Fraunhofer-Institute for Building Physics IBP
Head of Institute
Prof. Dr. Philip Leistner
Prof. Dr. Klaus Peter Sedlbauer

Biodiversity Impact Assessment of future biomass provision for biofuel production

Phase 1

Conducted on behalf of
Concawe

Jan Paul Lindner
Andreas Geß
Lars Ulrich Bippus

Department of
Life Cycle Engineering

Stuttgart, 8th April 2022

©Shutterstock/igor.stevanovic

Fraunhofer-Institute for Building Physics IBP
Nobelstraße 12 | 70569 Stuttgart
Telephone +49 711 970-00
Telefax +49 711 970-3395
www.ibp.fraunhofer.de

Contracted by Concawe

Contact: Alba Soler alba.soler@concawe.eu

Contents

Executive Summary

This study aims to determine environmental impacts on biodiversity due to biomass production for bioenergy use. For this purpose the Biodiversity Impact Assessment (B.I.A.) method presented by Lindner et al. [1,2] is applied to assess the impact of Miscanthus cultivation in Bulgaria and Germany. In addition, a methodological comparison to the impact assessment method by Chaudhary & Brooks [3] (called the Potentially Disappeared Fraction of species (PDF) method here) is drawn. Assumptions on the biomass cultivation are based on a preceding study by Imperial College London Consultants, which provides an estimation of biomass availability in line with the EU Renewable Energy Directive II (RED II) referring to unused, abandoned and degraded land in the EU.

The Fraunhofer study finds that the impact on biodiversity mainly depends on the state of the land before the cultivation of Miscanthus. However, regionally specific biodiversity value (addressed by ecoregion factors) and crop yields also affect the specific biodiversity value per biomass produced. Starting from this, a priority for areas (NUTS (Nomenclature des unités territoriales statistiques) region and land status types) to be used for the cultivation of Miscanthus can be derived. In a preceding study on biomass availability of Imperial College London and Concawe, up to 14.4 Mio. t/a of Miscanthus production was calculated, depending on the scenario. The cultivation of Miscanthus on initially degraded land can have a positive impact on the biodiversity value of the land. On initially unused and abandoned land, however, damage to biodiversity is very likely. Assuming the use of low biodiversity impact areas first, a certain amount of Miscanthus can be produced on abandoned and unused land, with biodiversity damage and benefit cancelling each other out. This point of net zero biodiversity damage is calculated under varying assumptions. Under the assumption that appears most probable, this point is at 6.9 Mio. t/a of Miscanthus production. If the use of the full biomass production capacity in the preceding study on biomass availability according to RED II is assumed, the biodiversity damage from Miscanthus cultivation on unused and abandoned land exceeds the benefits from cultivation on degraded land. Methodological challenges are identified regarding the assignment of hemeroby levels the land status types. For this reason, a sensitivity analysis is included in which different hemeroby levels are assigned to the initial state before Miscanthus cultivation. The results are very sensitive to this assignment. Depending on the assumed initial hemeroby level, either no benefits from Miscanthus cultivation at all, or significantly higher benefits are calculated. Thus, either no Miscanthus production would be possible without biodiversity damage, or the production of all 14.4 Mio. t/a linked to IC high scenario would be beneficial to biodiversity, depending on the assumed initial hemeroby level.

The characterization factors readily available for the PDF method do not allow differentiation between the different initial land use types. All areas are regarded as either natural habitat or regenerating secondary vegetation, with no biodiversity loss in the initial state. Miscanthus cultivation on each area results therefore in potentially lost species with the difference in damage per functional unit mainly due to yield differences between the areas. The PDF results show the lowest impact on land that was initially unused and the highest on land that was initially degraded; contrary to the B.I.A. results. However, a sensitivity analysis showed that, if different land use was assumed for the existing state of land and the characterization factors of other land use types – that are defined in the PDF methodology - are applied, the results are similar to the ones of the B.I.A. method.

Further studies on different feedstock types in different ecoregions and biomass types are recommended to estimate the potential biomass production for biofuels in Europe without decreasing biodiversity quality under different management parameters. This could lead to different conclusions in terms of the amount of biomass that can be produced with net zero impact to biodiversity, the prioritization of areas for cultivation, and the applicability of product specific biodiversity assessment methods to different cultivation methods for further biomass types according to RED II.

1 Introduction and Outline

1.1 Biomass provision compatible with RED II

In the Renewable Energy Directive II (RED II), the European Commission emphasizes the necessity of the transition to renewable energy sources and sets a binding target share of energy from renewable feedstock until 2030. Further, a set of rules is given to financially support the erection of renewable power plants and infrastructure.

In Annex IX, it also provides a list of legitimate biomass feedstock types for the generation of biofuels. The list reaches from algae and waste biomass and side products to non-food crops and cellulosic material.

The cultivation and production shall be focused on alternative biomass sources that do not interfere with the production of food and feed or the cultivation of food and feed crops. The RED II Annex IX promotes these kinds of crops, the use of waste streams, and limits the biofeedstock generating high indirect land use change (ILUC) . It does not explicitly consider the preservation of biodiversity or biodiversity friendly management and farming practices [4,5]. However, the EC addresses this issue in their Biodiversity Strategy 2030 by supporting the phase-out of bioenergy from high ILUC crops proposed in the RED II from a biodiversity conservation perspective [6].

1.2 Preceding Study on Sustainable Biomass Provision

In a previous study, Concawe contracted Imperial College London Consultants (ICL) to estimate the amount of biomass that could potentially be available for biofuel production in Europe in 2030 and 2050. and The Report is available from Concawe's website [7]. It provides the starting point for this biodiversity study.

In the ICL study, sustainable biomass availability from agricultural, forest and waste sources according to part A and B of Annex IX of RED II are analyzed. Three scenarios of different mobilization improvements levels are defined, representing low biomass mobilization, enhanced management practices and biomass mobilization in selected countries as well as improved research and innovation measures, enhanced management practices and mobilization in all EU countries. The study estimates biomass availability for bioenergy use after deducting the demand from non-energy sectors (power, industry, agriculture, services and buildings) from biomass availability for all markets. As a result, sustainable biomass availability for all markets and all feedstock from the EU-27 is estimated to 1 – 1.3 billion dry tons in 2050, of which 539 – 915 million dry tons (215-366 Mt oil equivalents) are estimated to be available for bioenergy. After taking into account imports and biomass use for non-transport, the net biomass is estimated at 101 – 252 Mt oil equivalents for 2050. On one hand, improved biomass mobilization through implementation of improved forest management practices and higher yields are expected to increase biomass availability. On the other hand, policies and regulations for sustainable use of land and water resources reduce agricultural land availability, slow transitions in forest management practices and waste reduction decrease biomass availability. For this reason, sustainable biomass availability remains about the same for 2050 compared to 2030.

Although ICL's biomass availability study includes different kinds of biomass mentioned in the RED II Annex IX, only primary and secondary production (i.e. the production of biomass specifically for the purpose of biofuel production) is considered relevant for this biodiversity study. Not included are waste streams – the majority of biomass types in RED II Annex IX – that are considered to be burden-free in terms of land occupation and transformation.

1.3 Project outline and assessed Feedstock

In the first phase of this study, an analysis of the impact on biodiversity was conducted using two different methods. The method by Lindner & Knüpffer (2020) assesses the impact of land use on the biodiversity value [1]. The method by Chaudhary and Brooks (2018), herein referred to as the PDF (possibly disappeared fractions) method, evaluates biodiversity by calculating the potential loss of species [3].

The scope of the project phase 1 is Germany and Bulgaria at NUTS 3 resolution. NUTS stands for Nomenclature of territorial units for statistics and is a system of identification for spatial areas within the EU. It is structured hierarchically with NUTS 1 being the most coarse and generally relates to the respective states of a country, while NUTS 3 is the finest spatial resolution, relating to districts. In Germany NUTS 3 level includes 402 areas, in Bulgaria 28. [8] Germany and Bulgaria are two representative countries with high biomass availability (total estimated biomass potential ≥20 million tons per year), but with different conditions: Germany has a strong infrastructure, good institutional framework, established policies/ targets for bioenergy, strong innovation profiles, while Bulgaria is less industrialized and has a lower population density, a higher range in biodiversity value and low costs for biofeedstock.

As a feedstock for future biomass generation, Miscanthus was chosen to align with the assumption of the above mentioned preceding ICL study. It represents a non-food crop that can be cultivated in various regions and climatic areas and on all kinds of soils, including marginal lands. Also, it shows fast growing rates and greater yields than other switchgrass varieties or sugarcane. As it is well useable for the production of biofuel, it shows high yields of acres per conversed ethanol. [9] In this study the annual production is used as functional unit. According to the background data of the study conducted previously by ICL [7], on degraded land 5.0 t/ha*a of Miscanthus can potentially be harvested each year, 8.8 t/ha*a on abandoned land, and 10.4 t/ha*a on unused land.

2 Methods

2.1 Land Use in Life Cycle Assessment (LCA)

Many processes in industrial product systems occupy significant amounts of surface area – arable land for food and biomass crops, pastureland for cattle herding, and forestry for wood, for example, immediately come to mind. The life cycle assessment (LCA) methodology, originating from environmental management focused on emissions, was originally ill-equipped to deal with processes tethered to the planetary surface and the impacts arising from structural modification of the surface. As Life Cycle Thinking always addresses impacts per unit of product – the functional unit-, land use in LCA also is calculated in relation to a certain amount of product. The scientific LCA community developed a consensus framework [10,11] that introduces "land quality" as a placeholder for surface-bound protected goods, such as soil erosion resistance. More overarching properties of land – e.g. biodiversity indicators – can also be used within this framework. For the assessment of indicators no official method consensus has been reached or proposed by any of the corresponding authorities like the European Commission (EC) or the Intergovernmental Panel on Climate Change (IPCC).

