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Summary

Protecting biodiversity against further loss is one of the goals of climate change mitigation. A reduction in greenhouse gas emissions due to biofuel production could prevent negative climate impacts on biodiversity in the future. However, land use for biofuel production could lead to a loss in natural area and biodiversity in the short term.

With the use of a balancing method that takes both local losses and indirect global changes into account, this paper shows that it may take centuries before losses in the short term, caused by direct land-use change, will be compensated for by avoided biodiversity loss in the future due to climate change mitigation.

Compensation periods related to indirect land use can also be calculated. When part of the displaced production would be realised through agricultural intensification, the compensation period will only be a part of that for direct land-use change, but can still amount to as much as a century. Moreover, additional greenhouse gas emissions related to indirect land-use change would add extra time to this compensation period.

This novel approach shows that when the ambition to mitigate climate change by using biofuels is high, a positive effect on biodiversity can only be achieved after a very long period. Uncertainties in calculating compensation periods are considerable, but the order of magnitude (centuries) is relevant, as it goes beyond the current policy horizon.

Introduction

There is a widespread concern that conversion of natural area into agricultural land for biofuel production would lead to additional loss of biodiversity and soil carbon. The EU Renewable Energy Directive (RED; EU, 2009) contains sustainability criteria for biofuel production that are meant to prevent major effects on biodiversity. This is achieved by excluding certain areas with specific types of land cover from being used for biofuel production, unless it can be proven that production does not interfere with existing biodiversity values (RED article 17.3). The excluded lands represent areas with special and highly valued biodiversity components and/or areas with high carbon storage.

The formulated exclusion rules are meant to prevent local and direct impacts from biofuel production on biodiversity within a production area, and are coupled to the involved product chain. Next to these direct effects, there are also indirect effects on biodiversity outside the production area. These effects result from the many interlinkages between food, feed and fuel production chains at regional, national and global levels (Ros *et al.*, 2010).

The RED (article 19.6) mentions that a proposal is requested, by 31 December 2010, for a methodology to calculate effects of indirect land-use change on greenhouse gas emissions. Regulation of indirect effects on biodiversity is not foreseen in the RED. Scientific studies, however, provide evidence that large-scale production of biofuels from food crops in Europe would contribute to agricultural expansion elsewhere (RFA, 2008; Eickhout *et al.*, 2008; Prins *et al.*, 2010). If this expansion leads to the conversion of natural land, such as forests, wetlands and natural grasslands, it will have detrimental effects on biodiversity (Phalan, 2009; Singh, 2009). This would mean that meeting the obligation under the Kyoto protocol could jeopardise the meeting of obligations under the Convention on Biological Diversity (Danielsen *et al*., 2008). It has been proposed that impacts of biofuels on biodiversity caused by land-use change in the short term should be quantitatively assessed against future avoided biodiversity losses from climate-change mitigation (Sala *et al*., 2009). This brief report takes a closer look at such an approach, also presented briefly in Eickhout *et al.* (2008). Here, land-use change is understood to be a change in land cover between

Drivers of biodiversity change, related to biofuel production and application **Table 1**

	Immediate impacts	Future impacts
Direct changes	Land conversion at production site Intensification of agricultural practices in production area	Lost opportunities for biodiversity restoration GHG emission reduction leading to avoided future climate change
Indirect changes	Land-use change elsewhere, leading to loss of biodiversity Intensification of agricultural practices, globally	Land-use change elsewhere, leading to loss of soil carbon with future impacts

land categories defined by the IPCC (forest, grassland, cropland, wetland, settlements and other), supplemented with perennial crops and forest plantations. A change in management activity is not considered land-use change (EC, 2010).

Impacts of biofuels on biodiversity

Biodiversity is a complex phenomenon, and refers to different underlying and complementary components. It encompasses genetic differences within species, the variety between species and the diversity of ecosystems (UN, 1993).

Several activities related to the production and use of biofuels, are known to have an impact on biodiversity (Sala *et al*., 2009; Alkemade *et al*., 2009):

- agricultural expansion with loss of natural areas;
- extending infrastructure in newly exploited areas;
- intensification of existing agricultural practices;
- increased water use, leading to lower water availability in dependant ecosystems;
- conversion of naturally carbon-rich soils, leading to higher greenhouse gas emissions.

