LAND USE, LAND USE CHANGE, BIODIVERSITY AND ECOSYSTEM SERVICES

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True pricing method for agri-food products

Land use, Land use change, Biodiversity and Ecosystem Services

Impact-specific module for true price assessment

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[4] For more information on the *PPS True and Fair Price for Sustainable Products*, please refer to https://www.wur.nl/nl/project/Echte-en-eerlijke-prijs-voor-duurzame-producten.htm

Relation to other components of the true price methodology for agri-food products

This **Land use, land use change, biodiversity and ecosystem services - Impact-specific module for true price assessment** was developed by True Price and Wageningen Economic Research within the *PPS True and Fair Price* for Sustainable Products.

This document contains the key methodological aspects to measure and value the impacts of agri-food products and value chains for land use, land use change, biodiversity and ecosystem services.

This impact-specific module is complemented by five other **Natural capital modules** and seven **Social and human capital modules**. The other natural capital modules are: 1) Contribution to climate change; 2) Soil degradation; 3) Air, soil and water pollution; 4) Scarce water use; 5) Fossil fuel and other non-renewable material depletion. These impact-specific modules are preceded by the **Valuation framework for true pricing of agri-food products**, which contains the theoretical framework, normative foundations and valuation guidelines, and the **Assessment Method for True Pricing of Agri-Food products**, which contains modelling guidance and requirements for scoping, data and reporting (Figure 1).

Together, these documents present a method that can be used for true pricing of agri-food products, and potentially other products as well.

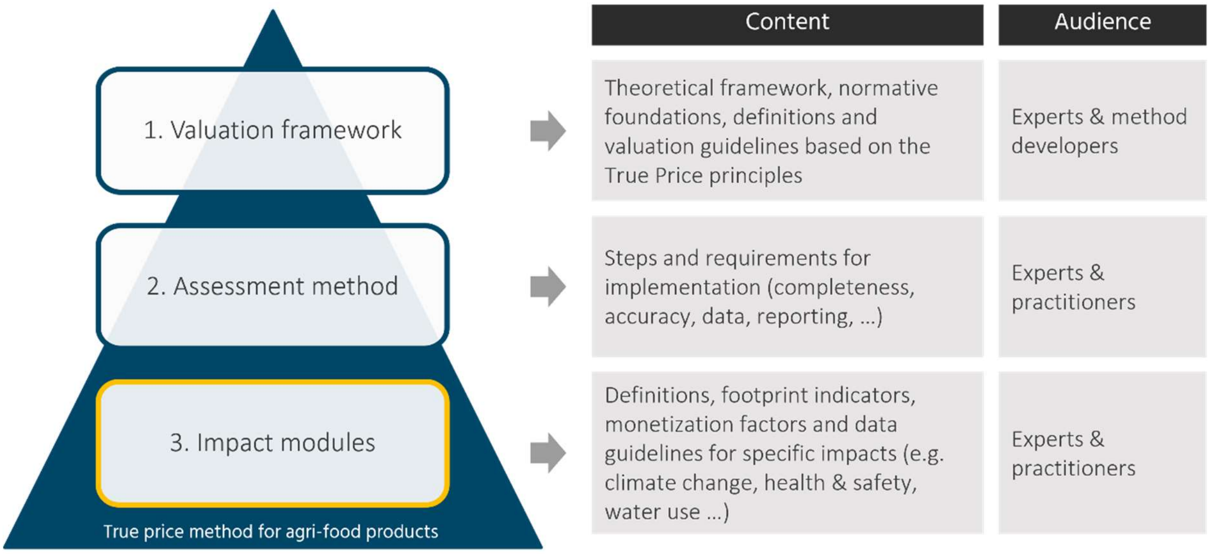

Figure 1: Components of the true price methodology for agri-food products. This document is one of the impact modules.

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1. Introduction

This document provides a method module for the assessment of the true price of an agricultural or horticultural product, within the public-private partnership 'Echte en Eerlijke Prijs'. It contains the key methodological aspects to measure and value two impacts of agri-food products and value chains: land use and land use change. It also contains additional information on how effects on biodiversity and ecosystem services are accounted for by the true price assessment method.