In the land use framework, the quality Q of a given piece of surface area A is tracked over time t (see figure). A reference quality level Q_{ref} is introduced and the deviation of the quality level Q(t) from the reference is called the quality difference ΔQ. Analogously to substance-driven impact assessment, ΔQ functions as a characterization factor for a land-using process, and the areatime (area multiplied by time, in square meter-years) functions as the amount to be characterized.

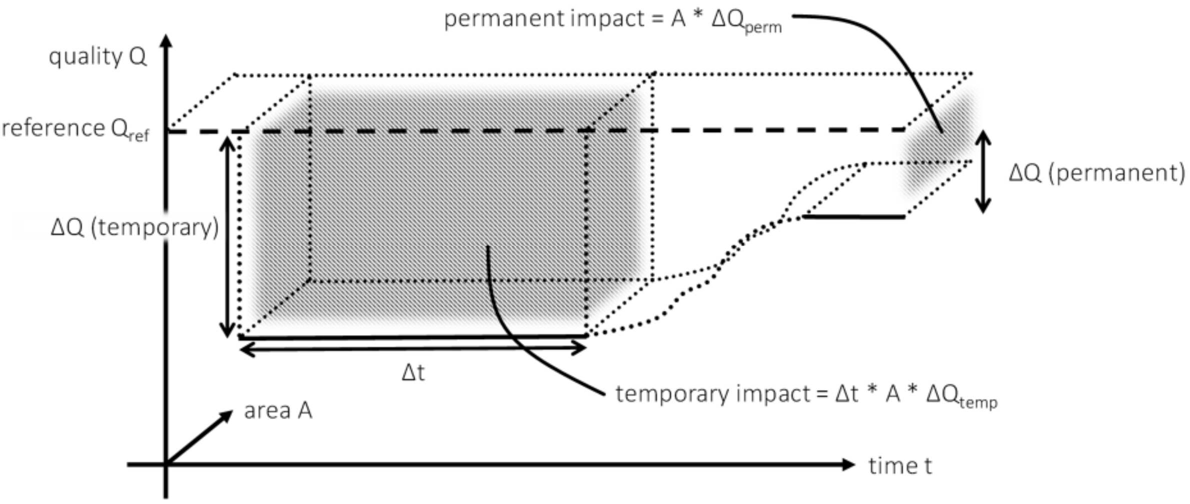

Figure 2-1 UN Life Cycle Initiative land use framework (quality-area-time framework), simplified according to Lindner et al. (2019) [1]

This framework for addressing land use in LCA is widely accepted (though it is not without its drawbacks) and the development of impact assessment methods for impacts arising from surface-bound processes aims at delivering a definition of the quality axis – i.e. calculation rules for defining the quality level of a patch of land occupied by any given process. Both biodiversity impact assessment methods described below do this.

The land use framework also allows differentiation between occupation and transformation impacts. Occupation impact relates to the quality difference incurred by the patch while the land-using process causing the impact is in place. Transformation impact relates to the quality difference between the state of the patch at different points in time (usually before and during a specific process).

For example, the occupation impact of a wheat field arises from the fact that the patch with the field is at a lower quality level than the reference level. The transformation impact of the same field arises from the fact that the patch used to be a pasture before it was transformed into a field. Given a high enough reference quality level, occupation impacts are almost always positive (i.e. more damaging – more impact means more damage in LCA). Transformation impacts, however, can be negative (i.e. the process is beneficial) if, for example, a sealed area is unsealed and a higher-value ecosystem is established.

The distinction is particularly relevant for this study because it focuses on transformation impacts between 2020 and 2050, and negative transformation impacts versus the current state of land occur in some scenarios. In contrast to the preceding study by ICL, the time step in 2030 was not assessed as the impacts from the management practices stay the same and only the productivity varies.

2.2 Biodiversity Impact Assessment according to Lindner et al.

The first biodiversity impact assessment method applied in this study was developed in a project funded by the German Federal Agency for Nature Conservation, building on earlier works by Fehrenbach et al. [12] and Lindner [13]. The principle and most relevant calculation steps are described in a journal paper [1], but the final project report [14] introduces one more calculation step, as well as a slight variation in the calculation of regional weighting factors (ecoregion factors). The calculation steps are documented in a guideline document [15] which refers to the project report, but is much more condensed and available in English.

According to [15] The calculation steps are as follows:

1) Each parameter x is transformed into a biodiversity value contribution y(x). For this purpose, a function with a general form is used, which is adapted to the individual case. The range of definition of the function is the interval [0, 1], i.e. the input values are normalized to this interval if necessary. The value range of y(x) is also [0, 1].
2) Several biodiversity value contributions (e.g. y_A and y_B) are aggregated into one criterion z (e.g. $z_{AB}(y_A, y_B)$). In certain cases, a criterion may contain only the biodiversity value contribution of one parameter, which is then directly adopted as the value of the criterion. Two or more biodiversity contributions are aggregated according to one of two possible functions: AND and OR. Here AND means that all parameters that constitute the criterion must contribute a high biodiversity value in order to achieve a high criterion value. OR means that one parameter with a high biodiversity value is mostly sufficient to achieve a high criterion value.
3) Several criteria (e.g. z_{AB} and c_{CD}) are aggregated to the land use-specific bio-diversity value BV_{LU} (e.g. $BV_{LU}(z_{AB}, z_{CD})$). For this purpose, the biodiversity value contributions of the criteria are weighted and summed, whereby the sum of the weighting factors is 1. Thus, the value range of BV_{LU} lies within the interval [0, 1].
4) The BV_{LU} retains its meaning within the respective land use type. The value ranges of the biodiversity values of different land use types are brought into a common value interval (BV_{norm}). In the scale of the BV_{norm} the range [0, 1] becomes the common interval of biodiversity values across all land use types. The minimum and maximum possible values of BV_{loc} depend on the minimum and maximum possible naturalness levels of the land use types.
5) The local biodiversity value BV_{loc} is calculated from the normalized biodiversity value BV_{norm} using an exponential function. It pushes the higher naturalness levels closer together and enables more differentiation between the lower naturalness levels, where the impact is understood to be more severe.
6) To derive a globally comparable value, the BV_{loc} is multiplied with a regionally specific weighting factor called the ecoregion factor (see [1] for details). The end result of the biodiversity value calculation is the global biodiversity value BV_{glo}.

Within the land use framework explained above, BV_{glo} is the land quality Q and the reference quality level Q_{ref} is at $BV_{norm} = 1$, so the actual value varies across ecoregions (because it depends on the ecoregion factor).

If specific parameters are unknown, the naturalness level can be taken from a table included in Lindner et al. 2020 [2]. More specifically, the method refers to the hemeroby concept that was made available for LCA by Fehrenbach et al. [12]. Hemeroby is defined as the degree of anthropogenic interference with the respective natural environment and the local ecosystems. The table with hemeroby values per land use type and intensity level is publicly available in the guideline document [15] and reproduced in Table 2 below. It should be noted that the biodiversity value of unused, abandoned, and degraded land before conversion to productive land for biofuel feed is determined using the discrete naturalness levels of the hemeroby concept, while the biodiversity value of the same land after conversion is determined using the more detailed multi-step method explained above.

In this specific study, some estimates and assumptions were necessary to cope with data availability issues. The input data from the previous biomass availability study – as well as additional data provided by Imperial College London Consultants – include most, but not all land management parameters. The parameters for which data were available are often estimated for larger geographical units, so many NUTS 3 regions are assigned the same input values. Two parameters had to be dropped from the assessment scheme – occurrence of Red List species, because no data was available, and crop rotation because it was not assumed for Miscanthus in the ICL's study. The respective criteria could be calculated without corrupting scientific accuracy.

2.3 Potentially Disappeared Fraction of species (PDF) according to Chaudhary & Brooks

The method presented by Chaudhary & Brooks [3] provides another approach to address biodiversity in life cycle assessment. In this method, biodiversity damage is expressed as the potentially disappeared fraction (PDF) of species due to land use and indicated in the unit "potential species lost per m²". The method follows the land use framework mentioned above [10], in which the characterization factors describe land quality. The calculation of the characterization factors is based on a species–area relationship model for mammals, birds, amphibians, reptiles, and plants. Characterization factors are presented for five different land use types and three intensity levels for each land use type (minimal, light, intense), plus regenerating secondary vegetation, resulting in 17 land use classes, see Table 1.

Table 1 Land use types presented by Chaudhary & Brooks 2018

Broad land use type	Management type	Details
Natural Habitat	None	Little or no human disturbance (pristine state)
Regenerating secondary vegetation	None	Little or no human disturbance
Managed (logged) forests	Minimal use (Reduced impact logging (RIL) forests)	Forests managed with RIL techniques designed to minimize impacts on biodiversity
	Light use (Selectively logged forests)	Forests where only selected commercially valuable trees are harvested at a time such that the disturbance is not enough to markedly change the nature of ecosystem.
	Intense use (Clear-cut forests)	Forests with extractive use, with either even-aged stands and clear-cut patches. The disturbance is severe enough to change the nature of the ecosystem.
Plantation forests	Minimal use	Extensively managed or mixed timber plantations in which native understorey and/or other native tree species are tolerated, which are not treated with pesticide or fertiliser, and which have not been recently (< 20 years) clear-felled.
	Light use	Monoculture timber plantations of mixed age with no recent (< 20 years) clear-felling.
	Intense use	Monoculture timber plantations with similarly aged trees or timber plantations with extensive recent (< 20 years) clear-felling.
Pasture	Minimal use	Pasture with minimal input of fertiliser and pesticide, and with low stock density (not high enough to cause significant disturbance or to stop regeneration of vegetation).
	Light use	Pasture either with significant input of fertiliser or pesticide, or with high stock density (high enough to cause significant disturbance or to stop regeneration of vegetation).
	Intense use	Pasture with significant input of fertiliser or pesticide, and with high stock density (high enough to cause significant disturbance or to stop regeneration of vegetation).