These types of activities, which are related to land-use change and land-use intensification, are the cause of direct and indirect effects on biofuels. Most of these effects are immediate and generally contribute to biodiversity loss and ecosystem degradation. Biodiversity may also benefit from biofuels when the cultivation of bio-energy crops help to restore degraded lands (Tilman *et al*., 2009). However, the scale at which this is (economically) feasible or probable is unclear (Hoogwijk *et al*., 2003; Dornburg *et al*., 2010). Table 1 presents a summary of the various elements to be considered in an overall assessment of the impact of biofuels on biodiversity.

Working Group 2 of the IPCC has concluded that climate change will significantly affect future biodiversity, based on reviewed modelling exercises and monitoring data. With a global average temperature rise of 2°C above pre-industrial levels, many terrestrial, freshwater and marine species are at a far greater risk of extinction than at any time in the geological past. Projected impacts on biodiversity are relevant, since global losses of species are irreversible (IPCC, 2007). Therefore, it is important for the overall assessment of biofuel impacts on biodiversity, to consider the contribution of biofuels to reducing greenhouse gas emissions. This is a long-term perspective, assuming that prospective negative effects of climate change on biodiversity could be partly avoided. The magnitude of this long-term effect depends not only on the reduction in greenhouse gas emissions from biofuel production, but also on indirect land-use effects on carbon stores (Fargione *et al*., 2008; Searchinger *et al*., 2008).

Integral assessment of the effects of biofuels on biodiversity

The integrative approach of assessing the impacts of biofuel production on biodiversity requires integration across space, direct versus indirect impacts, and over time, immediate versus future impacts. The combined impact of biofuel production, therefore, depends on the temporal and spatial scales under consideration.

We used the available IMAGE model framework to perform a comparative assessment of immediate versus future impacts of biofuels on biodiversity[1]. As indicator of biodiversity we chose Mean Species Abundance (MSA; Alkemade *et al*., 2009). This is partly a pragmatic choice because MSA enables quantification of the impact of various drivers on biodiversity in a scenario analysis. Further, the MSA indicator is based on several aspects that are relevant to the CBD Indicator Framework (sCBD, 2006). It should be realised, however, that there is no single indicator that covers all aspects of the complex phenomenon of biodiversity.

The MSA indicator, basically, is an index that presents population sizes of occurring species at a certain location, compared to occurring species and populations in an unaltered reference situation. The index is considered to be a measure of ecosystem quality and its original state, and can be seen as a measure of ecosystem naturalness. Behind the calculation is a database with empirical data on species abundance in locations that hardly suffer from human impact and in comparable locations that do suffer from human impact (such as land-use change, eutrophication, and increased access through infrastructure development). The index is used for scaling up the impact calculation to higher spatial scales (regions, countries, biomes), by multiplying ecosystem areas with their ecosystem quality. This leads to a quality-adjusted area (dimension m^2). The method is very similar to that of the Biological Intactness Index (Scholes & Briggs, 2005; Hui *et al*., 2008). For a more detailed explanation, see Alkemade *et al*. (2009).

Our approach enables a comparison of how different pressures affect biodiversity. Biodiversity loss due to climate change occurs worldwide and gradually, while land use leads to local and immediate losses. To overcome this difference,

1 Using the IMAGE 2.4, GLOBIO 3 and EUROmove models (Bouwman *et al*., 2006; Alkemade *et al*., 2009; Bakkenes *et al*., 2006) and greenhouse gas mitigation scenarios (Van Vuuren *et al*., 2008).

global loss from climate change is quantified and represented as if it were condensed on a specific area with complete biodiversity loss (a loss of 0.01% on 1000 km^2 equals a 100% loss on 0.1 km^2). Because of its area-based properties, the MSA indicator enables a comparison between different pressures, in this case land-use change and climate change.

The period of time over which (immediate) biodiversity loss from land-use change (in MSA) can be balanced against avoided biodiversity loss (in MSA) because of avoided long-term climate change, can be presented as a biodiversity 'compensation period'. This is an analogy to the carbon debt concept put forward in recent years (Fargione *et al.*, 2008; Searchinger *et al.*, 2008), that illustrated that indirect land-use change may lead to increased greenhouse gas emissions from ecosystem stores.