This module must be used together with the **True Pricing Assessment Method for Agri-food Products** (Galgani et al., 2021a). As for other impacts in true pricing, this methodology is compatible with Life Cycle Assessment (LCA).

This module is organised as follows: Section 2 gives key definitions on land use, biodiversity and its connection to ecosystem services. Section 3 discusses the rationale for including land use and land use change (often also called land occupation and land transformation) in a true price assessment. Section 4 discusses how biodiversity and ecosystem services are covered by the other impact modules in this method series and are related to land use and land use change. Section 5 provides guidance for the scoping phase. Section 6 summarises the relevant footprint indicators. Section 7 gives an overview of the modelling approaches for the impacts, as well as insight into associated data requirements. Section 8 provides the monetisation approaches. Lastly, Section 9 provides an overview of limitations and key items for further research. In addition, a glossary of key terms and an annex that discusses the link with rights in international agreements, are provided at the end of the document.

2. Definitions

Land use and biodiversity are environmental impacts of agri-food products**. In this module land use refers to the combination of two Natural Capital impacts land use and land use change.** In short, land use represents the impact of occupying land for the production of products, while land use change represents the impact of land use change from one land use type into another. This distinction is in line with LCA guidelines (Milà i Canals et al., 2007; Frischknecht & Jolliet, 2016). **In this method, biodiversity and ecosystem services (ESS) are not quantified as a separate Natural Capital impact, but through the other impacts**. They underpin the land use impact method and are taken into account in other impacts as well. Section 4 (Biodiversity and ESS in the Natural Capital method) explains how biodiversity and ESS relate to the various impacts in the true price method. Land use is a major driver of loss of biodiversity and ecosystem services and therefore, land use, biodiversity and ecosystem services are covered together in this module.

Land use, land use change, biodiversity and ecosystem services are defined below:

- **Land use,** or land occupation, represents the decreased availability of land for purposes other than the current one, through land occupancy. Land use by agriculture displaces habitats and ecosystems and therefore leads to biodiversity loss and loss of ecosystem services (Milà i Canals et al., 2007; Alkemade et al., 2009; De Groot et al., 2012).
- **Land use change,** or land transformation, represents changes in land-cover that can affect ecosystem services and the climate system. This impact includes the number of natural ecosystems – i.e. (tropical) forest, woodland, grassland, and (inland and coastal) wetland - that are transformed in a certain period of time. Land use change reduces the size of habitats and ecosystems and therefore leads to biodiversity loss and loss of ecosystem services.

Biodiversity and ecosystem services are defined as follows:

- **Biodiversity** is defined by the Convention on Biological Diversity (CBD) as '*the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and*

the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems' (UN, 1992). While this generic definition focuses on genetic diversity, a broader definition may furthermore define biodiversity according to *level* (e.g., world, species, ecosystems, families, etc.), *type* (i.e., alpha, beta, gamma) and *quality* (i.e., functional diversity, trait diversity, phylogenetic diversity, genetic diversity, anthrophiles vs. anthrophobes, rare vs. common, specialist vs. generalist, conservation value).
- **Ecosystem services** (ESS) are defined as '*the direct and indirect contributions of ecosystems to human wellbeing*' (Kumar, 2010). ESS are typically divided into four types: provisioning services, regulating services, cultural services and supporting services (Ranganathan, 2008 as cited in Croezen et al., 2011).

The level and mechanisms determining land prices are out of scope in this methodology. While distortions on the price of land and unfair prices are very relevant to the final market price of a product, they are not part of the true price in this method. This method focuses on yearly external costs that are added on top of the current market price due to the fact that occupying land displaces nature, and therefore ecosystem services are lost[5].

Relation between biodiversity and ESS

Biodiversity is seen as the foundation of ESS. Biodiversity is usually regarded as one of the indicators of the capacity of an ecosystem for providing ecosystem services (Croezen et al., 2011, p.21, MEA, 2005, Maes et al. 2016). Biodiversity and ESS are furthermore interlinked by the necessity of retaining adequate biodiversity in an ecosystem, to retain ecosystem resilience and stability (Haines-Young, 2009; Bruel et al., 2016, Figure 1, p.385). Biodiversity can be seen as one of the foundations of the quality of the biosphere (together for example with climate stability). This quality can be translated into benefits to humans as ecosystem services[6].