Cropland	Minimal use	Low-intensity farms, typically with small fields, mixed crops, crop rotation, little or no inorganic fertiliser use, little or no pesticide use, little or no ploughing, little or no irrigation, little or no mechanisation.
	Light use	Medium intensity farming, typically showing some but not many of the following: large fields, annual ploughing, inorganic fertiliser application, pesticide application, irrigation, no crop rotation, mechanisation, monoculture crop. Organic farms in developed countries often fall within this category, as may high-intensity farming in developing countries.
	Intense use	High-intensity monoculture farming, typically showing many of the following features: large fields, annual ploughing, inorganic fertiliser application, pesticide application, irrigation, mechanisation, no crop rotation
Urban	Minimal use	Extensive managed green spaces; villages
	Light use	Suburban (e.g. gardens), or small managed or unmanaged green spaces in cities
	Intense use	Fully urban with no significant green spaces.

To calculate the species loss for each land use class and ecoregion, the species-area relationship model is used. The number of species lost is allocated to land use classes based on their area share. The total number of species occurring in an ecoregion at a natural habitat state are brought into context to the number of species in the current land use by using an ecoregion-specific factor and the respective habitat area. Data for species richness is obtained from WWF Wildfinder database [16] and Kier et al. [17] and values for the species-area relationship from Drakare [17]. For the areas of each land use type and ecoregion, the land use map of Hoskins [18], which offers a high resolution and harmonized dataset for global land use, is combined with the intensity information (minimal, light, intense use) obtained from Global Land [19] and Arets et al. [20]. The IUCN Red List Habitat Classification Scheme [21] provides species-specific information on habitat utilization and is therefore used to calculate taxon affinity to a land use class in each ecoregion. First, taxon affinity to five broad land use types (managed forests, plantations, pasture, cropland and urban) are calculated. For this purpose, the fraction of species that can survive in a certain land use types is set into proportion with all species naturally appearing in an ecoregion. Next, taxon affinity to each land use intensity (minimal, light, intense) is obtained from literature [22] and previous works of Chaudhary [23]. Land occupation characterization factors for local species loss are transformed into global characterization factors by multiplication with a vulnerability score. The vulnerability score takes into account the proportion of the range size for each species occurring in an ecoregion and weighted by their category of extinction risk according to the IUCN Red List [24]. This way, the indicator takes both the number of species lost and the vulnerability of endangered endemic species into account. Finally, country specific characterization factors are calculated from the area weighted corresponding ecoregion characterization factors of the country and aggregating across five taxa to the unit potentially disappeared fraction (PDF). [3]

2.4 Application of the methods in this study

In the methodology by Lindner et al., the impact is calculated by 9 different parameters coupled into 5 different criteria. The parameters “red list species” and “crop rotation” have been cut off in this study, due to lack of data. The authors estimate that the accuracy of the calculation is not strongly impacted, and that the respective criteria values can be sufficiently determined through the remaining parameters. From the weighted aggregation of the assessed criteria the hemeroby level of the various NUTS 3 regions were calculated. From this, the biodiversity value index was calculated. All these steps were conducted for the prognostic agricultural state in the year 2050 according to ICL's biomass availability study.

To derive the change in biodiversity impact from the current situation in 2020 to the prognostic state, the hemeroby levels of the study area in the various NUTS 3 regions in 2020 had to be calculated as well. Here however, the calculation via parameters and criteria was not possible as the land was not used or cultivated. Therefore, the hemeroby levels of the different states – unused, abandoned and degraded – were estimated. Since the states "unused, abandoned and degraded" are not defined properly in the RED II or any other relating agricultural directive by the European Commission, the estimations bear a certain margin of discretion. For unused and abandoned land, the hemeroby level definitions of levels II and III fit quite well and were therefore applied. Degraded land however showed a broader spectrum of definition: In the RED II and the preceding study by the Imperial College London it is defined as "*'Severely degraded land' means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded.*" [5] The most fitting hemeroby level appeared to be level V, but for scientific honesty a sensitivity analysis has been conducted using also hemeroby levels III, IV and VI in the assessment of the 2020 state.

Table 2 Hemeroby level definitions according to Giegrich and Sturm, 1996,[25] as applied in Fehrenbach et al., 2015 [12] and Lindner et al., 2020 [14]

Hemeroby Level	Level description	Different types of land use; indicative examples, to be defined by measurements
I	Natural	Undisturbed ecosystem, pristine forest, no utilization
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

NUTS 3 specific ecoregion factors were calculated by intersecting GIS layers of the NUTS 3 regions [26] and the global ecoregions [27]. The intersected map is shown in Figure 2-2. With the resulting shares of ecoregion per NUTS 3 region, aggregated ecoregion factors could be calculated.

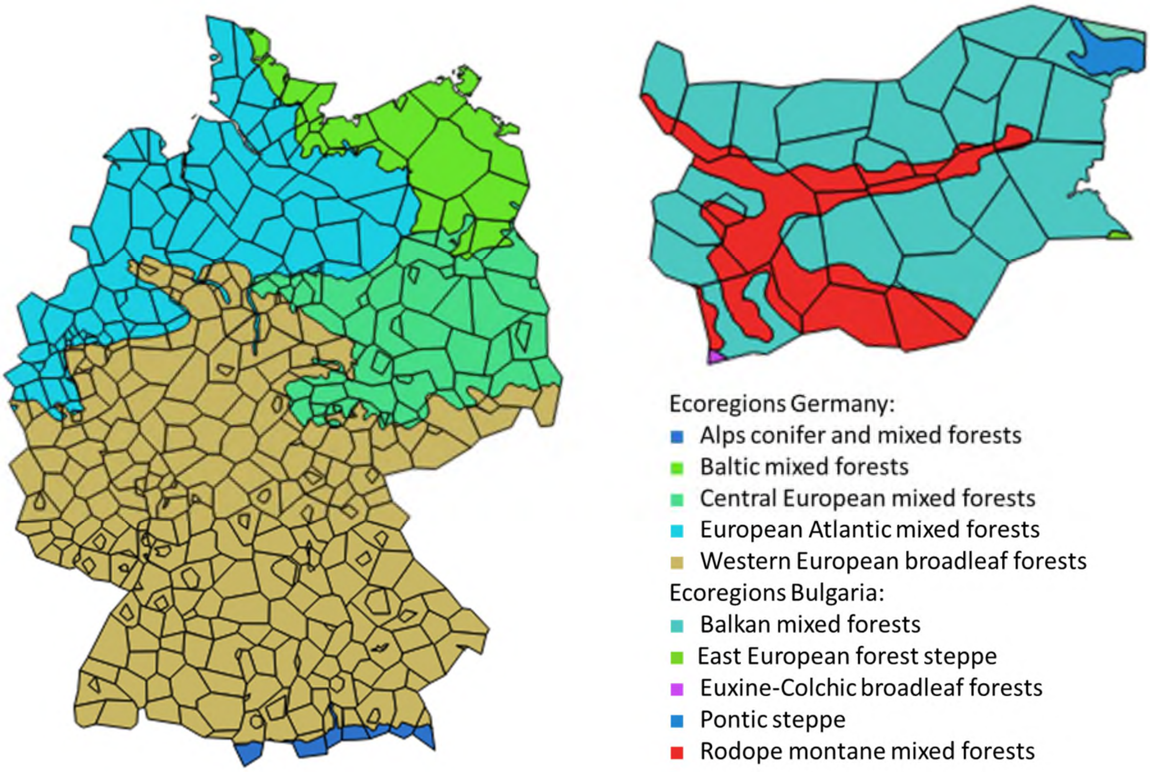

Figure 2-2 Intersected GIS layer of ecoregions and NUTS 3 regions in Germany and Bulgaria

The method by Chaudhary and Brooks uses a different land use classification system. The land use class “Regenerating secondary vegetation” is characterized by little or no human disturbance and refers to areas during regeneration. Though not an exact fit, the areas investigated in this study can be pragmatically assigned to the land use class "regenerating secondary vegetation" for the land use situation in 2020. This land use class is therefore assigned to all areas including unused, degraded and abandoned land for the land use situation in 2020. The authors of the method state that the land is considered to be abandoned and therefore not used for production. For this reason, secondary habitat area is not considered to be relevant for LCA purposes [3] and characterization factors for the land use class “Regenerating secondary vegetation” are not explicitly provided. The description of characteristics of this land use class matches with the reference state (natural habitat), so it is assumed that there is no differentiation between natural habitat and regenerating secondary vegetation on impact assessment level, meaning that there is no species loss in these areas with regards to the reference state. The cultivation of Miscanthus for biofuel production is classified as “Pasture minimal use”, which is characterized by minimal input of fertilizer and pesticides. The resulting characterization factors from the choice of land use type can be taken from the supplementary material.

3 Results

3.1 Biodiversity Impact Assessment according to Lindner et al.

The detailed result tables can be found in the supplementary data.

An overview of the increment in biodiversity value per produced kg of Miscanthus, BVI / kg, is given in Figure 3-1. The biomass production in the first listed area of the NUTS 3 regions shows the least BVI / kg, while the biomass production in the last listed NUTS 3 area at the bottom of the diagram causes the highest impact on biodiversity per biomass produced. About a third of all NUTS 3 regions show negative values. This indicates an increase in biodiversity quality meaning the cultivation of Miscanthus in this area is actually beneficial to the local biodiversity. This share of the assessed area comprises all degraded areas. The abandoned and unused areas show positive BVI/kg meaning a decrease in biodiversity quality. The fact that degraded land is characterized by an increase in biodiversity quality derives from the assumption of the reference hemeroby level in 2020. As the hemeroby level of a degraded area without land use was set to V, the human use of land is considered beneficial to the area in biodiversity terms. For both countries, Miscanthus cultivation on the degraded areas therefore have the lowest impact, while the abandoned areas tend to have the second lowest and the unused areas the highest impact, but some abandoned area show higher impact than some unused areas due to the respective ecoregion factors and biomass yield. This conclusion hinges on a hypothesis, though resulting from the coarse definitions of the state of land. For a sensitivity analysis of this issue, see chapter 4 Discussion.

