Spatially differentiated examination of biodiversity in LCA (Life Cycle Assessment) on national scale exemplified by biofuels

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Abstract

Purpose The critically discussed effects on biodiversity due to the intensive cultivation of energy crops are largely lacking in the LCAs of biofuels due to basic methodological deficits. This was the starting point to develop a new methodology for impact assessment on biodiversity. The central research question to be clarified was: how can the spatial references, which are necessary for the assessment of biodiversity, be included in the usually spatially unspecific LCA.

Methods Prevalent methods for both LCA and environmental planning were investigated with regard to interfaces and integration capabilities as well as differences. Drawing on this analysis a theoretical and methodological approach was developed which integrates the spatially specific procedure of environmental planning into the product-specific approach of the LCA. The available geodata and statistical data base for the assessment was examined for Germany and the method adapted to the data situation in Germany.

Results and discussion The resulting methodological approach is explained and tested. It is compatible with LCA principles and leads to product-specific quantitative results. The method can be applied on a higher geographic level (Germany) but, nevertheless, makes reference to spatial characteristics of biodiversity on different scales. This is achieved by combining area specific data about biodiversity with statistical data about pressure factors on the regional level. The procedure is demonstrated by the example of bio-ethanol from wheat. An overall view of the various indicators yields a "Biodiversity profile" for the considered fuel and a specific bio-fuel target. This approach leads the way for an integration of spatial knowledge about biodiversity into the spatially non-specific LCA.

Keywords: Biodiversity, Land Use, Geographic information system (GIS), Environmental planning, Biofuels, Methodology, Spatial indicators, Agricultural products

Zusammenfassung

Räumlich differenzierte Untersuchung von Biodiversität in Ökobilanzen auf nationaler Ebene am Beispiel biogener Kraftstoffe

Ziel Die kritisch diskutierten Wirkungen auf die biologische Vielfalt durch den intensiven Anbau von Energiepflanzen fehlen in Ökobilanzen von Biokraftstoffen weitgehend aufgrund methodischer Defizite. Diese waren Anlass zur Erarbeitung eines neuen methodischen Ansatzes zur Wirkungsabschätzung für Biodiversität. Als zentrale Forschungsfrage galt es dabei zu klären, wie die für die Beurteilung von Biodiversitätsveränderungen zwingend erforderlichen räumlichen Bezüge in die meist räumlich unspezifischen Ökobilanzen einbezogen werden können.

Methoden Die Methodenspektren der Ökobilanz und der Umweltplanung wurden systematisch in Hinblick auf Schnittstellen untersucht. Auf dieser Analyse aufbauend wurde ein Methodenansatz entwickelt, der das raumbezogene Vorgehen der Umweltplanung mit dem produktbezogenen Vorgehen der Ökobilanz verbindet. Die verfügbaren Datengrundlagen wurden für Deutschland geprüft.

Ergebnisse und Diskussion Es wurde ein mit der Ökobilanz kompatibler Methodenansatz entwickelt und getestet, der zu produktspezifischen quantitativen Ergebnissen führt. Die Methode kann auf einer höheren räumlichen Ebene angewendet werden, ohne flächenkonkret vorzugehen und stellt dennoch den für die Biodiversität notwendigen Bezug zu räumlichen Ausprägungen her. Am Beispiel Bioethanol aus Weizen wird das Vorgehen erläutert. In der Gesamtschau aller Indikatoren ergibt sich ein typisches „Biodiversitätsprofil" für den betrachteten Kraftstoff. Das methodisch neue Vorgehen zeigt damit im Ansatz einen Weg auf, wie eine Transformation von räumlichem Wissen über Biodiversität in die räumlich unspezifische Ökobilanz gelingen kann.

Schlüsselworte: Biodiversität, Landnutzung, Geografisches Informationssystem (GIS), Umweltplanung, Biokraftstoffe, Methodologie, räumliche Indikatoren, Agrarprodukte

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1 Introduction

The potential environmental impacts of products are usually assessed with the help of an LCA according to the ISO standards 14040/44 (ISO, 2006a; b). An LCA aims to represent the "ecological backpack" of a product along its entire life cycle in consistent units so that individual product paths can be compared (Kanning, 2001). Many studies exist which investigate the possible effects of biofuels and other biomass products on the environment (e.g. Zah et al., 2007; Bernesson, 2004; Kaltschmitt and Reinhardt, 1997; Malça and Freire, 2011). For example the emissions from the use of biofuels in internal combustion engines are considered with regard to different parameters (Krahl et al., 2009; Munack et al., 2009). However, the critically discussed effects on biological diversity due to the intensive cultivation of energy crops are largely lacking in the studies (Urban et al., 2007). The UNEP study "Assessing biofuels" (Bringezu et al., 2009) gives an overview of the research and emphasizes that biodiversity is generally lacking and that LCAs need to be extended by spatial parameters. Forecasts and assessments for the loss of biodiversity are dependent on scale and region (Sala et al., 2000; 2009; Dauber et al., 2010).

