

Hemeroby as an impact category indicator for the integration of land use into life cycle (impact) assessment

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Abstract

Purpose As most of the impact categories modelled in Life Cycle (Impact) Assessment, land use is influenced by an immense number of different impacts forming a complex interaction network. At present, there is no common consensus on the best practice for quantification of land use in LCA. However, land use and its consequences for biodiversity and ecosystem services are currently subject to intense public debate. Here, we review relevant methodology proposed to date with special reference to the hemeroby concept to identify a consistent method that captures the complexity of land use without oversimplification and loss of crucial information.

Methods The definition of the safeguard subject is of vital importance and predetermines the framework of all methods and requirements for a reliable impact indicator. We selected *naturalness* as the safeguard subject and identified the hemeroby concept as the most appropriate approach for quantification. The hemeroby concept is particularly well suited for a nuanced assessment of different types of land use management.

Results With the application of a system of seven ordinal classes, the diversity of naturalness in forestry and agricultural production systems can be adequately characterised. The applicability of the classification system of the hemeroby concept was reviewed and aspects in need of further development

and method refinement were identified. Furthermore, the hemeroby concept was compared to other common concepts for the integration of land use into LCIA.

Discussion The hemeroby concept was identified as an appropriate approach to quantify the safeguard subject naturalness as an LCIA indicator. In addition, it addresses subjects like biodiversity and intact ecosystems. Characterising the quality of utilised land by classes encompassing ranges on an ordinal scale offers considerable merits in comparison with single value systems on a cardinal scale. Such systems tend to oversimplify the highly complex variable land use by assuming a single quantifiable ecological indicator (e.g. soil carbon content or relative α -biodiversity) as representative proxy. In contrast to this, the hemeroby concept offers an approach that is able to retain sufficient complexity of the information available for a particular area, yet condense this information so that it may be modelled for LCA purposes without loss of crucial data.

Conclusions Among all the methods currently available for the quantification of land use, the hemeroby concept is the most promising in terms of practicality of the actual method and quality of the output data. The classification into hemeroby classes is superior at capturing the complexity of land use. The method has been applied successfully in the area of European forests and agriculture. However, global availability of spatial hemeroby data and their compatibility with the criteria stipulated here needs to be evaluated and further developed as necessary. Other approaches focus on a different safeguard subject, thus narrowing the scope of land use as an impact indicator.

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1 Requirements for an impact category indicator for land use

1.1 What is the safeguard subject?

Like all other impact categories, land use is part of a complex interaction network. As such, it is associated with a considerable number of different impacts. These are primarily defined by both the size of the area and the type of use. Moreover, a substantial number of impacts of higher order (e.g. secondary, tertiary, quaternary, etc. impacts) may be associated with land use; among them biodiversity, soil health and net primary production.¹ The nature of the safeguard subject and the chosen characterisation model determine the level at which an impact category is modelled in a specific LCA.

The UNEP/SETAC Life Cycle Initiative developed recommendations for the design of characterisation models for the impact category land use. Both biodiversity and ecosystem services are taken into account (Koellner et al. 2013a). The latter include erosion regulation potential, freshwater regulation potential, water purification potential, biotic production potential and carbon sequestration potential among others.

The impacts of higher order like biodiversity and soil health are further determined by additional parameters, such as acidification, eutrophication, short-wavelength UV radiation, and temperature. The causal links and interrelations are generally too complex for modelling without considerable reduction to primary mechanisms. The primary impact *land use* strongly suggests to focus the interest in knowledge on impacts at higher order. These impacts should have close causal links with land use, yet they are not explicitly covered by other primary impacts (e.g. acidification, climate change). One example for an impact of a higher order may be found in biodiversity (e.g. inferred from the quantification of plant species per area).

However, neither low productivity nor low species diversity alone can be interpreted as a definite sign of poor ecosystem quality or performance. For instance, high-alpine and arctic regions, steppes, and bog habitats are undeniably among the most valuable ecosystems despite their low productivity and in some cases limited biodiversity. Biodiversity must always be defined in context with the biome, i.e. the natural potential for development, and the stage of succession. In consequence, an indicator for species quantification alone may not lead to correct interpretation. The choice and definition of indicators must consider this issue in light of the chosen safeguard subject.

The quantification of ecosystem services also requires a reduction of complexity, e.g. soil productivity may be quantified with the simplifying indicator soil carbon content (Mila i

Canals et al. 2007; Brandão and Milà i Canals 2013), which is directly correlated with the impact category indicator. Such reductions of complexity are always based on a defined safeguard subject and thus necessarily on a value-based approach.

Traditionally, LCA studies carried out by the German Federal Environment Agency (UBA) include the impact category *use of nature*. The fundamental document still in force today defines three safeguard subjects under this impact category (UBA 1999): (a) structure and function of ecosystems, (b) human health and (c) resources. The UBA method for characterisation of land use is based on the metric *Degree of naturalness of areas*, defined as proximity to nature. In the context of this approach the term “naturalness” is defined in a relative sense, referring to the gradual proximity to the natural state of a certain area. Any area apart from pristine ecosystems combines a mosaic of natural characteristics and features altered by anthropogenic impacts. The primary target of the safeguard subject “naturalness” is the promotion of natural characteristics in general as favourable, instead of limiting its focus exclusively on pristine ecosystems. Despite the recent developments on land use characterisation models in LCI, the fundamental idea to characterise *naturalness* as an overarching protection target (desired state) acting as the basic concept to address selected safeguard subjects is still highly appropriate. The idea central to the concept follows the logic that intact ecosystems are resilient and impacts of higher order do not find their expression. Moreover, the safeguard subject *naturalness* is in line with public perception and awareness. Irrespective of the professional debate on nature conservation, in Germany the term *wilderness* is widely regarded as a positive asset and a threatened safeguard subject among the general public (BfN 2014a).

1.2 Midpoint versus endpoint—which indicator is appropriate?

In analogy with the methods proposed in (UBA 1999), and in recognition of the interaction network of causal links associated with land use, the safeguard subject naturalness may be defined with two major variables: (a) area size and (b) area quality. In this context, area size is a variable that may be quantified with exact scientific methodology, although it may be complicated to measure for the inventory. Qualitative aspects such as area quality, however, cannot be quantified directly. Thus, a definition of qualities that form the basis of the assessment is required.

In the case that the complexity of the definition of quality is not condensed into a single quantifiable parameter beforehand, the derivation of quality criteria must be justified in a transparent and replicable way.

An exact definition to classify an impact category indicator as midpoint or endpoint indicator does not exist. Selection of an endpoint indicator reflects the aim to consider the causal

¹ Endpoint indicators aim to illustrate the entire causal chain from the emission to the actual final harmful effect. Midpoint indicators are located between emission and final harmful effect. Thus, they are more closely correlated with LCI results. Ideally, midpoint indicators model the primary impact.

chain starting from the anthropogenic environmental aspect (extraction from, or emission into, the ecosphere) to the final harmful effect of higher order. The distinction if an impact category indicator can be classified as midpoint or endpoint indicator is geared with the proximity to the level of the life cycle inventory. A midpoint indicator shows closer proximity to the life cycle inventory results. In this case, the complexity of the final harmful effect of higher order is reduced beforehand to a single parameter that should be included in the life cycle inventory and be quantifiable on a cardinal scale.