Figure 3-1 Results of all NUTS 3 regions of Bulgaria and Germany and all initial soil states in order of BVI/kg

To calculate the maximum possible amount of produced Miscanthus without worsening the overall biodiversity value, a cumulative curve was calculated, see Figure 3-2. For this the possible biomass production per area type of each NUTS 3 region per year was assessed and set in relation to the cumulative biodiversity quality loss. This loss curve was calculated by going through all areas of the NUTS 3 starting with the one with the lowest BVI/kg and adding the biodiversity quality loss of the preceding area (essentially going from top to bottom in Figure 3-1). It shows that, if Miscanthus was grown in all areas that have a negative BVI/kg value under the assumptions described above, about 3.3 Mio t/a of Miscanthus could be grown and at same time increase the biodiversity quality – meaning a negative value of BVI m²/kg, see the nadir of the graph in Figure 3-2. Almost 6.9 Mio t/a of Miscanthus can be cultivated without lowering the overall present biodiversity value, see the zero crossing in Figure 3-2. The zero crossing indicates the point where an equal amount of biodiversity value is increased as is decreased, cancelling each other out, although not in the same places.

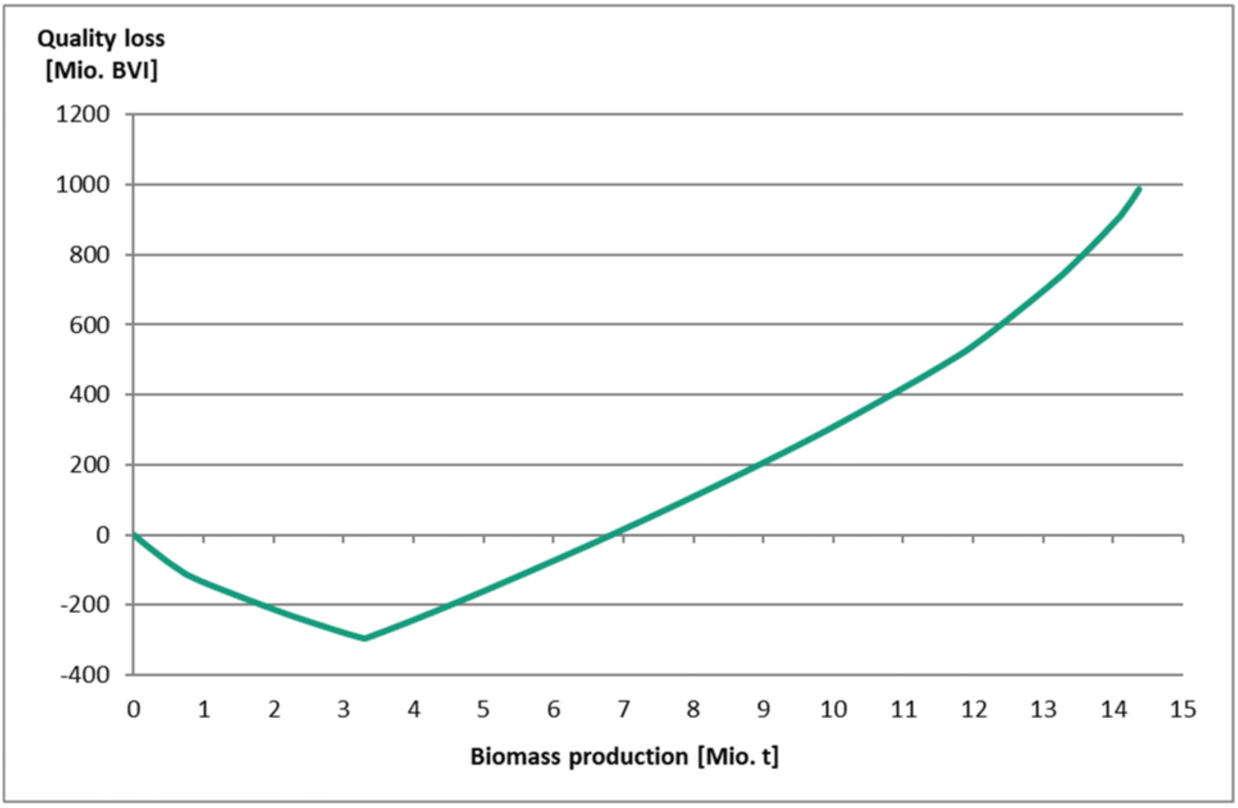

Figure 3-2 Cumulative biodiversity quality loss over cumulative biomass production for Bulgaria and Germany

The distribution of specific BVI/kg is presented for both countries in Figure 3-5. The areas investigated in Bulgaria show a broader range in specific biodiversity loss per biomass production than the ones in Germany, both for the areas in which Miscanthus production would increase BVI, as well as for the areas where it causes biodiversity loss. This is mainly due to the higher regionally specific weighting factor (ecoregion factor), representing the value of the local biodiversity, however there are also variations in criteria for the BVI calculation such as management parameters. Figure 3-4 shows a cumulative curve of BVI over biomass production, corresponding to the cumulative curve in Figure 3-2. Under the assumption of using the most advantageous areas regarding BVI for Miscanthus production first, 1.6 Mio t/a of Miscanthus could be produced without lowering the overall present biodiversity value in Bulgaria, and respectively 4.7 Mio. t/a in Germany, whereas the optimum for BVI would be reached at 0.8 Mio. t/a (Bulgaria) and 2.5 Mio. t/a (Germany), which represents the potential harvest on formerly degraded areas in both countries.

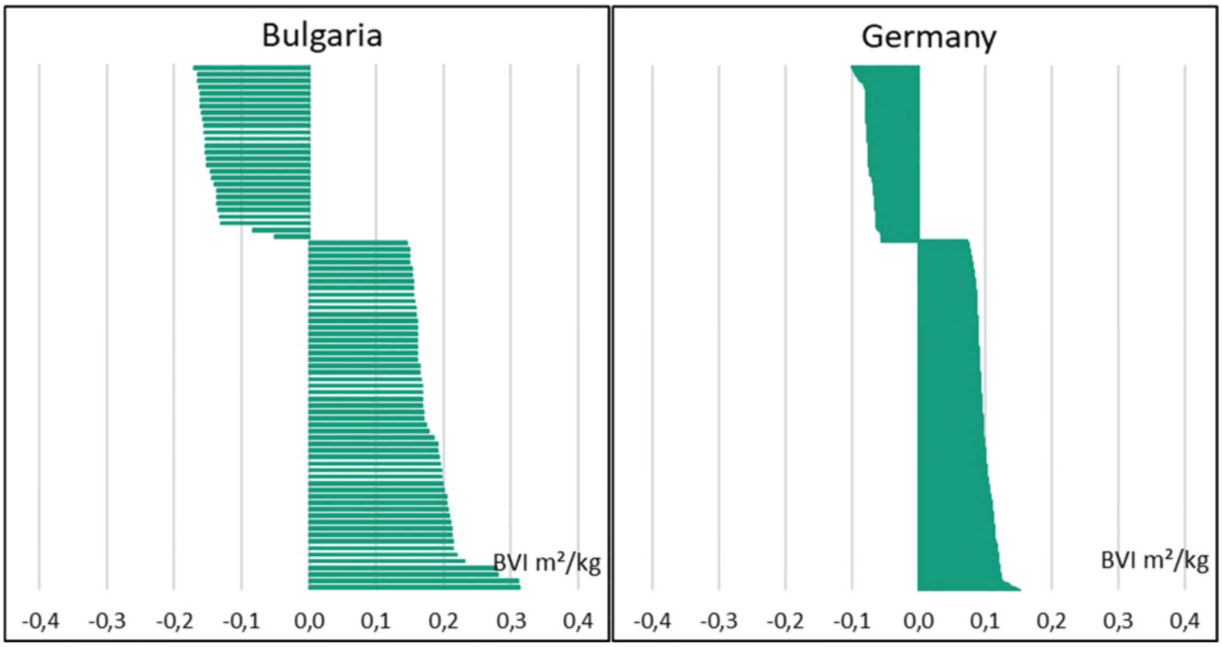

Figure 3-3 Results of all NUTS 3 regions of Bulgaria and Germany and all initial soil states in order of BVI m²/ kg by country