Because so far no accepted method is available for accounting the impacts on biodiversity in LCA (Milà i Canals et al., 2007; Klöpffer and Grahl, 2009), political decisions, which are based on LCA, are made on an incomplete information basis. Previous approaches either operate, as is customary in LCA, without considering or processing area-specific information or are restricted to local, place-based applications where site specific data are available (Schweinle, 2000; Haas et al., 2000; Geier, 1999). Spatially non-specific methods use general pressure-related characterization factors for land use e.g., the hemeroby - an indicator for the degree of anthropogenic influence on the ecosystem (Brentrup et al., 2002). Others are based on typical species numbers and -compositions of land uses (Koellner and Scholz, 2008; Koellner, 2003; De Schryver et al., 2010). In particular, there is a methodological deficit concerning the inclusion of impacts on biodiversity in the life cycle stage 'agricultural cultivation.'

An area-specific approach would be needed for assessing biodiversity on high decision levels, e.g., for calculating the effects that the introduction of different biofuels (or biofuel quotas) would have on biodiversity in Germany. The impact of energy crop cultivation differs depending on the sensitivity of nature and landscape. This is disregarded when a pure accounting of the cropland is performed. However, a spatially explicit approach is not feasible at the national level, because the specific future cultivation areas of energy crops are unknown.

Against the background of this dilemma and the basic deficits with regard to content and methodologies, the objective of the research presented in this paper is to develop an approach for the integration of biodiversity into LCAs on a national scale, which is sensitive to the requirement of spatial differentiation as well as suitable for LCA accounting. The research is a combination of a methodical development (how to integrate biodiversity in LCA) and a case study (biofuels in Germany with its impacts on biodiversity) based on data that are available on the national level in Germany. The principal research question to be solved is, how spatial references, which are necessary for the assessment of biodiversity, can be included in spatially superordinated LCAs. A possible approach is to use methodological knowledge of spatial environmental planning (e.g. von Haaren et al., 2004; Fürst and Scholles, 2008; Selman, 2000; Marsh, 2010) which was created to assess concrete spatial situations and adapt methods suitable for the structure and accounting procedures of LCA. In this paper we propose a methodological approach for accounting the impact of different biofuel targets on biodiversity (Section 2), as well as its operationalization with indicators based on nationally available data in Germany, and then test this approach (Section 3). The research concentrates on impacts on a national scale (Germany), the impact category land use (and here only impacts on biodiversity), and the life cycle stage agricultural cultivation.

2 Methodology

2.1 Basic concept

In order to design an approach that can be applied without knowledge of concrete sites, and nevertheless makes reference to spatial characteristics, spatially differentiated data and summarized impacts on different spatial scales are used. The starting point for a spatially differentiated impact assessment is a given quantity target (biofuel quota) and the spatial distribution in scenarios using a geographic information system (GIS) (Urban et. al., 2008, see also Geyer et al., 2010). In particular, the procedure is characterized by the following features:

1. In the goal and scope definition, a quantity target for the selected product needs to be defined.
2. Representative model cultures are the basis for the operationalization of the polluter side in the inventory analysis with agricultural statistical data at the national level (pressure indicators).
3. The affected side (the ecosystem) in the impact assessment is operationalized by state and impact indicators

for three ranges of impacts: impacts on the cropland itself, impacts on the (standardised) nearest surroundings of the plots and impacts on landscape scale (including functional impacts on areas beyond).
4. The indicators are shown spatially differentiated by using a GIS.
5. By scenario modelling, changes in biodiversity, compared to the status quo, are assessed in two variations (worst case, spatially optimized), which can serve as a basis for LCA-based decisions.

The key precondition for the integration of biodiversity information into the LCA (in our approach) is the operationalization of the indicators that must always lead to calculable values on the county level. By the existing relation of the indicator results to the required additional acreage for biofuel production, which is the cause for the change, a conversion is possible to a per hectare value. This allows the calculation of indicator values per functional unit, which are necessary for a characterization method. Many LCAs use a hectare of agricultural area as the functional unit (so do we), but a conversion to other functional units, such as passenger kilometers, is also possible (Zah et al., 2007).

2.2 Selection of a product (biofuel) and analysis of the current land use

The first step consisted in the selection of the biofuel ethanol from wheat, because the example application should be made with a common culture (with good data availability). Since the cultivation of wheat for bioethanol differs only slightly from the one of conventional wheat (Mentz, 2006), agricultural data that characterize existing wheat cultivation can be used. As the quantity target, a share of 5.75 % bioethanol in petrol sales in Germany was defined (former EU goal for the year 2010, defined in the Directive 2003/30/EC). This goal equals about 1.8 million tons of bioethanol, which require about 1 million hectares of land for growing (approximately 6 % of the agricultural area of Germany) (Schmitz, 2006). For the determination of space requirements in future calculations it would be possible to take different yield values for wheat in the various counties instead of an average value.