Direct land-use change and compensation periods

Model calculations learn that greenhouse gas emissions of 4 ktonnes CO_2 eq (± s.e. 1) will lead to future global biodiversity loss (from climate change up to the year 2100) with an equivalent size of one hectare[2]. Inversely, we argue that avoiding the same amount of greenhouse gas (4 ktonnes CO_2 eq) will avoid the loss of one hectare of (globally condensed) biodiversity beyond 2100.

2 The presented value is a conservative estimate, by applying the least sensitive parameters for the response of each biome to climate change. Biomes are climatically and geographically defined similar ecosystem types with distinct climatic conditions for communities of plants, animals, and soil organisms.

Direct emission reductions due to the replacement of fossil fuels by several biofuels are in the order of 5 to 20 tonnes of CO_2 eq per ha per year (Eickhout *et al.*, 2008). So, many consecutive harvests would be needed to realise an emission reduction equivalent to one hectare of biodiversity loss from land-use change . This could easily take hundreds of years (see text box for a detailed example of a specific case). Following this line of reasoning, biodiversity compensation periods can be determined for a range of energy crop harvest values (in GJ of biofuel/ha) and attained greenhouse gas saving percentages (see Figure 1). These are the two most characteristic parameters of biofuel chains.

The RED requires a greenhouse gas emission reduction of at least 35% from 2010 onwards. Higher percentages are foreseen for the future (50% in 2017; 60% in 2018). Taking the RED 35% reduction value (blue line in Figure 1), one can expect biodiversity compensation periods of over six centuries, where land-use change has led to considerable local biodiversity loss. It would take a greenhouse gas emission reduction of about 150%[3] and biofuel crop yields of 200 GJ/ha to achieve a compensation period of 100 years.

Indirect land-use change and compensation periods

Instead of converting natural ecosystems into production areas, biofuel production can take place on land that is already in use for agricultural production. In such cases, there would be no local land-use change and no local loss of biodiversity. Consequently, there would be no biodiversity compensation period. However, energy crops replace other agricultural crops, which will have to be produced elsewhere instead. There are two mechanisms for doing this; 1) agricultural land expansion elsewhere, to produce

Example: Direct losses and sugar cane

Based on model calculations, we found that a greenhouse gas emission reduction of 4 ktonnes CO_2 eq will avoid global biodiversity loss in the future (through climate change) of a hypothetical area with an equivalent size of one hectare. A typical greenhouse gas performance for biofuel ethanol produced from sugar cane is about 16 tonnes avoided CO_2/ha per annual harvest (Eickhout et al., 2008; without considering C-soil changes and indirect emissions), which compensates for about 0.004 ha of biodiversity loss from climate change (=16 tonnes/4 ktonnes). Consequently, when one hectare of a natural ecosystem is converted for sugar cane production, many consecutive harvests are required to make up for the immediate biodiversity loss from this land-use change.

In a literature review, we found that the residual MSA value of intensive agricultural practices is quite low (about 20% of the reference ecosystem, which may be forest or grassland; Alkemade et al., 2009). Biodiversity loss on 1 ha of sugar cane is therefore 0.8 ha MSA. The compensation period in this case would be (0.8/0.004) 200 years. Although the estimated value of 200 years is surrounded by a substantial uncertainty range, it is crucially important that this compensation period extends way beyond the time horizon currently under consideration in the climate change debate.

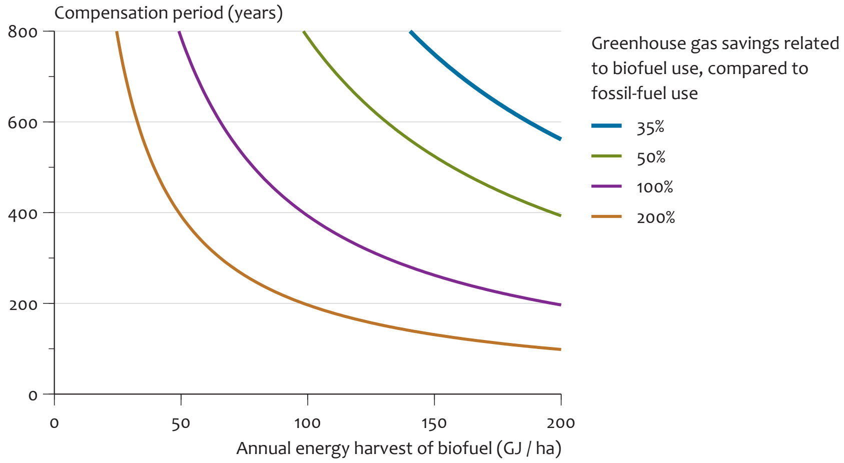
The uncertainty range is the result of model uncertainties on responses of the climate system and global biodiversity to rising CO_2levels and temperatures, next to variation between different land-use change combinations.