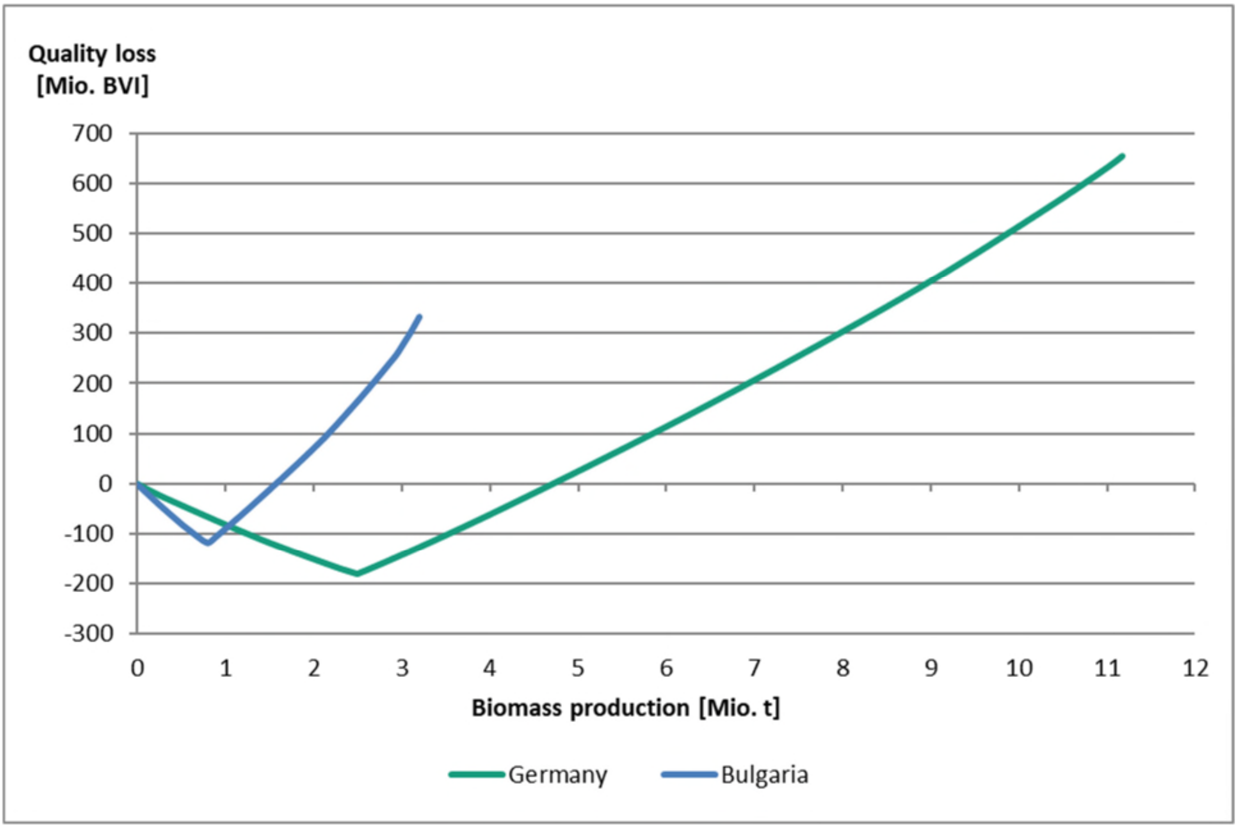

Figure 3-4 Cumulative biodiversity quality loss over cumulative biomass production for Bulgaria and Germany by country

3.2 Potentially Disappeared Fraction of species according to Chaudhary & Brooks

The detailed result tables can be found in the supplementary data on the Concawe website.

Figure 3-5 shows the results of the assessment of all area types of all NUTS 3 regions. Here, six distinct clusters can be seen. This relates to productivity of each area and the country specific PDF/m². For the Bulgarian NUTS 3 regions, the country specific PDF / m² was 2.69 times as much as the one for Germany, resulting in lower impacts of the German NUTS 3 region. In the graph this means that the first three "steps" are all German areas and the last three are all the Bulgarian. Due to the highest productivity the unused areas show the least PDF per annual kg of Miscanthus. For both countries, Miscanthus cultivation on the unused areas therefore has the lowest impact, the second lowest on the abandoned areas, and the highest impact on the degraded areas.

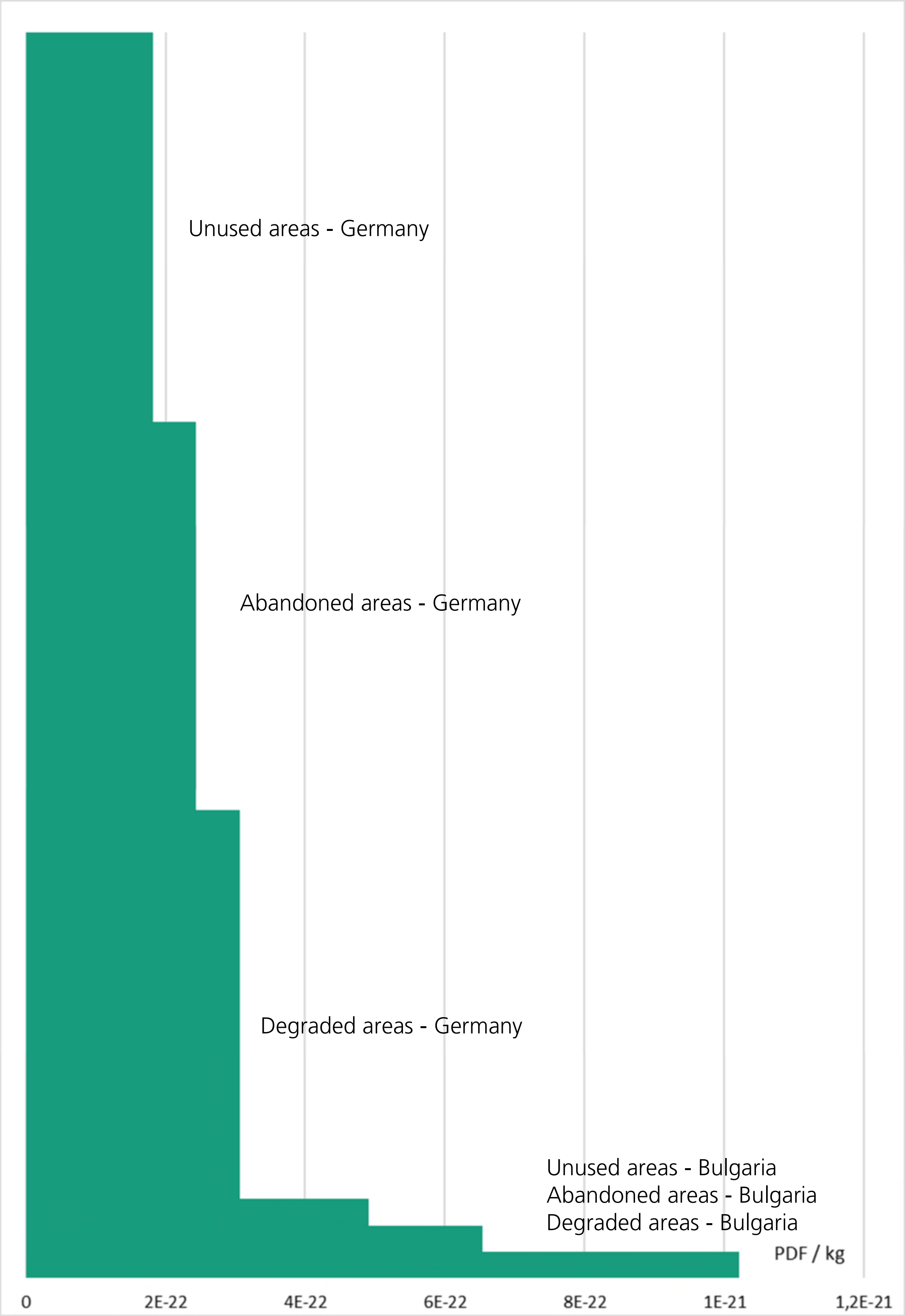

Figure 3-5 Results of all NUTS 3 regions of Bulgaria and Germany and all initial soil states in order of PDF / kg

In contrast to the **BVI** assessment in chapter 3.1, the **PDF** assessment shows no improvement through the cultivation of Miscanthus, see Figure 3-6. This is due to the fact that an area without human management always has a reference PDF value of zero regardless of its state (see Table 1 above). This means that the use of land by humans always has a negative effect according to this assessment method. Figure 3-6 shows how much Miscanthus can be produced in relation to the cumulative impact on biodiversity.

Figure 3-6 Cumulative PDF over cumulative biomass production for Bulgaria and Germany

4 Discussion

The results show a large potential for cultivating Miscanthus – almost 6.9 Mio t/a – at a net-zero impact to the current value of biodiversity under the assumption of degraded land falling in hemeroby level V and the resulting low reference biodiversity value. Based on this, the areas of degraded land in all **NUTS 3** regions show a potential of improvement of the local biodiversity value by the cultivation of Miscanthus.

As stated in chapter 2.4, the difference between the present (2020) and the prognostic state (2050) strongly depends on the quantification of the present state. The land use types and the resulting increment of biodiversity is well defined for the land use in 2050, since management forms are given, pesticide and fertilizer input is described, field sizes are given and yields are calculated [7]. For the 2020 state no land use was defined. The three soil conditions that were used as a baseline setup are taken from the **RED II** and are defined as following:

- Unused: "'unused land' means areas which, for a consecutive period of at least 5 years before the start of cultivation of the feedstock used for the production of biofuels, bioliquids and biomass fuels, were neither used for the cultivation of food and feed crops, other energy crops nor any substantial amount of fodder for grazing animals."

- Abandoned: "'abandoned land' means unused land, which was used in the past for the cultivation of food and feed crops but where the cultivation of food and feed crops was stopped due to biophysical or socioeconomic constraints."
- Degraded: "'Severely degraded land' means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded."

  [5,7]

Since the land is not used or managed, the assessment of the biodiversity state was conducted by matching these RED II definitions to the descriptions of the hemeroby levels by Fehrenbach et al. (2015) [12].

The description of unused land fits to hemeroby level II and the one for abandoned land fits to the one for hemeroby level III (compare Table 2 in chapter 2.4). Degraded land however is difficult to put into one description of hemeroby level as it comprises many different states of land and soil. For the assessment presented in chapter 3.1, the authors deem hemeroby level V the most accurate representation of the state of the land. Consequently, the assumed state in 2020 is assigned rather low biodiversity values. Therefore the differences of the 2020 state and the prognostic state of Miscanthus cultivation shows negative biodiversity increment values meaning an improvement in biodiversity value.