As a second step, model cultures were designed in order to characterize the pressure coming from wheat and other existing agricultural land uses. For the inventory analysis the data from all main agricultural uses is required (not only those of wheat for bioethanol), to show the impact of displacements between the cultures through the cultivation of biomass. On the basis of statistical data from the main field crops and grassland on a county level (simplified term for 437 NUTS-3 spatial units in Germany; NUTS is the abbreviation for Nomenclature of Territorial Units for Statistics; NUTS-3, in particular, designates small regions) the relevant data for model cultures were compiled (share of area, area sizes, yields, fertilizer and pesticide use). As county-specific values these data represent properties of the different typical cultures (wheat, barley, etc.) for the respective district (therefore no differentiation in varieties is useful). The model cultures in the districts are linked with spatial data in the GIS. Thus various spatial differentiations in the GIS can be performed, depending on the needs of the indicator system and scenarios. Aggregation of more detailed areas specific data is always done on the NUTS-3 level as the least differentiated spatial unit used.

2.3 Outlining of land use scenarios

To estimate the impacts of land use change through the cultivation of energy crops in the determined area size, two different spatial scenarios have been designed. The difference between the scenarios demonstrates the possible range of habitat impairment and associated flora and fauna changes. Baseline is the current wheat distribution in Germany. The allocation of the additional wheat areas is done in two steps:

1. In an initial distribution, equal for both scenarios, the additional areas needed for wheat production are allocated to the districts according to agronomic conditions (indicated by the present share of wheat). So each county gets allocated a certain quantity of wheat. As a crop ecology limit a maximal concentration of 66 % wheat per county is implemented, because this is the maximum concentration for wheat cultivation in the crop rotations (KTBL, 2009).

2. In the "spatially optimized" scenario the assumption for the distribution of additional wheat production areas *within* the counties is that no ploughing up of grassland areas and use of fallows takes place. More areas, which have been identified as important for biodiversity (3.1.1), are also excluded from a possible use for energy crop cultivation in this scenario. Altogether this means that the areas needed for wheat production are distributed in a way which is spatially optimized for biodiversity protection. In contrast, the "worst case" scenario claims preferentially these areas with a high risk of damaging biodiversity. For this purpose, shifts in crop cultivation are assumed in the counties corresponding with the agronomic potential. For example, wheat could be grown in recent winter barley areas, winter barley could move to previous grassland (assuming ploughing up in the worst case scenario), etc. Crops with low requirements on soil fertility are forced out by wheat and would shift to areas more valuable for biodiversity. Nevertheless the wheat would be the cause of this shift of cultivation.

2.4 Impact assessment of biomass cultivation on different spatial scales by indicators

The impacts of energy crop cultivation on biodiversity within the two scenario options are described and evaluated on the basis of proxies. In principle, different reference systems are possible (previous, no or alternative uses) (Jungk and Reinhardt, 2000). We chose the status quo of agricultural land use as suitable reference system. This state does not represent an undisturbed natural biodiversity but is characterized by different biotopes and species according to the site as well as land use intensity. The present land use effects are not attributed to biofuels. Only the changes caused by the cultivation of energy crops for biofuels are ascribed to them (similarly Kaltschmitt and Reinhardt, 1997; Jeanneret et al., 2009). The definition of agricultural land follows Corine Land Cover 2000 (CLC). This broad definition comprises arable land, permanent crops, pastures and heterogeneous agricultural areas including natural areas (Bossard et al., 2000). The biodiversity of this agricultural land is very different, depending on habitat type and connectivity as well as the intensity of use (Dauber et al., 2010; Stachow et al., 2003). The changes for biodiversity through altered land use due to energy crop production can be substantial, particularly through use of previously only extensively used agricultural land, if grassland is converted into cropland, if landscape structures like hedgerows are destroyed or impaired or if the input of fertilizer, pesticides and the intensity of tillage operations increases.

With the support of a GIS, regionalized ratings are carried out for all of Germany. Because of the size of areas there is a need for an extensive formalization of the valuations. Impacts on biodiversity are considered on three scale levels: at the landscape level, in the direct vicinity of the cropland, and on the cropland itself. Reference areas for the evaluation are the NUTS-3 areas (in Germany: counties). The LCA should account the impacts on all spatial scales in a summarized form for each NUTS unit.

