for the conversion of forest to agricultural land, and 75 to 364 tonnes CO₂ equivalent /ha for grassland or savannah (Searchinger et al, 2008, Fargione, 2008, Van Minnen, 2008). The Öko-institut presented an average value of 5 ton CO₂ equivalent /ha per year (Fritsche 2009). For regions with relatively more conversion of forests, this value might be higher. With the help of model calculations assessments are made for the area and type of land actually converted as the result of the production of a biofuel or any bio-energy product.

This has to be compensated by the emission savings from biofuel use, in many cases varying between 2 and 20 tonnes/ha per year (Eickhout et al 2008). In an overview of calculation results from different sources (including California EPA 2009, Searchinger et al 2008, Fischer et al 2009) ILUC-emissions (or overall indirect emissions) between 30 and 103 g CO₂-eq/GJ were presented (Ecofys 2009) (emissions from substituted fossil fuel are about 84 g CO₂-eq/GJ).

Theoretically, it can be the other way around. In case energy crops are grown on land with almost no vegetation and low-carbon content in the soil a net uptake of CO₂ might be the result. Restoration of degraded land can be combined with biomass production, but yields will be low.

b. Intensification of agricultural production

Direct effect that causes the indirect effects:

- Use of currently productive land

Cause-and-effect relationships:

- Displacement of food/feed crops (commodity in general)
- Changes in prices of food/feed
- Agricultural intensification: different agricultural management to produce more food
 - More fertiliser use and/or increase in fertiliser efficiency
 - More water use
- Possible effects: Change in GHG emissions (N₂O) and other emissions from fertiliser use, soils, other emissions from agriculture, water shortage, effects on surrounding ecosystems and biodiversity

Food crops formerly produced on agricultural land, that is now used for biofuel production, can be provided by intensification of agricultural production elsewhere. Intensification of current agricultural production is often regarded as the potential solution to the land-use change problems. Undoubtedly, on a global scale there is great potential for yield increases. The main challenge here is better agricultural management, which in many cases also needs more inputs, for example, fertilisers, pesticides, water, and energy. The main question is whether intensification will

lead to more, less or equal emissions per unit of product? It appears the answer depends strongly on the measures taken.

An increase in nitrogen fertiliser use without any other management measures might lead to indirect GHG-emissions, in some cases even higher than emissions from the substituted fossil fuels. However, in many cases an increase in fertiliser use efficiency (higher yields per unit of fertiliser) is possible and might even lead to extra emission reductions. So, the indirect emissions are very sensitive to the measures taken.

Based on global monitoring data on yields and fertiliser use we assume the average global effect to probably be about 0 to 10% of the emissions from fossil fuel use, although regional differences can be substantial.

In case of intensification, there is no loss of natural areas, but biodiversity in agricultural areas can be affected by intensification, other emissions may be relevant on a local scale, and water use might have negative ecological impacts in regions with water scarcity.

c. Substitution of traditional animal feed with by-products

Direct effect that causes the indirect effects:

- Production of by-products for animal feed

Cause-and-effect relationships:

- Replacement of other animal feeds on the market
- Decrease in animal feed production elsewhere
- Decrease in land use for animal feed production elsewhere
- Decrease in indirect land use for biofuels
- Decrease in indirect GHG emissions

In many cases, crops are resources for more products than only bio-energy. Crops, such as rapeseed (for biodiesel) or wheat (for ethanol) also deliver by-products with high protein content. These protein rich products can be applied as animal feed, substituting other feeds, such as soy meal, the most important protein source for cattle in Europe.

When soy meal is substituted, less land for soy cultivation is needed. For the energy crops wheat and rapeseed, depending on assumptions about the yields and the protein contents of the by-products, the reduction of land-use for soy production can be 50 to 100% of the land needed for the wheat and rapeseed. This substitution reduces the indirect land use and therefore the impact of indirect land use change and intensification substantially. Additionally, it is not yet clear what the real potential is of replacing soy meal, because of quality restrictions.

The impact of the by-products on land use can be included in model calculations on ILUC or in Life Cycle Analysis with allocation of land use based on substitution. It should be noted that if such an approach is part of a sustainability assessment, in fact the land use for soy meal is deduced from the land use for energy crops without considering the sustainability of soy.

d. Excess in production of animal feed

Direct effect that causes the indirect effects:

- Production of animal feed as by-product

Cause-and-effect relationships:

- Excess in production of animal feed as a by-product in biofuel production
- Decreasing animal feed prices
- Decreasing meat prices
- Increase in meat consumption
- Increase in meat production
- More emissions from animal husbandry (note that the land-use related emissions from livestock systems were accounted for under a.).

An increase in the supply of this animal feed from by-products could lead to a decrease in prices for animal feed, and subsequently to an increase in consumption of meat and dairy products.