A sensitivity analysis was conducted by assigning different hemeroby levels to the present state. In the Figure 4-1, Figure 4-2, and Figure 4-3, the results for BVI per kg produced Miscanthus and the cumulative quality loss per biomass production for the reference state for degraded land in 2020 at hemeroby levels III, IV and VI is presented analogous to the results presented in chapter 3.1 at hemeroby level V.

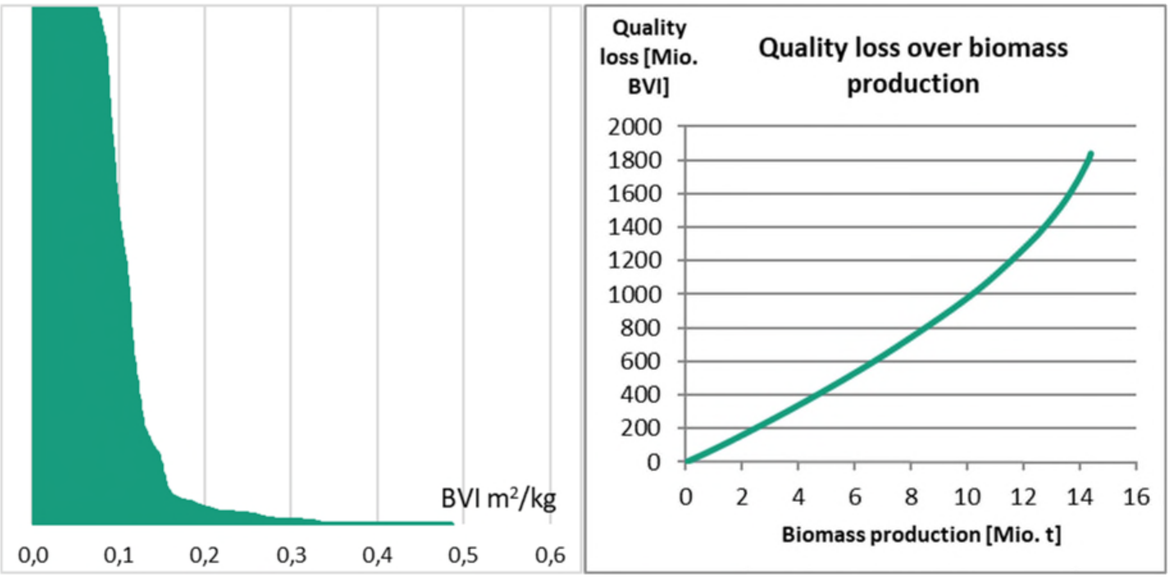

Figure 4-1 Results of all NUTS 3 regions of Bulgaria and Germany and all initial soil states in order of BVI / kg and cumulative biodiversity quality loss over cumulative biomass production for Bulgaria and Germany at hemeroby level III

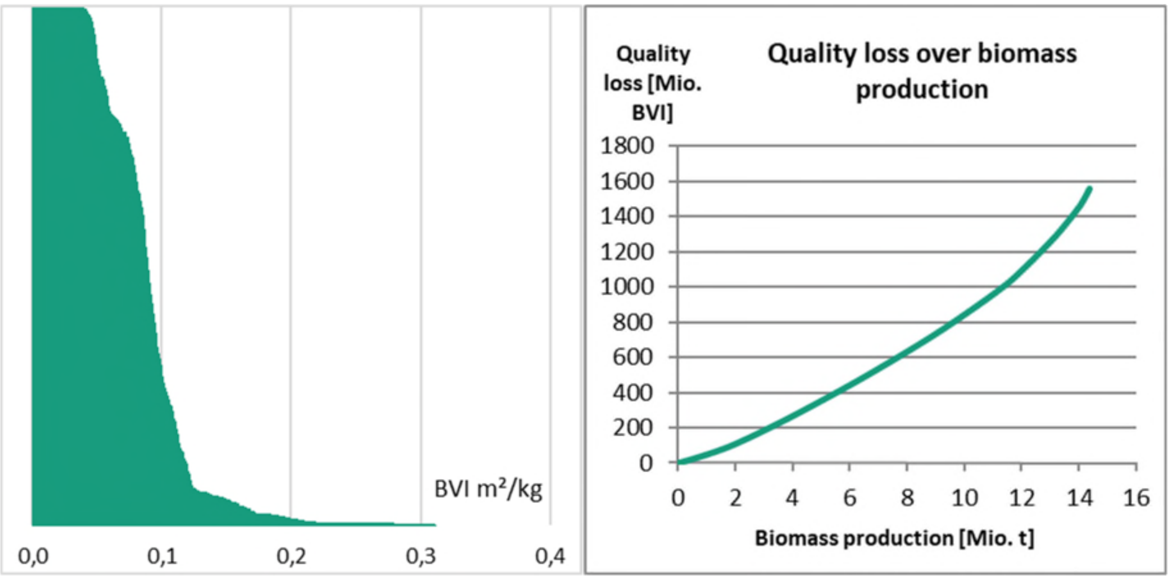

Figure 4-2 Results of all NUTS 3 regions of Bulgaria and Germany and all initial soil states in order of BVI / kg and cumulative biodiversity quality loss over cumulative biomass production for Bulgaria and Germany at hemeroby level IV

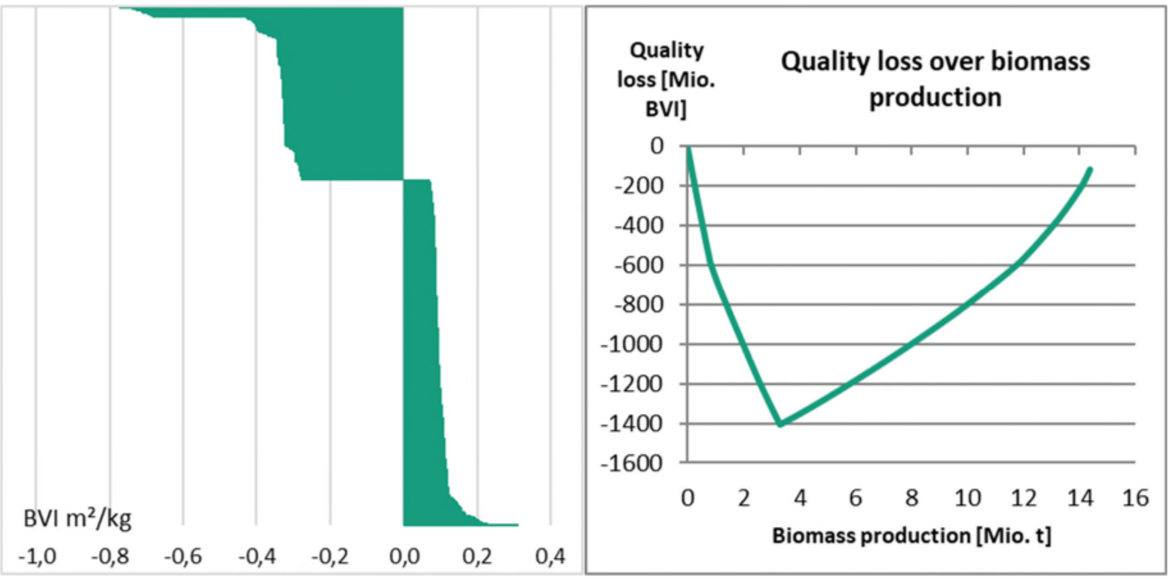

Figure 4-3 Results of all NUTS 3 regions of Bulgaria and Germany and all initial soil states in order of BVI / kg and cumulative biodiversity quality loss over cumulative biomass production for Bulgaria and Germany at hemeroby level VI

This sensitivity analysis shows that if the areas of degraded land in 2020 are estimated as hemeroby level III or IV, no positive development of the biodiversity value is calculated and the biomass production through Miscanthus cultivation show solely a loss in quality. If the hemeroby level in 2020 is set to VI, the calculated improvement of the biodiversity value through the cultivation of Miscanthus is even higher in comparison to the results presented in Figure 3-2 and Figure 3-5. Again a third of all areas – the degraded areas – result an even higher increase in biodiversity quality through the cultivation of Miscanthus, while the others show a decrease. Following this, almost 14.4 million t/a of Miscanthus, meaning all of the total Miscanthus production potential investigated in this study could be produced without worsening the overall biodiversity value (net zero). This is more than double the amount calculated based on the assumption that the reference state of degraded land in 2020 corresponds to hemeroby level V.

It is therefore concluded that without proper definitions of the areas and soils set forth by the EC in the RED II [5], a definite answer is hardly possible. It is possible, though, to state that if an area used for the cultivation of Miscanthus that fits the definitions of hemeroby state quoted in 2.4 with a value of V or higher, a gain in biodiversity quality can be achieved.

For the PDF methodology, a sensitivity analysis was conducted in a similar manner. Again the main point of discussion is the evaluation of the initial state of land, because the only characterization factors available for no land use result in a PDF value of 0. This leaves the obtained yield and the applied management practice in the future scenario as the only decisive parameters, which do not differ between the two applied impact assessment methods. In this study, this results in the examination that Miscanthus on degraded land has the highest impact on biodiversity per kg biomass while the cultivation of Miscanthus on unused land has the least impact per kg biomass. While the assumption of the unused and abandoned areas being similar to pristine land or areas with secondary vegetation and therefore being assigned a characterization factor of 0, appears reasonable, this assumption is debatable for the degraded areas. In the sensitivity analysis, the degraded areas are therefore assumed as lite cropland, intensive cropland and lite urban area. The results are shown in **Error! Reference source not found.** 4-4 and Figure4-5**Error! Reference source not found.**.