In contrast, when recently abandoned, extensively used agricultural land is used for sugar cane production, the local MSA loss due to altered agricultural management practices is much lower. Extensively used agricultural land has a MSA value that is already lower than that of a natural area (about 30%), but still higher than that of intensively used land. In this case, the compensation period is estimated to be about 25 years for local loss.

When low-productive agricultural land is used, there is a danger of losing certain highly valued agro-biodiversity. This is an issue certainly relevant in Europe (Hoogeveen et al., 2004).

Biodiversity Compensation Period for different greenhouse gas savings **Figure 1**

Direct land-use change from natural ecosystems into intensive agricultural use



Biodiversity Compensation Periods for direct land-use change as a function of annual energy-crop harvest. Isoclines represent different levels of greenhouse gas savings. The figure applies to cases where natural ecosystems are converted to intensive land use, with high local biodiversity losses.

these displaced agricultural products, and 2) agricultural intensification to increase yields produced on the same surface areas.

Figure 2 shows compensation periods for the various degrees of indirect land-use change, or displaced production (agricultural expansion in formerly natural areas), assuming that global agricultural intensification would account for the remaining displaced crops. It is further assumed that crop yields in the old and new situation are equal.

For a biofuel production chain with an emission reduction of 50% and a yield of 150 GJ/ha, the biodiversity compensation period for direct land-use change is about 500 years (Figure 1). When this biofuel crop displaces another crop, and indirect land use leads to 20% of land conversion and to indirect soil carbon emissions (causing a greenhouse gas emission reduction of 35%), the compensation period would be about 200 years (red line in Figure 2).

Recently, a lot of effort has gone into analysing global indirect land-use change by deriving an ILUC factor from scenario and model studies. The additional area that would be required, globally, for energy crop production, depends strongly on average yield increases and developments in global consumption. A review of model exercises on global changes due to additional biofuel production, shows varying ranges of indirect land-use change, from roughly 15 to 90% (Prins *et al.*, 2010).

The sensitivity of compensation periods to different percentages of indirect land-use change is shown by the different lines in Figure 2. Already at a low indirect land-use change percentage of 10%, compensation periods are higher than 100 years for yields up to 150GJ/ha.

Intensification in itself may also affect biodiversity, as it might lead to an increase in agricultural drivers of biodiversity loss, such as the load of nitrogen compounds, pesticides and water use. Taking these effects into account will further increase the compensation period.

Uncertainties in assessing the effects of biofuels on biodiversity

Based on uncertainty considerations it should be emphasised that the presented compensation periods primarily indicate an order of magnitude. Compensation periods of more than 100 years refer to hypothetical future situations, for which exact calculations are precarious. Still, in support of short-term policy decisions, they indicate the seriousness of the short-term effects on biodiversity, especially as these are substantial and more certain.