In our methodology the *landscape level* represents all supra-local effects that are beyond the scope of field / habitat and its immediate surroundings. At the landscape scale effects become visible which are possibly quantitatively negligible on the field or farm level. In this context, a principal advantage of the approach using national spatial data becomes clear, because changes and impairments due to a reduction of landscape diversity (e.g. national decline of grassland or nationally rare biotope types as well as narrowing of crop rotations) are recognizable. An approach that focuses only on the accounting for individual areas couldn´t reflect these important changes. The use of areas which are valuable for biodiversity is mentioned in the literature as the most serious threat from biomass cultivation (SRU, 2007; Dauber et al., 2010; EEA, 2007). This is because of the fact that, in this case, not only already intensive agriculture is modified, but the effect of biomass cultivation extends to land that has been extensively used or set aside so far and shows a high habitat quality. An indicator reflects this claiming of land (3.1.1). Furthermore, changes in crops that – individually – don't have significant effects can lead to a homogenization of cropping patterns at the landscape level with negative impacts on biodiversity. On this impact level an indicator has been found and operationalized which shows the changes in proportion and distribution of the different land use types (3.1.2).

In the immediate *surroundings of the cropland* in particular small structures and edge habitats could be affected by energy crop cultivation. Small structures and habitats such as small copses, hedges or hems are especially important under biodiversity considerations. By the changing land uses in the scenarios, the changes in the proportions of small biotopes at different biofuel targets can be estimated and compared with assessment criteria from the literature.

The impacts on the *cropland* itself were first indexed by a site-independent assessment of the crops in terms of their respective typical effects on biodiversity. This was based on literature reviews. In addition, a rating of the reduction in habitat quality of agricultural land was derived on the basis of indicators for management intensity (fertilization, crop protection) (3.1.3). Supplemental to the assessment of crops and management intensity the method provides a way to aggregate these indicators in combination with site conditions in order to integrate the different sensitivities of agricultural habitats. "Situation types" can be formed which are evaluated for their combination of crop type, management intensity and bio-geographical situation. The habitat development potential can be used to obtain a combination with local properties that can lead to a differentiated statement for habitat suitability.

2.5 Data availability

The optimal approach would start with the assumption that sufficient data would be available about the conditions of biodiversity at different scales. Unfortunately, such comprehensive data is not available for the Federal Republic of Germany. Somewhat problematic is the fragmentation of the German environmental monitoring, since it has lead to a confusing and incomplete data situation (SRU, 2004). So far, Germany has no nationwide monitoring program for biodiversity in cropland and grassland (Oppermann et al., 2009). Since there are neither homogeneous and detailed data at the federal level about biotope quality and size, nor on the distribution of populations of wild species in the "normal" cultural landscape (in opposite to protected areas, where detailed data are available), one has to resort to a mosaic of different sources of information in order to move closer to the required information. Spatially differentiated data sets are available for some agricultural data at the county level due to agricultural statistics (Statistische Ämter des Bundes und der Länder, 2008; Institut für Betriebswirtschaft, 1996). It is therefore necessary to use, as a reference point, these administrative units as an auxiliary means for the description of the use of natural influences on the natural-areas level and farm level. The spatial location of the administrative boundaries of the districts is done with the corresponding data of the Federal Agency for Cartography and Geodesy (BKG, 2007). For the regionalized analysis of the use of plant protection, data exist at the network for the determination of pesticide use in different, agriculturally relevant natural areas of Germany (NEPTUN) (Rossberg et al., 2002).

The data from Corine Land Cover 2000 (CLC) (UBA, 2004) have been used as a substitute for homogeneous geo-referenced data on biodiversity and agricultural areas at the landscape level and biotope level (including field). These data are the single homogeneous, area-covering and geo-referenced data, with which at least positioning of the agricultural land is possible nation-wide. A uniform data base for Germany that simultaneously locates and spatially differentiates the agricultural land and its crop-specific data, does not currently exist. Therefore, the data of agricultural statistics at the county level had to be brought together with data from Corine Land Cover to enable a GIS platform for a nationwide consolidation of data. Furthermore, the Natura 2000 network provides information on the rare or vulnerable areas for all of Europe in usable data quality (BfN, 2009). The data basis for regionalized small biotopes of the landscape is a directory of the Julius Kühn-Institut (JKI, 2004). It lists, for the Federal Republic, the proportion of small biotopes in agricultural areas.

3 Results

3.1 Operationalization of indicators and scenario based impact assessment

The necessary data were collected for Germany, the scenarios were designed and the indicators were realized and implemented in different degrees (Urban et al., 2011). For three of the indicators proposed in Section 2.4, a concrete operationalization was developed. The most influential of these (cf. 2.4), the indicator "Claiming of land that is particularly valuable with respect to biodiversity" was tested in a GIS application for all of Germany (3.1.1). The indicators "Cultivation proportion of agricultural crops" (3.1.2) and "Nitrogen fertilizer" (3.1.3) were tested exemplarily for one county to demonstrate the procedure.