1.3 Cardinal versus ordinal scale—a matter of perspective?²

Despite the plausible need for simplification of quality criteria, the complexity of naturalness (wilderness) is too great to be reduced to a single measurable parameter. In consequence, the application of a cardinal scale is not feasible. Such a scale would require the a priori simplification of the complexity inherent in the system (already when defining the impact, see Fig. 1) to a single quantifiable parameter. This would result in the conversion of the *naturalness* of an area into cardinal data, analogous to a physical mass flow or a concentration.

In light of the inherent complexity of the explicitly qualitative characteristic *naturalness*, such an extreme simplification would represent an inordinate and inappropriate reduction of information. On the contrary, information defining quality should be combined with information on the classification of that information. Such a combination is hardly feasible without the application of an ordinal scale due to the fact that parameters of highly variable character must be numerically processed to allow an assessment of quality (compare paragraph 2.2 on this aspect).

1.4 Occupation impact versus transformation impact

The UNEP/SETAC guideline on global land use impact (Koellner and Geyer 2013b; Koellner and Geyer 2013a; Koellner et al. 2013b) distinguishes between two fundamental impacts of land use activities: land occupation and land transformation. The latter is often referred to as land use change (LUC). Whereas land occupation focuses on the actual present state of an area, the consideration of land transformation includes the assumption of the state of an area before use. According to the guideline, even the period of use and the state that the area is likely to achieve after regeneration (including regeneration time) should be considered.

² Cardinal scale (or metric scale): a scale to distinguish discrete and continuous data, the magnitude of the distance between two values may be justified with logical arguments. Ordinal scale: distinction into qualitative criteria to establish rankings such as *greater*, *smaller*, *more*, *less*, etc. The distance between the individual classes is not numerically defined.

The UBA approach excludes land transformation as a factor, thus dispensing with the necessity to model a hypothetical construct. After all, all components and assumptions of such a model are generally unknown. Of all the assumed variables, the state before use is generally the simplest to describe. However, in the case of an extended period of use, even the pre-use state may be difficult to determine. In contrast, details on the total period of use are entirely theoretical and may only be defined per convention. After all, how many years precisely until the reasons or motivation to use a field expire?

However, the limitation to the occupation aspect of the impact of land use does not exclude the assessment of land use change in general. It is common practice in LCA to compare alternative scenarios, thus the scenario on non-use always offers the option to include a *no occupation* reference case in the assessment. In consequence, transformation impacts are then a component of the comparative LCA results, although they are not inherently integrated into individual life cycle inventory data or characterisation factors.

2 Hemeroby as an appropriate impact indicator

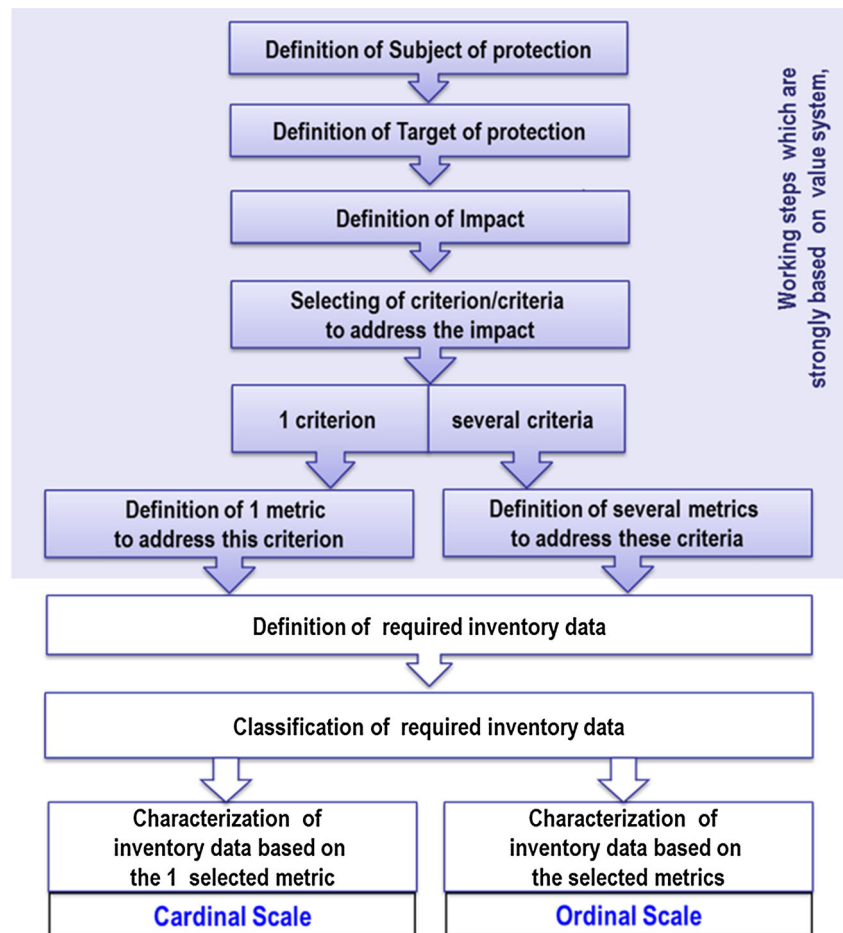
2.1 The hemeroby concept

2.1.1 The term hemeroby

Hemeroby (Greek: *hémeros*=cultivated, *bios*=living) is a term used in landscape ecology and literally expresses *distance to nature*. As such, it acts as the complementary term to the more common *naturalness*. The term hemeroby was initially introduced for the assessment of vegetation disturbance and has been in use since the 1950s (Jalas 1955). Sukopp (1972) went on to extend hemeroby into a system for the classification of habitats and vegetation types introducing a scale ranging from ahemerobic (no anthropogenic influence) to metahemerobic (biocoenosis completely destroyed). Klöpffer and Renner (1995) pioneered the application of the hemeroby system in LCA. In (UBA 1999), the German Federal Environment Agency adopted the concept of hemeroby classification developing an approach for woodlands. Moreover, the target situation, and thus the safeguard subject, was clearly defined: “An increase of wilderness areas is required, both in number and area size.”

The decision to shift the overarching focus of conservation to the protection of undisturbed ecosystems (wilderness) with hemeroby as the decisive indicator primarily represents a move away from anthropocentric protection targets. Ecosystem services, or the productivity of cultivated land from a human point of view, are explicitly not the top priority of the approach. Additional protection targets or impact endpoints in the context of land use are not necessarily sufficiently addressed by the hemeroby concept. For instance, an undisturbed primary forest area at the final succession stage in Europe is not associated

Fig. 1 Steps to reduce complexity



with the highest biodiversity per area, the highest net primary production or the highest soil carbon content. In fact, human intervention could maximise these factors.

2.1.2 Many variables, but no composite indicator

Kowarik (1999) defines hemeroby as a measure of human impact on ecosystems. Due to the immense complexity of both natural ecosystems and human intervention, it is not feasible to determine this measure with a single or a few selected metrics. In fact, a set of parameters is required to ensure representative and reliable result for the classification of a specific area in the appropriate hemeroby class. However, the considerable number of metrics does not translate into a composite indicator in the original sense of the term. As a rule, true composite indicators describe multidimensional concepts such as *wealth, sustainable development, environmental quality or economic competitiveness*.³

In contrast, the indicator hemeroby (or naturalness) refers to a clearly defined, concise protection target, i.e. the conservation of ecosystems undisturbed by anthropogenic influence.