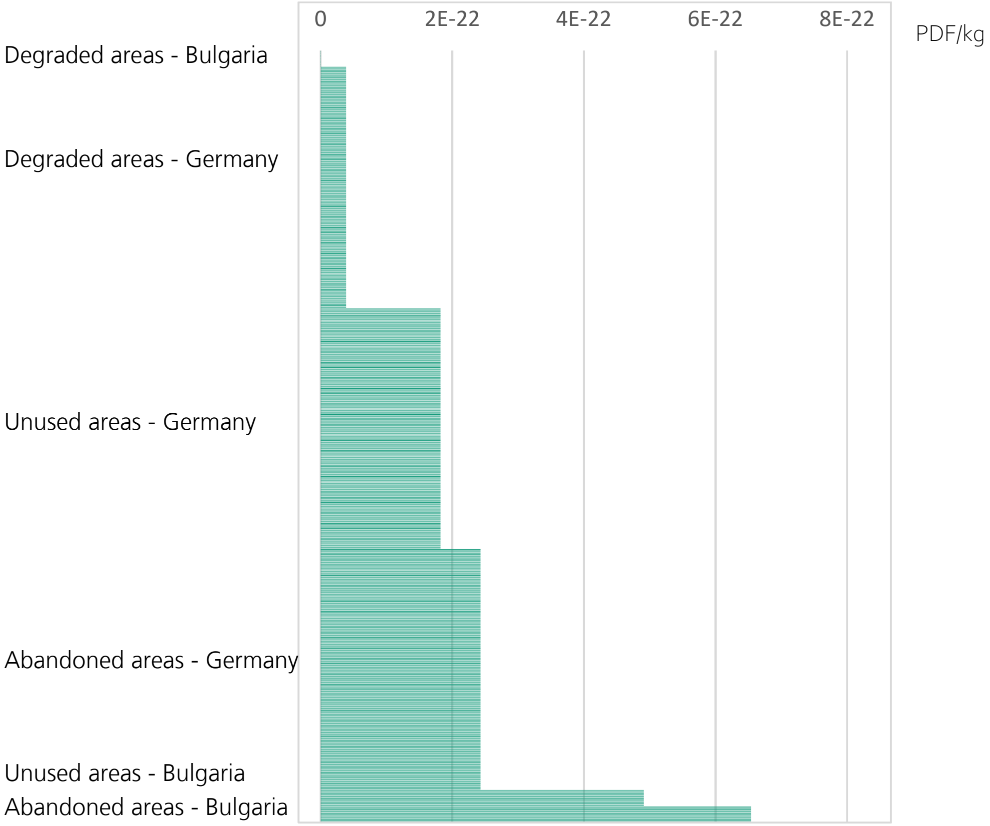

Figure 4-4 Sensitivity analysis for the PDF method with the degraded areas being assumed as lite cropland

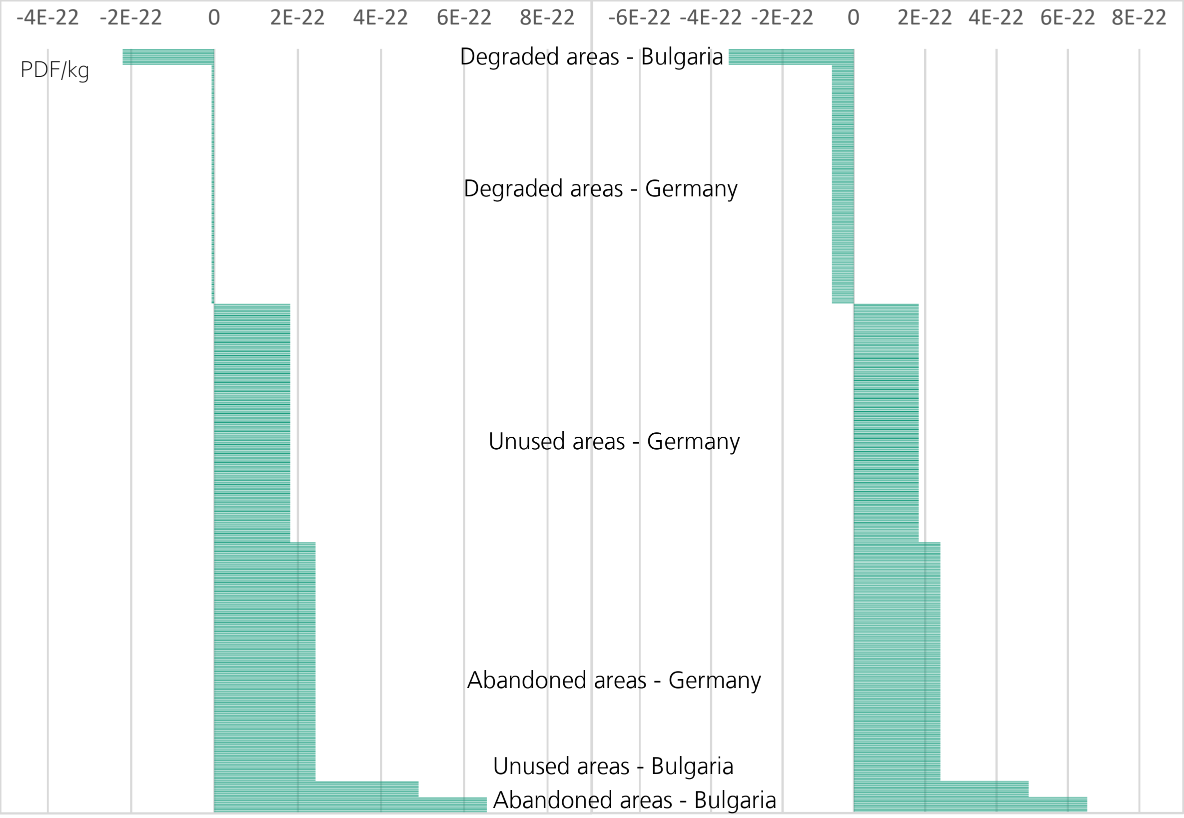

Figure 4-5 Sensitivity analysis for the **PDF** method with the degraded areas being assumed as intensive cropland (left) and lite urban areas (right)

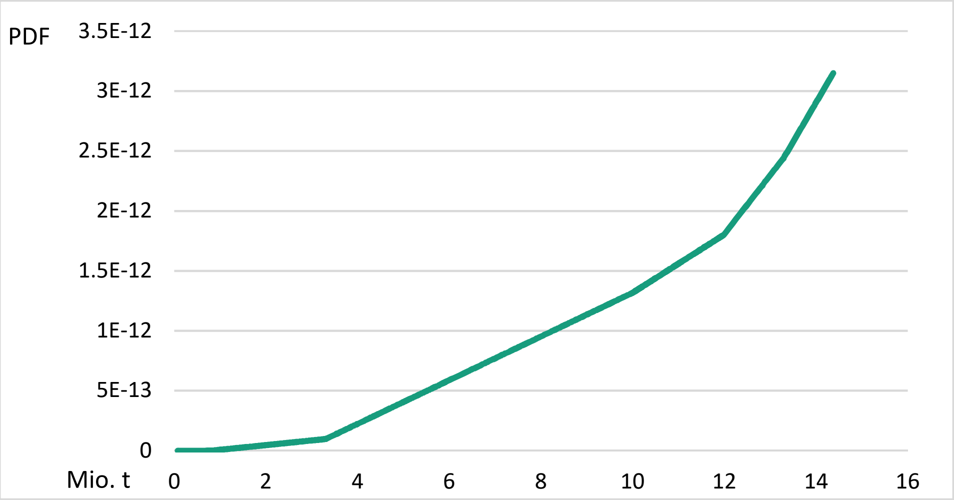

Figure 4-6 Quality loss over biomass production for the **PDF** method with the degraded areas being assumed as lite cropland

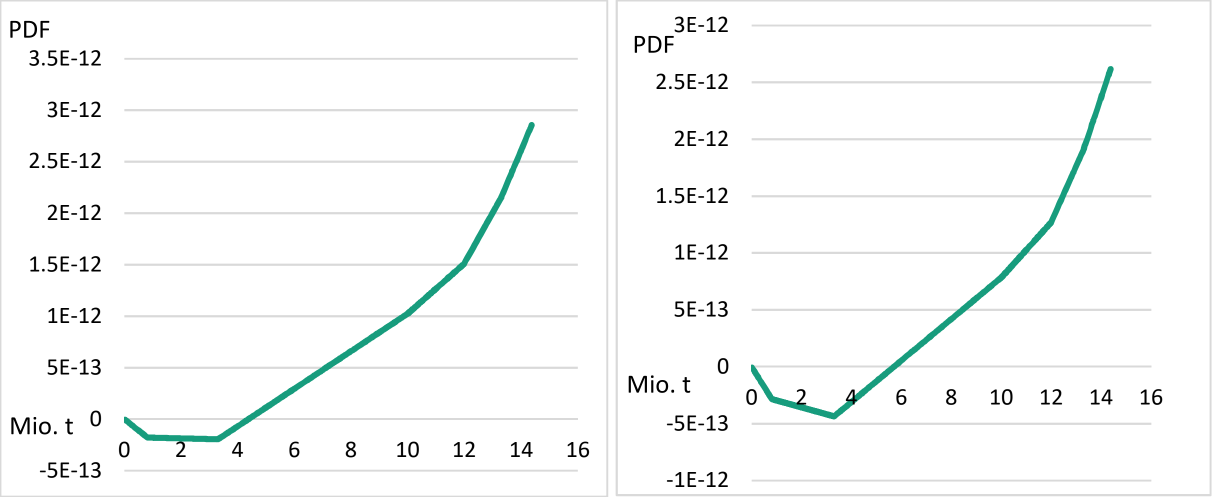

Figure 4-7 Quality loss over biomass production for the PDF method with the degraded areas being assumed as intensive cropland (left) and lite urban areas (right)

Under the assumption of degraded areas being similar to cropland or urban areas, the degraded areas show the lowest impact and for intensive cropland and lite urban areas even negative values meaning an increase in species occurrence and also a possibility to cultivate Miscanthus while being beneficial to local biodiversity, see Figure 4-6 and Figure 4-7. This shows that a different assumption of the initial state of the area has enormous repercussions on the outcome. Due to the lack of definitions for the degraded areas it is however most reasonable to go with the directive of the PDF methodology and assume a characterization factor of 0 for areas without land use. If definition of the degree of degradation were available an educated guess would be possible and a different characterization factor could be assumed to better describe degraded land.