Relation of land use to other impacts in true pricing

Land use, especially in agriculture, is linked to most or all Natural Capital impacts in true pricing[7]. The specific impacts of land use that are covered by the definitions of land use and land use change provided above, are covered in this document. For methodologies of the other Natural Capital impacts related to land use, refer to the respective method modules.

Next to this, breaches of land rights and breaches of indigenous rights are Social Capital impacts relevant for true pricing and related to the use of land. These two impacts are part of the method and will be explained and developed in separate modules at a later stage.

3. Background and rationale for including as part of the true price

Humanity benefits from the natural environment in various ways. It provides us with food, clean water and other resources, and it protects us from floods and soil erosion (TEEB, 2008 as cited in Croezen et al., 2011, p.21). Moreover, the natural environment has fundamental social, cultural and aesthetic importance. Ecosystem services represent these benefits and support the wellbeing of every human population (MEA 2005; Croezen et al., 2011; Frischknecht & Jolliet, 2016, p.127).

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[5] For more information on what is considered an external cost, the true price and the true price gap, and their relationship to the market price of a product refer to the Valuation Framework for True Price Assessment of Agri-food Products (Galgani et al., 2021b, p.6-7)

[6] Some might criticize this as a very anthropocentric approach; however, valuation is intrinsically anthropocentric.

[7] Other natural capital impacts in true pricing of an agricultural or horticultural product include contribution to climate change, scarce water use, air pollution, water pollution, soil pollution, fossil fuel and other non-renewable material depletion and soil degradation.

Biodiversity, as explained in Section 2, is the diversity of life on the planet, including diversity within species, between species, and of ecosystems. As such it underpins the existence, functioning and evolution of the biosphere, and therefore the wellbeing of humans (UN, 1992). In addition, international agreements, such as the International Convention on Biodiversity (Aichi Biodiversity Targets)[8] and the Sustainable Development Goals (UN, 2015) recognise the importance of biodiversity and ecosystem services[9]. The loss of ecosystem services leads to economic damage, which can be interpreted as the lost value of biodiversity and damage to human well-being and health (MEA, 2005)[10]. It is true that agricultural land use is necessary to be able to meet the right to food. This should rather be reflected in a measure of true value, which focuses on consumer value and positive externalities[11], than in the true price gap (see Galgani et al., 2021b).

As biodiversity and ecosystem services underpin the value of the biosphere, they are linked to many Natural Capital impacts in a true price assessment. Land use and land use change methods are key ones, because it is through land use and the way land is managed that agricultural value chains have the most direct (and often largest) impact on ecosystems and biodiversity. The rest of this module is focused on these two impacts. The links of biodiversity and ecosystem services with air, soil and water pollution, soil degradation and climate change are explained in Section 4 (Biodiversity and ESS in the Natural Capital method).

Land use and land use change are commonly included among environmental sustainability indicators for products in Life Cycle Assessment (Frischknecht & Jolliet, 2016). The fact that these are also negative externalities of production that should be accounted for in true pricing can be established through the link with internationally accepted agreements on the rights of current and future generations[12]. More specifically, land use change from a natural ecosystem to agricultural land involves the direct degradation of ecosystems, leading to loss of habitats, biodiversity and ecosystem services. Land use for agricultural purposes displaces nature and therefore leads to biodiversity loss and has an opportunity cost in terms of ecosystem services. Additionally, it indirectly contributes to land use change as well.

Considering the arguments above, economic actors have a responsibility to limit land use and the loss of biodiversity and ESS on land that is under their control. Annex A specifies the link with international rights and international conventions.

4. Biodiversity and ESS in the Natural Capital method

Biodiversity and ecosystem services are included together with land use when measuring the true price. However, (loss of) biodiversity relates to many other Natural Capital impacts in true pricing. The same holds for ecosystem services. This section explains how biodiversity is taken into account in various parts of the method. An overview of the relation of biodiversity and ESS with other Natural Capital impacts can be seen in Figure 2.

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[8] https://www.cbd.int/sp/targets/

[9] For more information, refer to Annex A and the Valuation Framework for True Price Assessment of Agri-food Products (Galgani et al, 2021b).