³ Definition of composite indicator please see OECD: <http://stats.oecd.org/glossary/detail.asp?ID=6278>

Due to the fact that anthropogenic influence happens in manifold ways and individual ecosystems may show a wide range of reactions, only a complex tool for quantification is appropriate to capture the inherent variation.

2.1.3 Quantification in discrete numerals or classes?

There are two general options to express hemeroby data as numerical results: (a) as discrete numbers on a finite or infinite scale (e.g., a hemerobic score of 3.785) or as ordinal classes (e.g. I, II, III etc.). As mentioned above, the application of classes is now common practice. The classification system introduced by UBA (1999) consciously avoids the simplification of complexity to a single parameter expressed as a discrete numerical result of a measurement. In consequence, the aggregation of life cycle inventory results for the purpose of impact assessments (characterisation, normalisation, see Chapter 4) is facing other challenges. However, the ordinal scale of the results corresponds with results from landscape ecology research. Any indicator data in precise numerical form would suggest a pseudo-objective accuracy that is not supported by actual science.

Moreover, the classification in seven relatively coarse classes allows an assignment into common classes of

land use typology. For instance, species-rich extensively managed hay meadows can be classified as class IV (semi-natural), thus capturing the highly variable range of its formations, whereas the assignment to a single discrete value on a cardinal scale would render any reference to land-cover types impossible. Area-related terminology in general should only be represented in classes covering ranges. This is the only approach to provide guidance and translate common terminology and established typology in a plausible and reliable fashion (see right column in Table 1).

2.2 Hemeroby classes

The classification in the system introduced by UBA (1999) (see Table 1) follows a systematic approach based on a number of criteria and metrics. Central to the concept is the assessment of characteristics that qualify the area under investigation as more or less natural or hemerobic. In this context, the criteria address local conditions (status quo assessment) and current actions (degree of influence through cultivation). The defined metrics must be suitable for the assignment of investigation results to a hemeroby class (see Fig. 2). The criteria system has to capture a broad range of area-related information to adequately reflect the diversity of area conditions below the highest class (natural). Moreover, the approach has to remain practical and should consider the necessity of a degree of abstraction common in LCA practice. After all, it is not an actual area under investigation in the majority of cases, but generalised generic inventory data within the scope of an LCA.

The highest class of naturalness (undisturbed ecosystem, e.g. primary forest) does not play a role for application in LCA because its use, and thus its integration into a product system, is by definition excluded. The relevant areas are those that are actively utilised for production purposes (e.g. forestry, agricultural land, mining) or serve additional purposes within the system boundaries (e.g. landfills, settlements). These areas are assigned to hemeroby classes II to VII according to the

results of the systematic approach via defined criteria and metrics. Hemeroby classes for the assessment of land use in LCAs were also proposed by Brentrup et al. (2002). However, the classification in their approach is based on entirely descriptive typology after Kowarik (1999). For land use risk assessment, Penn-Bressel (2013) developed an approach based on hemeroby classes.

2.3 Linking hemeroby with other protection targets

The hemeroby approach is directly and indirectly linked with other protection targets (see above). The central idea of the approach promotes this as a desired side effect, i.e. the minimisation of human intervention in ecosystems is likely to have a positive influence on additional safeguard subjects and protection targets (e.g. soil quality or climate change mitigation). However, the metrics for the quantification of hemeroby are still explicitly focused on hemeroby alone. Neither the soil quality in itself, nor soil carbon content or soil carbon flux and turnover for a greenhouse gas balance are addressed explicitly. Instead, the central question is: Is a particular land-use management associated with severe alterations of natural areas (biotope and biocoenosis), or are management practices sufficiently gentle to allow the area to remain relatively intact and close to the potential natural state?

In the context of land use, it may be useful to consider different impact indicators addressing different protection targets, and integrate all results according to goal and scope in the interpretation phase of an LCA. For instance, the impact categories acidification, eutrophication, ecotoxicity, climate change, stratospheric ozone depletion and photochemical ozone creation potential all place a different focus on the common safeguard subject *intact ecosystems*. According to goal and scope of LCA studies, different impact category indicators addressing ecosystem services and/or naturalness may be appropriate. The close linkage between some of the impact endpoints and the hemeroby concept is illustrated by Wrbka et al. (2004) with the example of the human

Table 1 The classification system of hemeroby classes (from Giegrich and Sturm 1996, amended)

Class	Class name	Different types of land use; indicative examples, to be defined by measurements
I	Natural	Undisturbed ecosystem, pristine forest, no utilisation
II	Close-to-nature	Close-to-nature forest management no thinnings
III	Partially close-to-nature	Intermediate forest management (moderate thinnings, natural assemblage of species); Highly diversified agroforestry systems, low input
IV	Semi-natural	Semi-natural forest management (regular thinning, exotic species); close-to-nature agricultural land use, extensive grassland, orchards, highly structured cropland with low input
V	Partially distant-to-nature	Mono-cultural forest; intermediate agricultural land use with moderate intensity, short rotation coppices
VI	Distant-to-nature	Distant-to-nature agricultural land use
VII	Non-natural artificial	Long-term sealed, degraded or devastated area

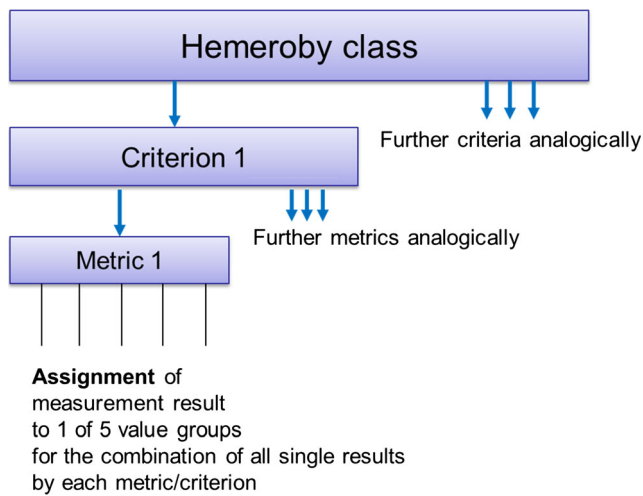


Fig. 2 Criteria system for the classification of areas in hemeroby classes

appropriation of net primary production (HANPP). Figure 3 illustrates the network of hemeroby impacts at different levels.

3 The hemeroby concept is applicable for every land use type

In principle, any form of land use can be described with the hemeroby concept. The practical focus in LCA is currently on areas involved in the production of renewable raw materials in relevant quantities. In this context, many diverse and highly complex types of habitat (e.g. rock and scree communities, moraines and glacier termini or bog habitats) are considered negligible, although they add considerable ecological value to the landscape. However, these landscape elements may be relevant when integrated into the surrounding cultivated landscape in a broader sense (e.g. corridors linking habitats within agricultural areas). Thus, these areas must be included for normalisation purposes during the specification of the reference area (e.g. total area in Germany, Europe, etc.). The implementation of the hemeroby

concept for the main areas of application is described in the following.

3.1 Forest systems

3.1.1 Model system

Giegrich and Sturm (1996) initially applied the hemeroby concept for woodland areas in central and northern Europe and extended it for application in a product LCA for graphical papers (Tiedemann 2000). The model system for naturalness is based on the concept of *process conservation*. In forestry, this concept stipulates dynamic change as a defining principle of all living systems from single species, communities and entire ecosystems, and calls for the conservation and safeguarding of all natural processes. First priority in conservation is given to the minimisation of human influence on forest soil and vegetation, thus allowing undisturbed and continuous development (Sturm 1993).