3.1.1 Indicator: "Claiming of land that is particularly valuable with respect to biodiversity"

Following the "high nature value farmland indicator" (HNV indicator) (EEA, 2004) the following areas can be defined as valuable agricultural land for biodiversity:

- CLC Category 242: Complex cultivation patterns
- CLC Category 243: Land principally occupied by agriculture, with significant areas of natural vegetation
- Natura 2000 sites, which lie within the agricultural area.

As a result for Germany 4,976,219 hectares of valuable agricultural land have been identified by means of the GIS, which correspond to 23.2 % of total agricultural land (Figure 1).

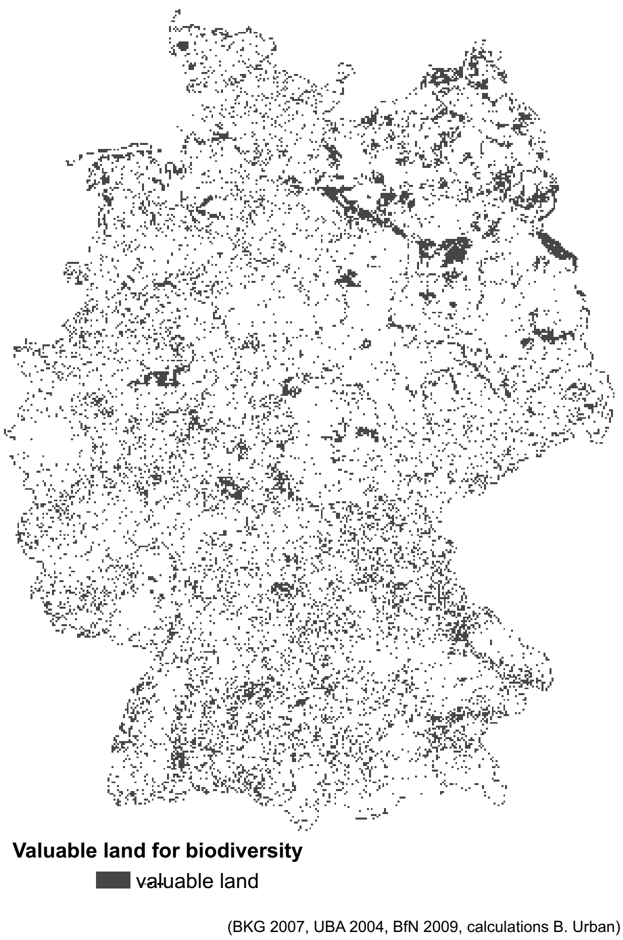

Figure 1:
Agricultural areas valuable for biodiversity in Germany

For the calculation of the indicator, the valuable agricultural land is determined in the GIS separately for each county in absolute and percentage size and compared with the

Table 1:
Calculation example for the claiming of land valuable for biodiversity in the fictional Counties A, B and C

County	Agricultural area (AA) (ha)	Additional wheat area (ha)	Valuable areas (ha)	Valuable areas (% of AA)	Worst case occupancy (ha)	Worst case conservation (ha)	Worst case % of occupied valuable areas in county	Spatially optimized % of occupied valuable areas in county
A	1000	115	50	5	50	0	100	0
B	1000	59	70	7	59	11	84	0
C	1000	7	30	3	7	23	23	0
total	3000	181	150			34		

respective additionally required land for wheat. The following sample calculation based on simplified numbers in hypothetical counties is used to clarify the procedure.

In County A, 115 hectares of area are needed because of the additional wheat cultivation for ethanol (volume allocation based on arable conditions done in the scenarios). Fifty hectares of farmland in the county have high value for biodiversity, and in the worst case scenario this area will fully be occupied by shifts within the county. In County B, 59 hectares of land required for wheat are accompanied by 70 hectares of valuable land. In the worst case, 59 hectares of valuable land are claimed and 11 hectares remain untouched. In the spatially optimized scenario, all valuable areas will remain in their valuable state for biodiversity. Therefore for the indicator "Claiming of land that is particularly valuable with respect to biodiversity" is assumed, that the spatially optimized scenario has no impact on biodiversity since none of the valuable land is affected (0 % in the last column of Table 1).

In the simplified example, in both the baseline and the spatially optimized scenario 150 hectares of 3000 hectares are rated as valuable; the indicator value for Germany is therefore 0.05 (5 % of the agricultural land). In the worst case scenario, only 34 hectares of 3000 hectares remain valuable; the indicator value amounts then to 0.0113 (1.13 % of the land remains in its precious status). Thus a deterioration in the amount of 0.0387 can be observed. The indicator calculated as shown, reflects the valuable land per hectare agricultural land and can be calculated both county-based as well as for Germany as a whole.