The opposite effect of what is described under c. and d. could occur, if waste products from agriculture or the food industry, which are used as animal feed in the present situation, are turned into a resource for fuel production instead. In those cases, feed has to be produced elsewhere and even ILUC effects cannot be excluded.

e. Impact on oil prices

Direct effect that causes the indirect effects:

- Bio-energy production

Cause-and-effect relationships:

- Bio-energy replaces fossil fuels
- Decrease in fossil fuel demand
- Decreasing fossil-fuel prices
- Increase in fossil-fuel using activities
- Increase in fossil-fuel use
- Increase in GHG emissions

Mandatory bio-energy production can lead to decreasing prices of crude oil, and thereby eventually lead to an increase in crude oil and total energy consumption. This so-called rebound effect can reduce the possible gain from biofuels, substantially, especially if not all sectors are facing some form of climate policy, or not all countries participate in climate-change policies.

The magnitude of this effect is rather uncertain, but could reach as much as 50% of potential gains (Barker et al., 2009). Our calculations with LEITAP/IMAGE resulted in an extra indirect emission of about 30% from the reduction in direct emissions. So these indirect emissions are in the order of 10-40% of the emissions of the substituted fossil fuels.

f. Impact of climate change on agricultural production

Direct effect that causes the indirect effects:

- Direct GHG emissions

Cause-and-effect relationships:

- Climate change / change in temperature
- Change in agricultural productivity
- More agricultural land use because of less favourable circumstances (see a.)
- Less agricultural land use because of more favourable circumstances, leading to productivity increase (water availability, more favourable temperature or CO₂ fertilisation)

GHG emissions have an effect on GHG concentrations, climate change, and all impacts of climate change, such as biodiversity loss. Via multiple feedbacks in the system, there are also indirect effects on agricultural production.

Higher CO₂ concentration leads to higher CO₂ uptake by the vegetation and therefore to higher plant productivity, and potentially to less deforestation, as yields increase and less agricultural areas are needed. Emission of nitrogen compounds might have the same fertilising effect.

Temperature increases and changing rainfall patterns are climate aspects with relevant potential impacts on agricultural productivity, positive in some regions and negative in others.

Effects on biodiversity

The impact of bio-energy on biodiversity is strongly determined by the combined effect of land use and greenhouse gas emissions. Conversion of natural areas results in a (well known and certain) short-term loss of biodiversity. A reduction in greenhouse gases has a (modelled and more uncertain) positive impact in the long term. We propose a method that compares short-term losses with possible long-term gains and delivers an indication of the required biodiversity compensation period (the period needed to compensate immediate biodiversity losses with future avoided losses from climate change mitigation) (Alkemade et al 2009, Bakkenens et al 2009, Eickhout et al 2008).

Even with emission reductions of 35 or even 60% (criteria for direct emissions in the EU-Directive for biofuels), model calculations indicate that it would take several hundreds of years to compensate for the short term direct biodiversity loss due to the conversion of natural area for the energy crop.

In case of indirect land use changes, the overall GHG-emissions and the net land conversion are different. Both are strongly dependent on the ratio between indirect land conversion for agriculture and agricultural intensification (preferably by improving fertiliser use efficiency). As we have discussed before, it is expected that indirect effects will decrease emission reductions. Although indirect land conversion may be smaller than direct land use for the energy crop, it is still probable that some natural land is converted. In case future developments in land conversion and intensification will be the same as in recent years the indirect effects implicate a high probability of very long compensation periods. The exact length of this period is uncertain, but

it is robust to say that it is of the same magnitude as the envisioned policy period (target in 2100). This makes it unlikely that biofuels as a solution for climate change mitigation will deliver a co-benefit for global biodiversity.

Conclusions

There is no fixed indirect emission factor for a specific bioenergy product.

Indirect effects of bio-energy products, such as biofuels are not an unambiguous fixed characteristic of the bio-energy product, but the variable result of the interaction with dynamic (global) economic and physical systems. So, indirect GHG emissions do not only bear a scientific uncertainty, they also vary in time. This implies that any policy on indirect emissions (including the possible use of an ILUC-emission factor in GHG-calculations) is a matter of precaution and risk management.

Indirect effects on GHG emissions are very relevant.

Reported emissions from indirect land-use change (ILUC) caused by bio-energy products are in the order of 30 to more than 100% compared to the fossil fuel emissions.

Intensification of agriculture in general is a way to minimise indirect land use change. However, if higher yields are the result of increasing fertiliser use only, indirect emissions equal to the fossil fuel emissions might occur. The focus should be on measures to improve fertiliser use efficiency with the potential to further reduce GHG-emissions.

Some of the by-products of biofuel production are suitable as animal feed. It is important to include the by-products in GHG-assessment, because of their potential impact on the overall emissions.

More biofuels on the market could reduce the oil prices resulting in more economic activity. This might lead to extra emissions equal to 10-40% of the fossil fuel emissions.

Indirect effects on biodiversity are strongly related to land conversion.

Reducing GHG-emissions by substituting fossil fuel by a bioenergy product – considering all indirect effects – can result in less negative impact on biodiversity from climate change on the long term. However, it will indeed take a long period (much more than the 100 years policy period) to compensate for the short term loss of nature due to direct land conversion for the energy crop. In case of indirect land use this period for compensation can be shortened by stimulating global agricultural intensification, especially an increase of fertiliser use efficiency.

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