[10] Another impact of land use occurs when land is used for one economic purpose; it is unavailable for another. This economic opportunity cost, however, is considered internalised in the land price (e.g., rent) and is therefore out of scope in the current method.

[11] Whether to combine positive and negative externalities is a normative choice. In this method, positive externalities are not part of the true price. The underlying idea is that the true price should avoid netting positive and negative impacts, since these can be borne by different stakeholders (Galgani et al, 2021b, p.13). Looking at positive externalities, the true value of a product can be measured.

[12] For more information, refer to Annex A and the Valuation Framework for True Price Assessment of Agri-food Products (Galgani et al, 2021b).

This is based on the framework developed by Bruel et al. (2016, Figure 1, p.385), which links biodiversity to ecosystem services, through multiple ecosystem functions.

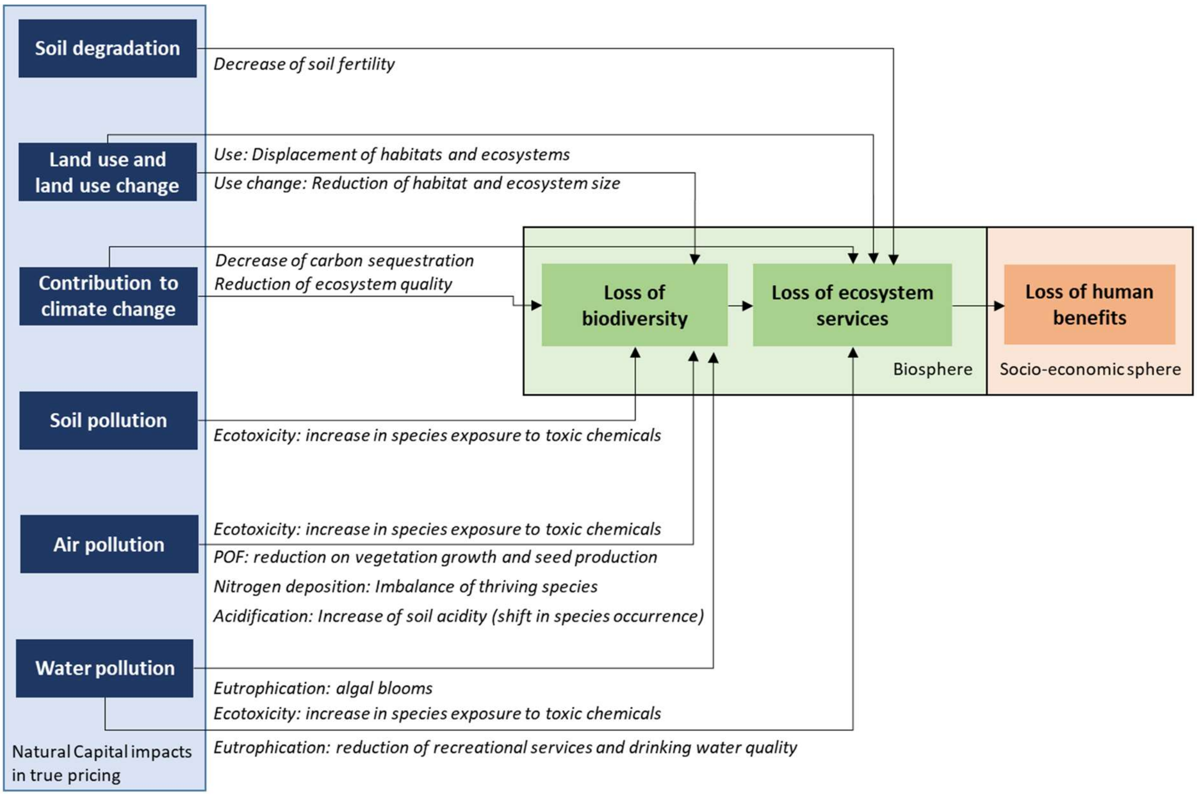

Figure 2: Overview of the relation of biodiversity and ESS loss with Natural Capital impacts of a True Price assessment.