3.1.2 Criteria and metrics

Three criteria were defined for implementation of the method: (1) Naturalness of the soil, (2) Naturalness of the forest community and (3) Naturalness of the development conditions. For each of the criteria, six or seven metrics were developed (see Table 2). These metrics allow the characterisation of the naturalness of the respective criterion.

For instance, the quantification procedure is illustrated with the first metric of the first criterion (Intensity of mechanical earth working). The result is attributed to the corresponding value group (see Fig. 2) from the following list:

During the observation period,

1. No earth works were carried out across the entire area under investigation.
2. Superficial earth works were carried out in parts of the area.

Fig. 3 Network of impacts around hemeroby

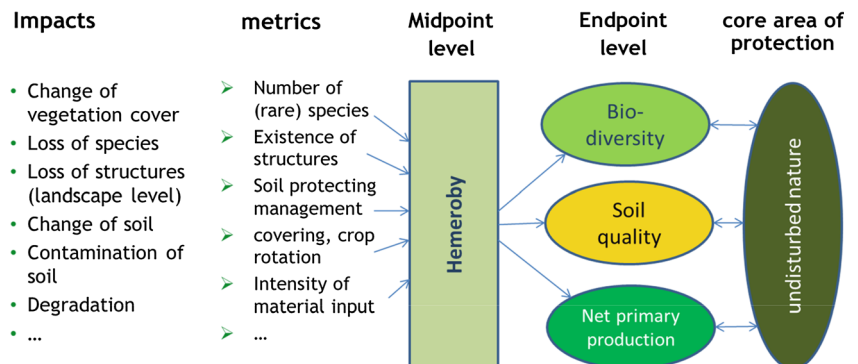


Table 2 Criteria and metrics to characterise the naturalness of forest systems (from Giegrich and Sturm 1996)

Criterion 1: Naturalness of the soil		
Metric 1: Intensity of mechanical earth working		Active management metric
Metric 2: Forest dissection		Status quo metric
Metric 3: Intensity of material interventions (liming and fertilization)		Active management metric
Metric 4: Intensity of material interventions (pesticide deployment)		Active management metric
Metric 5: Continuity of soil development		Status quo metric
Metric 6: Continuity of mature forest sites		Active management metric
Metric 7: Unspoiled water regime in the top soil		Active management metric
Criterion 2: Naturalness of the forest vegetation		
Metric 1: Natural character of the vegetation mix		Status quo metric
Metric 2: Natural character of the cultivated areas		Active management metric
Metric 3: Relative tree species diversity		Status quo metric
Metric 4: Vertical and horizontal structural diversity		Status quo metric
Metric 5: Dead wood content		Status quo metric
Metric 6: Typical microstructures		Status quo metric
Criterion 3: Naturalness of the development conditions		
Metric 1: Spontaneity of vegetation growth		Status quo metric
Metric 2: Spontaneity of forest renewal		Active management metric
Metric 3: Spontaneity of vegetation development		Status quo metric
Metric 4: Intensity of management interventions		Active management metric
Metric 5: Continuity of vegetation development		Status quo metric
Metric 6: Intensity of final use		Active management metric
Metric 7: Assumption of random developments		Active management metric

3. Superficial earth works were carried out across the entire area, with up to 10 % subject to deep ploughing, i.e. within the mineral soil layer.
4. Earth works affecting the mineral soil layer in parts of the area.
5. Earth works affecting the mineral soil layer across the entire area.

The assignment to value groups is carried out in analogy for all metrics. The respective group may be found in Giegrich and Sturm (1996).

3.1.3 Algorithms

The combination of results is carried out following the same principle, as exemplified in the paragraph on farming below. For simplification and standardisation purposes, the original approach of Giegrich und Sturm (1996) is slightly modified. The formal procedure includes the calculation of the arithmetic mean from all metric results per criterion, followed by the calculation of the final arithmetic mean from all criteria (for specifics, see paragraph 3.2.3)

The final result is the classification of the woodland area under investigation into one of the classes introduced in paragraph 3.2.3, ranging from class II (close-to-nature forest) to class V (mono-cultural forest).

3.2 Agricultural systems

3.2.1 Model system

In contrast to woodland ecosystems, areas used for agricultural purposes are by definition subject to human influence. In consequence, *unspoiled nature* does not qualify as the ecological model system to pursue for agricultural areas. Conversely, modern agricultural practices have been identified as the main perpetrators responsible for the dramatic loss of biodiversity among flora and fauna for some time (Korneck et al. 1998). Among the key factors are habitat destruction, land use change and agricultural intensification. This development distinctly contradicts the image of the central European agricultural landscape up until the mid-nineteenth century. The common practice of diverse small-scale parcelling of land was associated with considerable structural and biodiversity richness distinctly exceeding the species richness of woodland habitats (Jedicke 1990). However, the reintroduction of pre-industrial agricultural landscape patterns is both unfeasible and unrealistic due to the complete and utter change of the present-day social and economic situation. Nonetheless, lessons to be learned from historical records include the distinct ecological potential inherent in diverse agriculture that may support a multitude of individual ecological niches and thus maximise biodiversity.

The concept of *High Nature Value Farmlands (HNV farmlands)* addresses similar issues and is part of the set of EU indicators for the integration of environmental concerns into common agricultural policy (EC 2006). The German Federal Government (BMU 2010) also applies the indicators for monitoring of the national biodiversity strategy. The BfN (2014b) defines *HNV farmland* as an agricultural area “that is used extensively, forms a small-scale mosaic of cultivated and natural areas and/or supports habitats for rare or endangered species. The focus is on both extensively managed areas and typical structural elements in agricultural landscapes. Pivotal factors for a high nature value are both species richness and structural diversity of the agricultural landscape.” This definition is consistent with the model system for the classification into hemeroby classes proposed by Fehrenbach (2000): “The goal is an agricultural ecosystem rich in structural and species diversity in which disturbance caused by production practices is reduced to the minimum necessary for the

maintenance of sustainable productivity”. Please note that this model system was developed for central European agricultural landscape. An extension to distinctly different geoeological settings (e.g. steppes of central Asia) is not appropriate.

3.2.2 Criteria and metrics

The criteria and metrics for this model system were developed for agricultural areas based on several evaluation systems (see Fehrenbach (2000)). Selected criteria and metrics describing both area-related parameters and operational criteria are reported in Tables 3 and 4. The operationalisation of the assessment of naturalness is carried out with a classification according to the compliance with the individual metrics. For each metric, there are five tiers. With the help of an offsetting rule, the overall resulting hemeroby class of an agricultural area is calculated from the individual tier classifications. The options

Table 3 Area-related criteria and metrics; the result for the area under investigation is assigned to the respective tier (1 to 5)