Accordingly, the individual values for the indicator in the counties are based, on the one hand, on the additional wheat area depending on the agricultural conditions, and on the other hand, they are based on the existing land valuable for biodiversity. The values were determined and calculated in GIS for all counties of Germany. Figue 2 shows the county-related deterioration of the indicator when switching from the spatially optimized scenario to the worst-case scenario. For the whole of Germany, the indicator value for both the baseline and the spatially optimized scenario is 0.232, according to the 23.2 % valuable agricultural land that was found (Figure 1). In the worst case scenario, the value is 0.189, according to 18.9 % valuable land. Thus a deterioration of 0.043 is observed and the valuable land will decrease by 4.3 percentage points (absolute: 925,108 hectares).

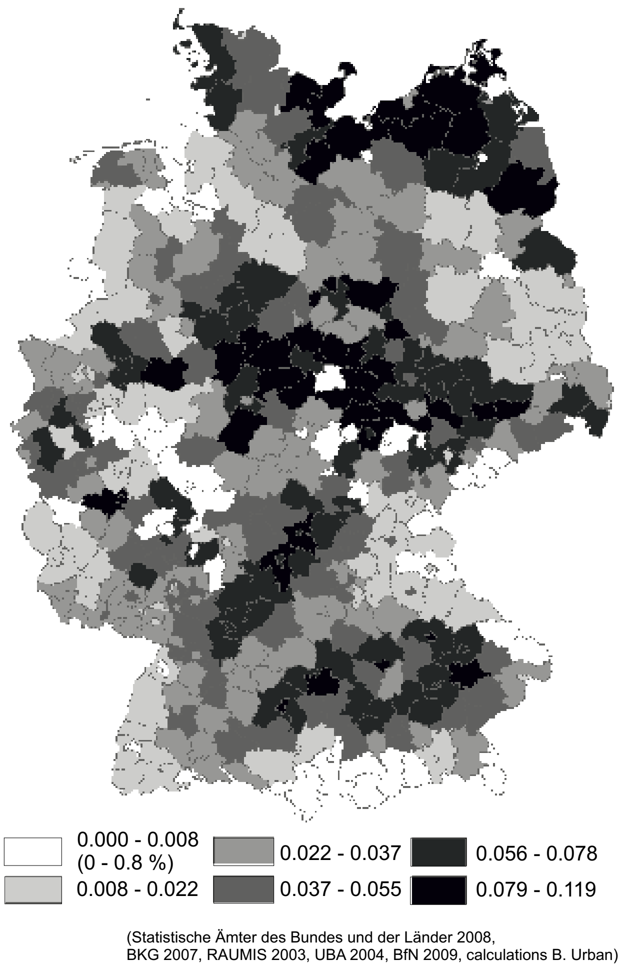

Figure 2:
Worsening of the indicator "for the biodiversity valuable land per hectare agricultural area" from the spatially optimized scenario to the worst case scenario in the counties of Germany

As a first step in assessing the validity of the results, a test is performed for this indicator. It examines the extent to which the areas considered (on the basis of Corine Land Cover) really represent the valuable biotopes which are important for biodiversity. For this purpose, the results obtained nationwide were checked by random sampling with the more accurate data that is available at local and regional level in some cases, but does not or does not homogenously exist for the whole of Germany. The results of both information bases were compared. Compared with the selective biotope mapping in Lower Saxony, a coverage level of 62 % was found for the areas considered. A comparison with the mapped biotope types of very high importance in the more detailed regional landscape plan of the county Verden resulted in a coverage rate of 51 % valuable land identified in the project. This plausibility check reveals that about 38 % to 49 % of the valuable biotopes are not found with the available data on the national level.

3.1.2 Indicator: "Cultivation proportion of agricultural crops"

This indicator is operationalized with a modified Shannon-Weaver index, which describes the cultivation proportion of agricultural crops (following Wetterich and Koepke, 2003). The valuation standard is basically the diversity in agricultural crops. A high index value stands for high crop diversity. It is assumed that a higher diversity of agricultural crops on landscape scale is better for biodiversity than a homogenous agricultural landscape with monocultures (Haber, 2008; Glemnitz et al., 2008). Piorr and Lehmann (2003) have calculated the baseline for the counties in Germany and found 2.83 as a maximal value. Crop rotation is not considered since the evaluation does not take place on the farm level. At the county level, the crop composition remains the same, only the individual areas are changing. With the Shannon-Weaver index, the change in the diversity of agricultural uses in the two scenarios compared to baseline are ascertained:

$$H = -\sum_{i=1}^{s} p_i \cdot \ln p_i \qquad (1)$$

H Shannon-Weaver Index
s Number of crops
p_i Proportion of the i-th crop

Table 2 shows for example the determination of the Shannon-Weaver index for the baseline and the worst case scenario in the county of Hildesheim. The indicator value shows that the diversity of use has decreased (-0.28) in the county.