The ranking order of the three land quality classes regarding the biodiversity impact depends on the applied method. With Lindner et al., degraded land is most favored; with Chaudhary & Brooks, unused land is favored – but here the sensitivity analysis showed that the ranking order changes if the degraded areas are assessed with different characterization factors These contradicting results of two methods that both aim to measure “biodiversity” hint at two underlying issues. First, characterization factors - if properly defined for various states of land - are useful even for land that does not produce any products. From this perspective, the method by Chaudhary and Brooks appears to be less suitable for this particular study. Second, a multi-faceted safeguard subject like biodiversity can produce contradicting results depending on which aspect is the focus of a given method (i.e. species richness or other aspects). In the opinion of the authors, a composite index that aims for a holistic assessment, such as the B.I.A. method, is more suitable.

However, it has to be stated that neither method is perfectly suited for this study. In the B.I.A. method, a coarsely defined hemeroby level has to be assumed as the reference state in 2020. The PDF method lacks categories for unused land in a non-natural state entirely and due the very limited descriptions of the categories, no other assumption could be made without further knowledge. Both methods are designed for use within the overall LCA framework, i.e. for the environmental evaluation of products and their respective value chains. Alternative approaches, e.g. Environmental Impact Assessment, are often more tailored to the specific question, but typically require site-specific primary data collection, which is not realistic for such a wide geographical scope. More abstract methods allow large areas to be easier assessed than with on-site methods, and they can highlight trends emerging over a larger amount of data points. With a fitting definition of the state of land for the B.I.A. method, and fitting characterization factors for the PDF method, it is likely that more consistent results could be obtained.

5 Outlook and recommendation for further Inquiries

The use of unused, abandoned or degraded land bears great potential for fuel crop production. However, it is crucial to precisely define the existing state of an area to calculate its potential. It is therefore recommended to the European Commission to craft proper definitions for unused, abandoned or degraded land so that future land use and biodiversity studies are able to produce more robust results.

However, it can be concluded that if an area is evaluated as strongly influenced by human activity and therefore shows a higher hemeroby level than V, the extensive cultivation of Miscanthus can be beneficial to local biodiversity. In this study, a densely populated and highly industrialized European country and a European country that is less densely populated and not as industrialized were evaluated (Germany and Bulgaria). As they only resemble a small variety of ecoregions and climatic zones, it is recommended to broaden the study to the whole of Europe. Different feedstock and ecoregion factors could provide strong variations of biodiversity impact and outline the total production potential of biofuel feedstock without an increment in biodiversity quality.

As Miscanthus shows high growth rates and biomass yields even on unfavorable soil, it is therefore a showcase crop for biofuel production. The assessment of other feedstock listed in the RED II Annex IX is recommended [5].

The assessment according to the PDF methodology showed a sole dependency of biodiversity increment per produced biomass to the biomass yield and the applied management practice. A sensitivity analysis displayed that if characterization factors for the state of unused land were available, different results could be obtained. It is therefore concluded that the method is not fit for this kind of study, at least not in its present form. If a differentiation between different unused area types is added to the methodology in future versions and corresponding characterization factors are provided, this would make the PDF methodology more suitable for the kind of question in this study.

In study, a first approach was taken to assess the increment or benefit for biodiversity of using marginal lands to produce biofuel. Both methods show the potential for a top-down evaluation on country scale, but without proper definitions of the state of area – especially for degraded land - clear assertions are hard to make. In conclusion, it can be stated that the cultivation of marginal areas bear a certain potential, but it’s assessment require precise examination and evaluation of the areas in questions.

6 References

1. Lindner, J.; Fehrenbach, H.; Winter, L.; Bloemer, J.; Knuepffer, E. Valuing Biodiversity in Life Cycle Impact Assessment. *Sustainability* **2019**, *11*, 5628, doi:10.3390/su11205628.
2. Lindner; Jan Paul; Knuepffer, E. *LC.biodiv.IA Final Report*, 2020.
3. Chaudhary, A.; Brooks, T.M. Land Use Intensity-Specific Global Characterization Factors to Assess Product Biodiversity Footprints. *Environ. Sci. Technol.* **2018**, *52*, 5094–5104, doi:10.1021/acs.est.7b05570.
4. European Commission. Renewable Energy – Recast to 2030 (RED II) - EU Science Hub - European Commission. Available online: https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii (accessed on 19 November 2021).
5. European Commission. Directive (Eu) 2018/2001 Of The European Parliament And Of The Council on the promotion of the use of energy from renewable sources **2018**.
6. European Commission. EU Biodiversity Strategy for 2030: Bringing nature back into our lives **2020**.
7. Panoutsou, C.; Maniatis, K. Sustainable Biomass Availability in the EU to 2050 **2021**.
8. Eurostat. Regions in the European Union: Nomenclature of territorial units for statistics NUTS 2006 /EU-27 **2007**.
9. Emily A. Heaton; Nicolas Boersma; John D. Caveny; Thomas B. Voigt; Frank G. Dohleman. Miscanthus (Miscanthus x giganteus) for Biofuel Production – Farm Energy. Available online: https://farm-energy.extension.org/miscanthus-miscanthus-x-giganteus-for-biofuel-production/ (accessed on 18 November 2021).
10. Milà i Canals, L.; Bauer, C.; Depestele, J.; Dubreuil, A.; Freiermuth Knuchel, R.; Gaillard, G.; Michelsen, O.; Müller-Wenk, R.; Rydgren, B. Key Elements in a Framework for Land Use Impact Assessment Within LCA (11 pp). *Int J Life Cycle Assess* **2007**, *12*, 5–15, doi:10.1065/lca2006.05.250.
11. Koellner, T.; Baan, L. de; Beck, T.; Brandão, M.; Civit, B.; Margni, M.; i Canals, L.M.; Saad, R.; Souza, D.M. de; Müller-Wenk, R. UNEP-SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA. *Int J Life Cycle Assess* **2013**, *18*, 1188–1202, doi:10.1007/s11367-013-0579-z.
12. Fehrenbach, H.; Grahl, B.; Giegrich, J.; Busch, M. Hemeroby as an impact category indicator for the integration of land use into life cycle (impact) assessment. *Int J Life Cycle Assess* **2015**, *20*, 1511–1527, doi:10.1007/s11367-015-0955-y.
13. Lindner, J.P. Quantitative Darstellung der Wirkungen landnutzender Prozesse auf die Biodiversität in Ökobilanzen. Dissertation, 2016.
14. Lindner, J.P.; Fehrenbach, H.; Winter, L.; Bischoff, M.; Blömer, J.; Knüpffer, E. *Biodiversität in Ökobilanzen*: *Weiterentwicklung und vergleichende Studien;* Bundesamt für Naturschutz: Bonn-Bad Godesberg, 2020.
15. Lindner; Jan Paul; Knuepffer, E. LC.biodiv.IA Guideline document **2020**.
16. World Wildlife Fund. Wildfinder: Online Database of Species Distributions: Jan 2006 version.
17. Drakare, S.; Lennon, J.J.; Hillebrand, H. The imprint of the geographical, evolutionary and ecological context on species-area relationships. *Ecol. Lett.* **2006**, *9*, 215–227, doi:10.1111/j.1461-0248.2005.00848.x.
18. Hoskins, A.J.; Bush, A.; Gilmore, J.; Harwood, T.; Hudson, L.N.; Ware, C.; Williams, K.J.; Ferrier, S. Downscaling land-use data to provide global 30″ estimates of five land-use classes. *Ecol. Evol.* **2016**, *6*, 3040–3055, doi:10.1002/ece3.2104.
19. van Asselen, S.; Verburg, P.H. Land cover change or land-use intensification: simulating land system change with a global-scale land change model. *Glob. Chang. Biol.* **2013**, *19*, 3648–3667, doi:10.1111/gcb.12331.

20. Arets, E.; v. d. Meer, P.; Verwer, C.; Hengeveld, G.; Tolkamp; Nabuurs, G.; Oorschot , G. , M. *Global wood production*: *Assessment of industrial round wood supply from forest management systems in different global regions*. Alterra Report 1808, Wageningen UR, Netherlands, 2011.
21. International Union for Conservation of Nature and Natural Resources. IUCN Habitat Classification Scheme: version 3.1. Available online: http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3.
22. Newbold, T.; Hudson, L.N.; Hill, S.L.L.; Contu, S.; Lysenko, I.; Senior, R.A.; Börger, L.; Bennett, D.J.; Choimes, A.; Collen, B.; et al. Global effects of land use on local terrestrial biodiversity. *Nature* 2015, *520*, 45–50, doi:10.1038/nature14324.
23. Chaudhary, A.; Burivalova, Z.; Koh, L.P.; Hellweg, S. Impact of Forest Management on Species Richness: Global Meta-Analysis and Economic Trade-Offs. *Sci. Rep.* 2016, *6*, 23954, doi:10.1038/srep23954.
24. International Union for Conservation of Nature and Natural Resources. IUCN Red List of Threatened Species. Available online: http://www.iucnredlist.org.
25. Giegrich, J.; Sturm, K. Methodenpapier zur Naturraumbeanspruchung für Waldökosysteme. *Materialband „Methodische Grundlagen" in: Tiedemann A (2000) Ökobilanzen für graphische Papieren* 1996.
26. European Commission. *NUTS - GISCO: Geographische Informationen und Karten - Eurostat*.
27. *Terrestrial Ecoregions GIS Data*, 2021.