Criterion 1: Diversity of weeds			
	Metric 1: Number of weed species in the cultivation area	Metric 2: Existence of rarer species	
Tiers applied to assign the measurement	<ol style="list-style-type: none"> 1. High diversity of species and associations of plants; more than 150 species (not only typical species fields) per hectare 2. Stable existence of species belonging to different associations; from 100 to 150 species per hectare 3. Stable existence of species belonging to different associations; from 50 to 100 species per hectare 4. Sporadically existing flora, exclusively typical weeds; up to 50 species per hectare, predominantly strongly competitive characters 5. Area nearly free from weeds; only sporadic existence of only strongly competitive and common species 	<ol style="list-style-type: none"> 1. Stable existence of several species marked in the “Red Data Book” of threatened species; including some that are at least “strongly threatened” (cat 3). 2. Steady existence of at least one species marked in the “Red Data Book” of threatened species 3. Sporadic existence of species marked in the “Red Data Book” of threatened species 4. (not occupied) 5. Only common species existing. 	
Criterion 2: Diversity of structures			
	Metric 3: Elements of structure in the area	Metric 4: Size of cuts	Metric 5: Variety of landscape
Tiers applied to assign the measurement	<ol style="list-style-type: none"> 1. Formation of the farmlands with many structural elements present (more than 10 % hedges, trees and habitable area in the farming field) 2. Many point and linear structure elements with a high level of flora/fauna flow between them (up to 10 %) 3. Individual linear structure elements (up to 5 %) 4. Individual point structural elements (few per hectare) 5. No structural elements present, no overlaps or borders for wildlife 	<ol style="list-style-type: none"> 1. No mono-structured cuts (e.g. extended agro-forestrial structure) <p>Average size of cuts <0,5 ha</p> <ol style="list-style-type: none"> 2. Average size of cuts 0.5 to 1 ha 3. Average size of cuts 1 to 2.5 ha 4. Average size of cuts >2.5 ha 	<ol style="list-style-type: none"> 1. Landscape has high spatial diversity, a parkland-like appearance rich of wood; high integration of field, meadows and woods 2. Varied farmland, fine-meshed structure of landscape, richly pervaded by woody zones or other scenic elements 3. Frequent changes between fields, meadows and woods 4. Predominantly monotonous landscape, structural elements rare 5. Spatially monotonous unstructured landscape

Table 4 Action-related criteria and metrics; the result for the area under investigation is assigned to the respective tier (1 to 5)

Criterion 3: Soil conservation			
Tiers applied to assign the measurement	Metric 6: Intensity of soil movement	Metric 7: Ground cover	Metric 8: Crop rotation
	1. Soil movement locally and temporarily restricted to sowing and planting	1. Soil covered throughout the year by several complementary techniques (mulching, multi-seasonal green manure, alley cropping, integration of trees)	1. Mixed cultivation with many different types of crops
	2. Soil movement strongly restricted, no heavy machinery	2. Soil mostly covered, regular cultivation of green manure and intercrops	2. Cultivation of six different types of crops over 6 years in a balanced pattern of exchange between grains and other crops (animal feed, proteins, oils). No root crops are grown.
	3. No deep ploughing, limitation to grubber or similar tools	3. Several techniques of soil coverage, preference of above-average covering cultures (fodder crops, winter rye, barley, oil fruit but rarely root crops)	3. Over 6 years, five or six of the crops are rotated, some cultivation of root crops, regular fallow periods.
	4. Deep ploughing at most every second year.	4. Root crops only combined with sowing in layers of mulch or similar techniques	4. Over 6 years rotations four to five different crops are cultivated, including root crops.
	5. Deep ploughing every year, regular employment of heavy machinery	5. No employment of soil cover techniques	5. A maximum of three different crops are rotated through, many root crops and otherwise grains.
Criterion 4: Material input			
Tiers applied to assign the measurement	Metric 9: Procedure of fertilising	Metric 10: Intensity of fertilising	Metric 11: Plant protection agents
	1. Fertilising only by means that are disposed by the farm itself, no supply from outside	1. no additional input of N besides green manure	1. No active pest control (but indirect measures like <i>weed management</i>)
	2. Input of nitrogen and phosphorus only by manure or composted manure and/or other hardly soluble fertilisers (e.g. thomas meal, bone meal)	2. less than 50 kg N per ha if weak soil fertility and cultivation of hardy crops (if not→group 3)	2. Only biological and mechanical methods of pest control
	3. Predominance of manure or composted manure	3. 50 to 100 kg N per ha if weak soil fertility and cultivation of hardy crops (if not→group 4)	3. Application of pesticide not exceeding once per annum, or up to three times on less than 50 % of the total area
	4. Predominance of artificial fertilisers and/or liquid manure no application outside the growing season	4. 100 to 150 kg N per ha	4. Up to three applications per annum
	5. Exclusively artificial fertilisers and/or liquid manure also outside the growing season	5. more than 150 kg N per ha	5. Regular employment of pesticide (several times per annum)

for classification of agricultural areas are the hemeroby classes III to IV.

3.2.3 Algorithm

The selection of metrics covers an adequate and comprehensive range of parameters to sufficiently characterise the naturalness of an agricultural system in all its nuanced intricacy. Some metrics address common themes, e.g. the number of weed species (metric 1) is usually strongly correlated with the intensity of soil movement (metric 6) or the application of plant protection agents (metric 11). The overall view characterised by all 11 metrics, however, provides a detailed evaluation that allows the consideration of many special cases.

The wealth of nuanced information integrated into the final result acts as a safeguard for accurate and scientifically sound methodology. In consequence, complicated procedures to offset the individual metric results in a separate step would not be appropriate and lead to a lack of transparency in the overall result.

Thus, the aggregation is calculated following simple mathematical procedures:

- Classification into tier 1 of a metric is associated with one point, whereas classification into tier 2 of a metric scores 2 points, etc.
- The scores of all metrics of a criterion are reported as the arithmetic mean.

- From the respective arithmetic means of the criteria, the overall arithmetic mean is calculated. The resulting value between 1 and 5 is further classified into one of the hemeroby classes designated for agricultural areas following the conversion in Table 5 (the HNV farming approach of the BfN (2014b) also distinguishes four quality classes for agricultural areas).

3.3 Other land use

In principle, any form of land use can be associated with a hemeroby class. Relevant areas in product LCA are often developed areas (e.g. landfills), or areas used for the mining of feedstocks and raw materials, among them quarries, opencast mining areas and mine tailings. In context of the hemeroby concept, all of these areas are non-natural or artificial, thus they are classified as class VII. It is debatable whether this class should be divided into subgroups to accommodate precise data on the different forms of land use. The original work on hemeroby by Sukopp (1972) distinguished between polyhemerobic (mostly artificial) areas including partly sealed areas, mining areas and landfills (due to subsequent restoration) and metahemerobic areas that are fully sealed and devoid of any vegetation.

The universal application of the hemeroby concept would require the integration of general settlements and other areas shaped by human interference that are not directly involved in the production of goods. At present, there are no criteria available for the classification of such areas. However, forms of land use associated with buildings in a spatial distribution that involves either single locations or mosaics of buildings in otherwise undisturbed landscape are becoming increasingly relevant. Examples include wind energy and photovoltaic parks. In both examples, the original state of the area could be relatively natural (e.g. woodlands, coastal habitats, low-nutrient meadows). The classification into hemeroby classes requires criteria linking the value of the original state of the land with significance of the artificial disturbance associated with the operations. Approaches for quantification are in the process of development. At present, the hemeroby concept also excludes water bodies. Again, appropriate approaches are currently in the early stages of development.