Table 2:

Calculation example of the Shannon-Weaver Index in the county of Hildesheim (data source: Statistische Ämter des Bundes und der Länder, 2008; RAUMIS, 2003)

County of Hildesheim	Baseline (%)	Worst case scenario (%)	Difference (%)	H Baseline	H Scenario	Difference H
Grassland	6	5	-1			
Wheat	51	63	12			
Rye	0.2	0.1	-0.1			
Winter barley	7	6	-1			
Spring barley	1	0.4	-0.6			
Oat	1	0.4	-0.6			
Triticale	0.2	0.1	-0.1	1.52	1.24	-0.28
Potato	1	1	0			
Sugar beet	22	17	-5			
Rape	3	2	-1			
Maize	0.4	0.3	-0.1			
Fallow	8	4	-4			

3.1.3 Indicator: "Nitrogen fertilizer"

The relationship between nitrogen fertilization and decrease of the typical plant and animal species in agricultural ecosystems is well known (e.g. Flade et al., 2003). Using information provided by various authors, Vogel (2009) derived grades of nitrogen fertilizer application for arable land and grassland, which were used for the indicator assessment (Tables 3, 4).

Table 3:

Rule for evaluation of N-fertilizer levels in cropland (after Schumacher, 1995b; modified in Vogel, 2009)

N-fertilizer (kg/ha)	Grades of impact	Utilization adjusted to nature conservation
> 170	5	very small
100 to 170	4	small
50 to 100	3	medium
0 to 50	2	high
0	1	very high

Table 4:

Rule for evaluation of N-fertilizer levels in grassland (after Schumacher, 1995a; b; modified in Vogel, 2009)

N-fertilizer (kg/ha)	Grades of impact	Utilization adjusted to nature conservation
> 230	5	very small
150 to 230	4	small
50 to 150	3	medium
0 to 50	2	high
0	1	very high

The county-specific fertilizer data for the various crops were described for the model cultures. For each county, crop-specific fertilizer data of the original state are compared with the corresponding values of the scenarios due to the changing land uses. Table 5 shows as an example the calculation for the baseline in the county of Hildesheim. The average level of impact per hectare of agricultural land in Hildesheim is calculated as follows:

$$286{,}616 : 67{,}522 = 4.24 \qquad (2)$$

The difference to the scenario values can show the relative change of the indicator in the county by the additional wheat cultivation.

Table 5:

Calculation of the evaluation of the nitrogen fertilizer levels for the baseline in Hildesheim (data source: Statistische Ämter des Bundes und der Länder, 2008; RAUMIS, 2003)

County of Hildesheim	N-fertilizer kg/ha	Grade of impact	Baseline (ha)	Area (ha) x grade of impact
Grassland	119.3	3	3798	11394
Wheat	196.7	5	34859	174295
Rye	137.8	4	104	416
Winter barley	155.5	4	4839	19356
Spring barley	82.8	3	382	1146
Oat	82.2	3	378	1134
Potato	129.7	4	732	2928
Sugar beet	154.7	4	14850	59400
Rape	189.5	5	2046	10230
Maize	143	4	261	1044
Fallow	0	1	5273	5273
total			67522	286616

3.2 Linking of the indicators with the impact assessment of LCA

For the implemented example indicator (3.1.1) the following calculation arises:

$$\frac{0.043}{1 \cdot 10^{6}\ \text{ha}} = 4.3 \cdot 10^{-8}\ \text{ha}^{-1} \qquad (3)$$

The change of the indicator value of *0.043* (reduction of valuable land for biodiversity) is related to the additional wheat area of 1 million hectares (*1 × 10^6 ha)*, which is the cause for the change of the indicator. For the given biofuel target the indicator value for valuable agricultural land is deteriorating, under the described assumptions, by *4.3 × 10^{-8} per hectare* grown wheat. So it results in an indicator value (*4.3 × 10^{-8}*) per functional unit (ha grown wheat) that can basically be used similarly to other impact categories. No valuable land is claimed in the spatially optimized scenario and the result for this indicator is thus a value of zero. It should be noted that no proportional calculation is possible in the sense that, for example, a doubling of the additional acreage results in twice the loss of valuable land. The results are valid only for the predetermined quantity target (to the discussion of non-linearity see Geyer et al., 2010). The calculations for the other indicators operate analogously. For instance the Shannon-Weaver Index could be calculated for all counties and also related to the 1 million hectares of wheat.

An aggregation of the various indicators into an overall indicator was not performed. Rather, the various indicators result in an overall view of a "Biodiversity profile" for the considered fuel with a specific biofuel target. This "profile" could be compared with the results of another biofuel.