Types of biodiversity uncertainty

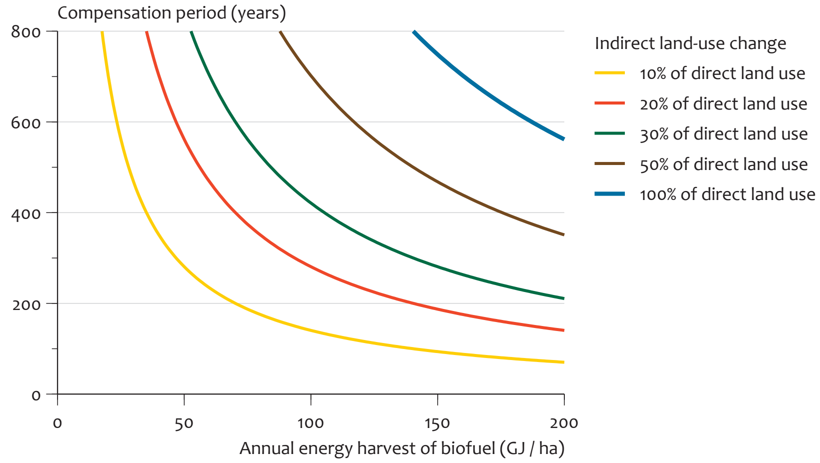
It is important to realise that land-use changes will occur in the short term, and that such local effects are based on monitored changes that are well known. The long-term benefits of avoided climate change depend on the earth–atmosphere response to reduced greenhouse gas emissions, and on the global biodiversity response to meteorological changes. These effects are primarily based on model calculations, and much less on already monitored changes. Many uncertainties play a role in quantifying long-term future effects, both conceptual (model concepts) as quantitatively (model parameters and scenario assumptions). Together, they determine the uncertainty range of the calculated compensation periods. The order of magnitude (up to centuries) is therefore more indicative than an exact value.

Weighing different ecosystem types

Because the MSA biodiversity indicator assigns the same value to different ecosystems, it does not matter whether a tropical forest, a temperate forest or tropical savannah is affected by biofuel production. Treating such different

Biodiversity Compensation Period for different levels of indirect land-use change **Figure 2**

Assumed greenhouse gas savings: 35%



Biodiversity compensation periods for indirect effects, as a function of annual crop energy harvests. The isoclines represent different percentages of indirect land-use change (additional conversion of natural land). The assumed greenhouse gas reduction is 35%, the level required in the RED (EU, 2009).

ecosystems equally, with regard to their biodiversity value, may seem odd, but it reflects the CBD target of protecting at least 10% of all distinguished global eco-regions (and not just species-rich tropical rainforests). Giving different weights to different ecosystems is possible, based on the known species numbers per major ecological region, but this introduces a value-biased element in the methodology.

Treating dynamic adaptation processes in the future

The MSA indicator is based on empirical data under specific circumstances (including stress factors) and the ecosystem quality at a specific point in time. The difficulty of predicting ecological responses to future environmental conditions, is that these responses exceed the range of current experience (Williams *et al*., 2007), creating considerable uncertainties (IPCC, 2007). Furthermore, the capacity of species and communities to respond and adapt to a changing world should be taken into account (Fox, 2007). This has not been incorporated in the presented method.

Using scenario analyses or single indicators

Biodiversity developments can also be analysed in a scenario context, comparing options with a high and low ambition for climate change mitigation (sCBD and MNP, 2007). However, in such a context, the specific contribution of biofuels to either further biodiversity loss or avoided climate change would be obscured by several global developments (Prins *et al*., 2010). The presented compensation indicator reduces that model and scenario complexity, and enables to focus on biodiversity pressures that are most relevant in the biofuel discussion.

Conclusions

A reduction in greenhouse gas emissions due to biofuels might avoid negative climate impacts on biodiversity, in the long term. However, land-use change for biofuel production can lead to loss in natural area and biodiversity on the short term. It is not easy to weigh these pros and cons quantitatively, because of the complex behaviour of biodiversity in response to many different drivers and over long periods of time.

This brief report uses available methodologies to integrate the effects of these different pressures, making comparisons and assessment possible. To do so, the influence of different pressures is presented by a common unit, namely quality adjusted area. The proposed method allows calculation of a compensation period, in which biodiversity loss from land-use change for biofuel production is equal to the mitigated biodiversity loss from climate change, brought about by consecutive energy harvests of a specific biofuel crop.

Presented biodiversity compensation periods show that it may take several centuries to compensate for short-term losses from land-use change. This is based on a single biodiversity indicator (Mean Species Abundance) that contains several elements of the CBD Indicator Framework, but cannot present all different aspects of the complex phenomenon that is biodiversity.

The calculated compensation periods related to indirect land-use change are smaller than those related to direct land-use change, because part of the displaced production can be realised by agricultural intensification. Still, these compensation periods have a magnitude of 100 years or more.

Indirect soil carbon emissions and global agricultural intensification also introduce new drivers of biodiversity loss: increased greenhouse gas emissions, water use, pesticides, and nitrogen compounds.

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