Table 5 Match of agricultural area data with correspondent hemeroby classes

Criterion mean	Hemeroby class
1 to <2 →	III partially close-to-nature
2 to <3 →	IV semi-natural
3 to <4 →	V partially distant from nature
4 to 5 →	VI distant from nature

3.4 Temporal reference

A characterisation model based on the concept of hemeroby classes considers the strain on a particular area per functional unit in the product system under investigation and addresses the question whether the quality (hemeroby) of the area in question is influenced during the period of use. The actual length of the period required for the production of the functional unit and the state of the area before and after use is excluded from this approach. Instead, the status quo of quality of the area is assessed. Area qualities in the past or potential future developments are not taken into account. The focus is on land use rather than land use change (see paragraph 1.4). The unit of land use in this approach is area × period of use [$\text{m}^2 \text{ a}$]. This is the same unit proposed by UBA (1999). The reference period of use for all data is 1 year. Appropriate allocation rules may be defined if necessary, e.g.:

- Woodland/ forest system: temporal reference based on the growth of a defined quantity of wood in an area per annum.
- Agriculture: In the case that one wheat crop per annum is harvested, the area under cultivation must be charged to that crop in full. In the case of intermediate crops, allocation to the respective crop is required. However, the temporal reference period of 1 year remains valid. Similar rules apply for crop rotation (see Baitz et al. 2000).

In consequence, primary data collection is carried out with the unit biomass production per area and per annum [$\text{kg}/\text{m}^2 \text{ 1a}$]. In reference to the functional unit, the unit for land use is [$\text{m}^2 \text{ 1a}/\text{tE}$].

4 Method refinement

4.1 Lessons learned from application in LCA

Since the first application in an LCA on graphical papers (Tiedemann 2000), the hemeroby concept has been frequently used for LCA purposes. For agricultural production, the concept was applied by Kauertz et al. (2011) and Carus et al. (2014), among others. Thus, the general practicability of the approach has been demonstrated. However, broad implementation of the approach is limited by a few details in need of further development. For instance, standard application of the concept is hampered by the lack of sufficient general data, e.g. default input data for the most common and relevant products from forestry and agriculture. The question of data availability is particularly relevant outside of Europe. Furthermore, both criteria and metrics require revision and updated research as appropriate to reflect advances in science since the advent of the concept in the late 1990s. If indicated, adaptations to the

current state-of-the-art in the respective area of science may be integrated.

4.2 Development of generic inventory data for key products

The application of the hemeroby concept to abstract products (independent of a specific production location), e.g. 1 t of wheat or 1 m³ of timber from Germany, requires a generalised application of criteria and indicators to the overall situation Germany, with the possible extension to Europe and beyond. In consequence, generic inventory data sets for the classification of an area into a hemeroby class are required. The range of product systems included should be as broad as possible. However, the compilation of global data is going to be very elaborate and time-consuming. Expertise is required due to the fact that hemeroby classes may vary considerably across different vegetation zones. Thus, high standards of methodological transparency must be maintained for the development of classes and the symmetry and consistency of classification of a given form of land use into a specific hemeroby class. These designations should be considered in collaboration with experts and competent institutions representing forestry and agriculture.

An extension of the available data would allow universal classification. In an LCA context, this would considerably simplify normalisation, or rather allow reliable normalisation in the first place due to the fact that the actual situation within the reference system (e.g. Germany, Europe, world-wide) has to be known. In addition, many other areas of application would substantially benefit from a detailed spatial zonation into hemeroby classes. Walz and Stein (2014) show that implementation of hemeroby zonation would be feasible with high resolution for all of Germany. Similar work has already been carried out in Austria (Rüdisser et al. 2012). Another conceivable option would be a link with the HNV farming approach of the BfN (2014b). There, the agricultural areas across all of Germany have already been classified for the year 2009.

4.3 Development of characterisation factors

Up to this point, the approach introduced here excludes the application of characterisation factors. In previous studies, life cycle inventory data for areas were reported classified according to the respective hemeroby class. The authors recommend this method as the primary approach. The requirements stipulated in ISO 14044 (clause 4.4.2.4 and 4.4.5) for characterisation factors are far from trivial: they must use “a distinct identifiable environmental mechanism and/or reproducible empirical observation”. Value-choices and assumptions used shall be identified and documented.

However, the aggregation into a single indicator value may be useful for certain applications. For these cases, the authors propose a method for the derivation of characterisation factors. The initial steps require:

1. The determination of the maximum range between the characterisation factors for area classes that are included as inventory data.
2. The determination of the differences between the classes.

The maximum margin between area classes ranges between the most natural area (class II) and the most severely disturbed area (class VII). Class I may be considered negligible due to the fact that any use is excluded per definition. Thus, it will not feature as life cycle inventory data in any LCA. The derivation of the factor between these two classes follows this logic: the global share of area classified as class VII amounts to approx. 3 % of land area.⁴ In consequence, the ratio between class VII land and the sum of the other areas is 1:33.

The empirical approach for the derivation of characterisation factors detailed below is based on the implicit premise that the current area mix is unlikely to develop towards increased disturbance and less naturalness. Moreover, it is ensured that the product of area and characterisation factor of the existing class VII area does not exceed the results of the entire remaining land area, assuming that land area was classified as class II. In other words, under application of characterisation factors, the total impact of the 3 % non-natural land area must not receive a more favourable assessment than the remaining land area in its entirety assuming maximum natural use. A closer ratio than 1:33 would come to the conclusion that conservation-oriented best-practice global land use through human impact is less beneficial than the measure of class VII area currently in existence. Figure 4 illustrates these ratios. Thus, the total range should not fall short. However, distinctly greater ranges are of little value due to detrimental consequences for the results, i.e. the factors will only converge against zero below the most disturbed class (VII) more quickly, and the differences between the classes dissolve more easily.

One caveat is the stability of the empirical reference value that defines the basis for the characterisation approach. In this context, the proportion of 3 % assumed for class VII area may be a rough estimate, yet it appears robust for the medium term.

⁴ According to UNEP (2014), 2 % of global land area were developed in 2012. Assuming another percent of devastated area, the total class VII amounts to 3 % For comparison: Within the EU, 8.8 % of the land area is developed (land used for residential, commercial and industrial purposes) http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Land_cover_and_land_use_statistics_at_regional_level#More_than_8.8.C2.A0.2.5_of_EU_land_used_for_residential.2C_commercial_and_industrial_purposes

However, the trajectory depends on political decisions to take action against expanding urbanisation (UNEP 2014). Favourable scenarios for the projection of settlement development reveal that the developed area is likely to remain at approx. 3 % in the year 2050 (Electris et al. 2009).

There are several different options for the designation of *numerical intervals between the factors* of each class, e.g. linear constant intervals or exponentially progressing. Dedicated intervals reflecting certain circumstances are also possible. The linear option not be ideal due to the fact that the *qualitative difference* between class VII (sealed) and VI (intense agriculture) is greater than the difference between III (semi-natural) and II (partly close-to-nature). Thus, it may be justified to establish a wider interval between VII and VI (e.g. factor 10) while distributing the remaining intervals more or less equidistant between 0.1 and 0.5. This would strongly emphasise the starkest difference appropriately. However, the differences between the remaining classes would be minimised, particularly between VI (intensive agriculture) and V (structured, less intensive agricultural land).

The drawbacks of the options introduced above may be corrected with an exponential approach. Conveniently, the simple doubling or halving of intervals between the classes II to VII results in a ratio of 1:32 which is very close to the target ratio of 1:33 acting as the reference value derived from the global proportion of class VII area. The *coincidence* of the *convenient* nature of the doubling or halving of intervals is supported empirically. The exponentially greater proximity to naturalness of the hemerobic classes (II and III) compared to class I (characterisation factor 0) is reflected in the exponentially longer periods of time that these more natural habitats require for development. The return of a sealed class VII area to agricultural land under cultivation (class VI) is estimated to take 5 years.⁵ The development of more natural organic farming practices requires approx. 40 years (Waldhardt et al. 1999). Woodland and forest formation may exceed 100 years, with naturalness increasing with longer development times. This observation corresponds well with the doubling of factors commencing with class II.