4 Discussion

The essential goal of a methodical linking of the LCA with spatial methods of environmental planning for the assessment of biodiversity could be achieved (in terms of "pathfinding"). An approach was designed that follows some methods of environmental planning with comprehensive statistical data and impact indicators, by which the polluter (pressure) and affected side (state and impact) are operationalized. No area-specific overlays are performed (because the concrete sites are not known). However, a Germany-wide spatial differentiation can be obtained through the conversion of spatial characteristics into percentages at the county level and by the use of scenarios. An advantage of the method lies in the fact that it allows different spatial levels (cropland, plot vicinity and landscape) to be combined by reference to the functional unit and the treatment of model cultures. The effects on the different spatial levels are projected by the proposed approach on a single spatial scale (county as an assessment object).

In principle it is possible to aggregate these values for the different scales to one biodiversity value to facilitate integration into superordinated LCIA methods. However, in consequence the relevant information from the measurement of individual indicators would be lost. Therefore the method only results in non-aggregated indicator values (similarly the methods of Oberholzer et al., 2006 for soil or Schweinle, 2000 for land use) that could be compared in a biodiversity profile in addition to the usual LCA.

In sum, abstract statements for the LCA can be formulated at national level which have the necessary spatially diverse background for biodiversity and include in particular impacts on the landscape scale. The method is basically leading the way. However, it has to be improved, especially with regard to better input data and in consequence differentiated indicators. The examination of the results for the indicator "Claiming of land that is particularly valuable with respect to biodiversity", for example, makes clear that for this indicator, due to data gaps, the actual effects in the worst case scenario are still greatly underestimated (see 3.1.1: a large percentage of valuable biotopes were not found). Thus only a rough estimate is possible with the national data available in Germany. To obtain better results, uniformly classified and assessed biotope maps on the national level are particularly necessary. With this data much more accurate results could be calculated. A most urgent goal is the inclusion of data about habitat connectivity. Such spatially differentiated results for habitat networks were recently produced for the national level in Germany (Fuchs et al., 2010). For legal reasons these (GIS-) data were not available for this research. However, they could be integrated if provided.

Another option for further development of the method is the scenario construction. The focus of the approach presented here is on impact assessment on the basis of a probable crop distribution from a cultivation point of view. This approach could be improved by an area-specific land use distribution modelling using more parameters. For the future this would be a starting point for the coupling with agro-economic models. Different approaches of spatially explicit modelling of biomass production should be tested (Hellmann and Verburg, 2008; 2010; Lovett et al., 2009). Furthermore, the method and particularly the indicators were so far chosen for agricultural land uses. An application to other forms of land use (e.g. forest) is in principle imaginable. Currently only agricultural products can be compared, because the indicators do not reflect the impact of forestry and other land uses. Thus a fuel derived from grain cannot yet be compared with one made of wood. The indicator "claiming of land that is particularly valuable with respect to biodiversity" (3.1.1) could be extended to other land uses if further valuable areas for biodiversity (apart from agricultural land) are included in the calculation. In addition, for forestry, the indicators "amount of deadwood" or "tree species diversity" may be suitable.

A transferability to other product systems, especially other agricultural products and other geographical areas is in principle possible. For other products the scenarios and indicators have to be calculated with the data of the corresponding product. The data availability has to be examined for this purpose and for other geographical regions. The data of CLC are available for all of Europe. The problem is the availability of data on valuable land for biodiversity.

5 Conclusions

The sensitivity and value of biodiversity can only be calculated with spatial relationships. Only if concrete production sites are known, can concrete accounting be done. For all other cases the necessary spatial reference has to be integrated into LCA by proxies. A suitable – though still incomplete - approach has been demonstrated in the research presented here.

The attempt to integrate the complex issue of biodiversity into the LCA also provoked some questions as to the suitability of the categories of the LCA (look also to the discussion in Curran et al., 2011; Finnveden et al., 2009). The impact category "land use" is intended to encompass such diverse impacts as nature conservation as a whole, including biodiversity, soil protection, erosion and other environmental effects. The attempt to cover the issue of biodiversity in LCA by methods environmental planning revealed, that there is a difference between pressure categories like eutrophication, which are (implicitly) considered to be generally harmful in LCA and impact categories like impairment of biodiversity which result from the combination of a potentially harmful pressure with a vulnerable /sensitive acceptor biotope or species. This difference should be better expressed in future LCAs.

A simple integration of the presented approach into existing LCIA methods is in the current state of the proposed method not possible. Further research would be necessary for this purpose. In the present state the proposed biodiversity assessment would be in addition to the usual approach of LCA. A complex and detailed process is necessary for the assessment of biodiversity that cannot be easily integrated in LCA like CO_2-equivalents.

Finally, the approach could be of interest for further developments of other spatially influenced environmental impacts (e.g. soil, water) in LCA. The proposed spatially differentiated approach could be transferred with adjusted indicators. As also indirect land use changes are considered it should be investigated whether the basic approach can be applied to the much-discussed indirect land use change in the impact category climate change. A global analysis of individual areas, which uses are displaced from others, is hard to imagine. In contrast, a regional approach of displacements as shown here would be quite plausible.

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