Depending on the hemeroby class, it may be far from trivial or even impossible for the habitat to return to a more natural state by means of human intervention due to the fact that natural succession may be facilitated but not substituted. The characterisation factors selected for the range presented here reflect the effort required to achieve improved naturalness. The more natural the status quo of an area, the more involved the optimisation of its naturalness. Therefore, the characterisation factors consider the development period required for a

⁵ Without human intervention, nature would obviously not establish fields for agricultural purposes, but return to the final successional stage depending on the biome, e.g. via ruderal communities and forest succession to mature forest.

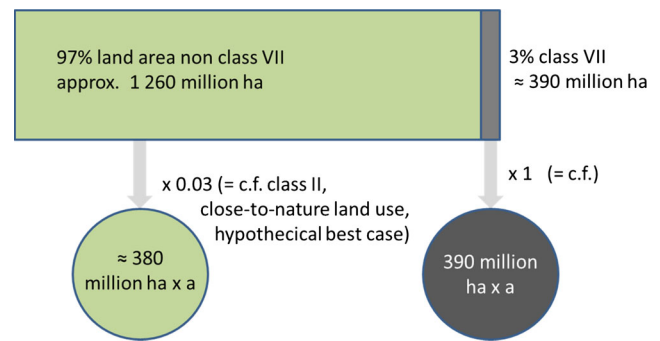


Fig. 4 Relations between the empirical proportion of area VII of the total land area and the remaining areas, multiplied with the smallest characterisation factor possible

system to return to advanced naturalness supported by anthropogenic facilitation. Moreover, they provide implicit information of the anticipated effort involved in the implementation of improvement potentials.

Brentrup et al. (2002) also proposed characterisation factors for their system of hemeroby classes. Those proposed factors are in principle similar to the factors introduced here. However, Brentrup et al. (2002) pursue a linear approach, i.e. the intervals between the ten classes of their system remain constant at 0.1. Figure 5 illustrates the different options for characterisation factors.

For the impact category land use, the approach results in an impact category indicator *Distance-to-Nature-Potential* (DNP) [$\text{m}^2\text{e } 1\text{a}$] with the characterisation factors DNP_i [$\text{m}^2\text{e } 1\text{a}/\text{m}^2_{\text{Hemeroby class } i}$] (see Table 6).

5 Alternative approaches

In the following, selected approaches for modelling of land use with information on area quality in the literature are described:

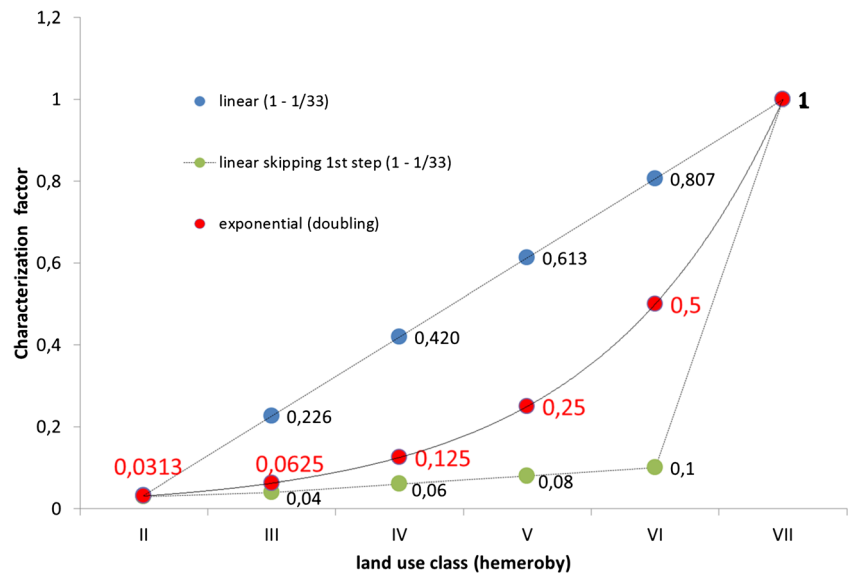
- The LSF indicator by (Mila i Canals et al. 2007) and
- the modification of this approach by (Brandão and Milà i Canals 2013)
- the LANCA concept
- the biodiversity damage potential (BDP) indicator by (de Baan et al. 2013)

All these alternative approaches target a different safeguard subject than the hemeroby concept.

5.1 LSF indicator

The ILCD Handbook (JRC 2011) refers to the method of (Mila i Canals et al. 2007). In this approach, the content of soil organic matter (SOM) acts as an indicator of the life support function (LSF) of soils. The concept is applicable to

Fig. 5 Characterisation factors for the individual hemeroby classes depending on different approaches



agricultural and forestry systems. The metric is the change of SOM over the course of a particular form of land use. The LSF indicator value in [kg C a] is calculated from the difference of SOM values according to system modelling. A single absolute SOM value cannot be the indicator because the value without reference would be meaningless. In consequence, data on the situation before and after land use are required. The authors emphasise the relevance of the method for consequential LCA studies. This is meaningful if the SOM after land use can be deduced or the form of land use is supervised with ongoing data collection until the end of the process. In the case that the approach is applied in attributional LCAs, a reference scenario needs to be defined for the calculation of the difference between the SOM at the time of the investigation and a SOM at a prior point in time. However, the method proposed in JRC (2011) does not include such steps.

5.2 SOC concept

In contrast to the previous concept, Brandão and Milà i Canals (2013) propose an alternative approach: Instead of the Life Support Function (LSF) based on SOM, the content of soil

organic carbon (SOC) is quantified in [kg C/m²]. The concept proposes the following methodology:

- Following Koellner et al. (2013a, b), the reference for the natural state of the system is the natural soil cover depending on biome and regional ecosystem features.
- Calculation of the SOC with data from (IPCC 2003, 2006) for
 - the reference state (SOC_{pot}: potential carbon content in undisturbed areas—native SOC)
 - the form of land use under investigation (SOC_{LU}) sorted into coarse categories depending on different agricultural and forestry systems.
- Calculation of SOC change
 - both for land use applicable in attributional LCA,
 - and land use change applicable in consequential LCA.
- The characterisation factor is the calculated difference of the carbon content (ΔC): Deviation of the soil carbon content as a result of a defined agricultural or forestry regime in reference to the soil carbon content in the near-natural state of an area not influenced by human activity. The resulting unit for ΔC is kg/m².

Hemeroby class	Characterisation factor [m2e 1a/m ²]
VII	1.0
VI	0.5
V	0.25
IV	0.125
III	0.0625
II	0.0313

One caveat of the method lies in the low level of differentiation of carbon content based on data from IPCC. For instance, there is no difference in characterisation factors of forest and permanent cropland. Mining and sealed areas cannot be incorporated into the concept.

The safeguard subject in both the LSF and the SOC concept is soil fertility, quantified as the carbon content of the soil as a measure for the biological production potential (BPP) of an area. According to the UNEP/SETAC Life Cycle Initiative Programme on LCA, the BPP is one key element in the impact assessment of land use. Additional key elements are biodiversity and ecological soil quality.

In conclusion, both approaches attempt the quantification of area quality with the help of a single criterion. The selection of carbon content as a measure of the BPP is a substantial simplification with distinct reduction of complexity. Additional safeguard subjects such as naturalness or biodiversity are not considered.

5.3 LANCA®

Based on the approaches of Baitz (2002), Beck et al. (2010) went on to develop the topic land use and biodiversity in collaboration with stakeholders from industry and science. The work resulted in the publication of the LANCA® (Land Use Indicator Value Calculation Tool) calculation tool for application in LCA.

The method is based on the following ecosystem services:

- *Erosion resistance*: the capacity of the soil to resist against soil erosion exceeding natural erosion levels
- *Mechanical filtration*: the capacity of the soil to filter a suspension via mechanical bonding of pollutants to soil particles
- *Physico-chemical filtration*: the capacity of the soil to absorb substances suspended in the soil, thus preventing entry into the groundwater
- *Groundwater replenishment*: the capacity of the soil to contribute to the generation of groundwater
- *Biotic production*: the capacity of the soil for biomass production.

The LANCA calculations are based on geoecological classification systems and require location-specific input data for application. The impacts of occupation (land use) and transformation (land use change) are quantified in the form of individual indicator results. There is no aggregation of indicator values, the information remains at the inventory level.

LANCA indicator results calculated by users are adopted into GaBi processes in the form of *inventory flows* without any characterisation factors. For a number of land-intensive processes, the LANCA tool has already been used to calculate data sets for the GaBi database. Hence, both foreground systems (e.g. biomass production) and background systems (land use in upstream systems such as ore mining) may be incorporated into the overall LCA (Beck et al. 2010). Baitz et al. (2000) developed the precursor method of the LANCA tool based on the hemeroby concept and an approach of the former

Federal Institute for Forestry and Wood Research (now Thünen Institute).

5.4 Biodiversity damage potential

De Baan et al. (2013) developed characterisation factors for different land use forms referring to relative species richness targeting the safeguard subject biodiversity. This approach is based on exemplary works by Koellner (2000) and Koellner and Scholz (2007, 2008). The BDP characterisation factors provide the respective biodiversity score which correlates the regional biodiversity of a certain land use form with that of the (semi-)natural reference habitat in the respective biome. The medians of a selection of regional land use forms are reported in Table 7. De Baan et al. (2013) point out considerable deviation for the means of the results depending on a number of factors. The input data for biodiversity quantification on a global level are derived from the GLOBIO3 database (Alkemade et al. 2009) compiled from a literature survey. The biogeographical differentiation of the biomes follows the key of the WWF identifying 14 major habitat types (Olson et al. 2001).

In contrast to the approaches described above, the BDP exclusively focuses on the occupation impact (land use phase) following the systematics of the UNEP/SETAC-Guidelines (Koellner et al. 2013b). The approaches LSF, SOC and LANCA®, however, consider transformation impacts, thus including periods before (natural or semi-natural initial state) and after land use (regeneration). Both the BDP concept and the hemeroby concept introduced here focus on the occupation impact only. Moreover, the initial state is contained in the characterisation factors for both the BDP indicator and the hemeroby classes. On a scale between 0 and 1, it represents the reference point 0 in the respective concept.

Aside from the different safeguard subjects, the main difference between the two approaches is found in the fact that similar to LSF and SOC, the BDP also focuses on a single criterion and a single metric. The BDP identifies the relative species richness as the sole metric for biodiversity, although the limitations of this simplification are discussed appropriately. The authors of the BDP proposal assess the approach as follows: “The (...) approach allows for a first rough quantification of land use impact on biodiversity in LCA on a global scale. As biodiversity is inherently heterogeneous and data availability is limited, uncertainty of the results is considerable. The presented characterization factors for BDP can approximate land use impacts on biodiversity in LCA studies that are not intended to directly support decision-making on land management practices. For such studies, more detailed and site-dependent assessments are required.”

Table 7 World average and regionalised characterisation factors CF (median) for biodiversity damage potential (BDP) per land use type (derived from de Baan et al. 2013)

Land use type Biome (selection)	Forest, not used	Secondary vegetation	Forest, used	Pasture/ Meadow	Annual crops	Permanent crops	Agroforestry	Artificial areas
Total world average	0	0.18	0.18	0.33	0.6	0.42	0.2	0.44
Biome 1 (Sub-)tropical moist broadleaf forest	0	0.22	0.13	0.45	0.54	0.42	0.18	–
Biome 4 Temperate broadleaf forest	0	0.08	0.22	0.52	0.76	0.02	–	0.4
Biome 5 Temperate coniferous forest	0	0.17	0.15	0.24	0.54	–	–	0.5
Biome 7 (Sub-)tropical grassland and savannah	0	0	0.01	0.12	0.65	–	–	–

6 Conclusions

The implementation of an impact-related assessment of land use or use of the natural environment in LCA is a complex challenge. In contrast to almost all other impact categories, there are no a priori definitions of the target of conservation or the specific impact to be avoided. For instance, climate change mitigation is characterised by the prevention of additional global warming. This aim is pursued with the reduction of greenhouse gases. Human health is protected with the minimisation of toxic pollutant emissions. However, the pivotal question in land use and nature conservation remains the fundamental query what precisely we are attempting to protect. This question may be answered in a number of different ways. Biodiversity conservation may be the primary goal, or safeguarding of ecosystem services, the conservation of soil fertility or naturalness. Any of the above qualify as a possible and appropriate answer.

Depending on the definition of the safeguard subject, it is possible, or even required, to select impact category indicators accordingly. The definition of goal and scope in an LCA study must clarify how, and for what purpose, land use shall be addressed.

The approach introduced here is based on naturalness as the safeguard subject. We identified the hemeroby concept as an appropriate basis for a characterisation model focusing on this safeguard subject. Hemeroby expresses both the degree of human influence on a natural space or area and the distance of that area to the undisturbed state. Due to the fact that human interference may manifest itself in many different ways, accurate quantification on a simple scale seems highly unlikely. Thus, this indicator clearly distinguishes itself from others such as biodiversity (number of species) or soil carbon (concentration).

The quantification of hemeroby is thus carried out with multiple criteria and instruction for measuring. It results in a classification of the areas under investigation into a system of ordinal classes (I to VII). This is fully consistent with the methodology of relevant scientific applications of hemeroby.

The classification of an area into a hemeroby class qualifies as the first step of impact assessment. The inventory-level

result of the use of an area (quantified in m^2) is characterised in classes and allows discrimination of qualitative differences. However, this step does not imply derivation from numerical characterisation factors.

Due to the immense complexity of naturalness, a quantification derived from characterisation factors based on unequivocally identifiable environmental impact mechanisms is not feasible. Comparable empirical observations are required, and ultimately, justified and transparent value-based decisions are inevitable. The approach introduced here seeks to strike a balance between empirical data and reliable validity of results. We emphasise that the hemeroby approach is a powerful tool due to the detailed inventory results. If the information according to the goal of the LCA shall be further processed into one impact indicator value, characterisation is required and a characterisation model is proposed.

The concept described here is ready for application to almost any form of land use in central and northern Europe. Thus, solutions for other regions around the globe have to be developed. This is particularly relevant for areas involved in the cultivation of biogenic raw materials for the global material flow management. In this context, the availability of spatial hemeroby data and their compatibility with the criteria stipulated here needs to be evaluated and further developed as necessary. Thus, a system for the consideration of land use can be established beyond Europe and the differentiated evaluation of environmental burdens of renewable raw materials in global supply chains can support the LCA interpretation.

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