4.1. Biodiversity and ESS in land use and land use change

Land use affects biodiversity, the functioning of ecosystems, and the services they provide (Koellner et al., 2013a). Therefore, land use is an important driver of global biodiversity loss and loss of ecosystem services (De Groot et al., 2012; De Baan et al., 2013).

The methods for land occupation and transformation measure loss of ecosystem services and biodiversity loss due to human activities that require land (such as agriculture, animal husbandry, forestry, etc). Land use looks at the opportunity cost of this on an annual basis and it is measured in MSA.ha.year, which represents the amount of land occupied adjusted for the degree of biodiversity loss. The monetary valuation of land use is done through the value of lost ESS (see Section 8). It represents the opportunity cost of land use as opposed to the value of nature, measured as ecosystem services. Land use change captures the loss of natural habitats in previous years and is measured in MSA.ha and valued through restoration cost (see Section 8).

The following sections of this document explain this method in more detail. An overview of how biodiversity and ecosystem services are covered in other method modules (soil degradation, air, soil and water pollution, and climate change) is given in the rest of this section. The general line of argument is that different pressures (midpoint indicators) cause changes in biodiversity. The sum of all effects caused by the different pressures is the total change in biodiversity. So, part of biodiversity change is explained by land use and land use change, part by soil degradation, part by climate change and part by pollution (see Figure 2).

4.2. Biodiversity and ESS in soil degradation

In this method, soil degradation is specified separately from land use and biodiversity because it focusses solely on the effects on soil. However, ESS are part of soil degradation since soil fertility is an ecosystem service and a part of soil degradation links to a loss of soil biodiversity. In that sense, soil degradation could be considered a sub-impact of land use. For example, Soil Organic Carbon (SOC) loss, is considered an indicator of land transformation in the PEF (European Commission, 2013), but is considered in the true price method as a separate issue, because the reference for land use change and land use is sustainable use of the land, where soil degradation is the consequence of unsustainable use of the land.

For more information consult the **Soil degradation impact-specific module for true price assessment** (Galgani et al, 2021c).

4.3. Biodiversity and ESS in air, soil and water pollution

Air, soil and water pollution and their effects are closely linked to biodiversity and ecosystem services. In particular, the following indicators (midpoints) have an impact on ‘ecosystems’ (endpoint) which uses biodiversity loss as indicator: acidification, ecotoxicity, photochemical oxidant formation (POF), nitrogen deposition, freshwater and marine water eutrophication and ozone depleting emissions. Freshwater and marine water eutrophication, which are indicators under the impact of water pollution, lead to damage to freshwater and marine ecosystems, accordingly (Huijbregts et al., 2017). They are measured in kg N or P/kg N or P emitted to water bodies, which represents Ecosystem Services Damage Potential (ESDP) (residence time). The valuation of eutrophication and ozone depleting emissions, as included in the pollution module, also consider damage caused due to the loss of biodiversity and damage to agricultural crops, respectively. For all other indicators, impact on ecosystems is valued using restoration cost (Ott et al. 2006), which uses loss of biodiversity as PDF.m2.yr as an endpoint indicator[13]. This means, for example, that loss of pollination services from pesticide use is already included in the impact terrestrial ecotoxicity from emissions to soil. For more information consult the **Air, soil and water pollution impact-specific module** of the true pricing method for agri-food products (Galgani et al, 2021d).

4.4. Biodiversity and ESS in climate change

Considering climate change, when land is transformed from one state to another, carbon stocks contained in trees, vegetation and soil may decline, emitting this carbon into the atmosphere (Dumortier et al., 2011; Searchinger et al., 2018) and affecting biodiversity and ESS. This impact is measured using the same footprint indicator used to measure climate change, which is GHG emissions in kg CO2-eq (Metz et al., 2007). Since the valuation of climate change, as included in the climate change module, is done using a marginal abatement cost, no further distinction is made between damage to human health and ecosystem impacts. For more information consult the **Contribution to climate change impact-specific method for true price assessment** (Galgani et al, 2021e).

4.5. Other losses of Biodiversity and ESS

All or most environmental effects related to loss of biodiversity and loss of ecosystem services are covered by the impacts included in the Natural Capital method modules listed above. If there are strong reasons to believe important effects are left out, these could be added to the method and the assessment under the name of “Other loss of biodiversity” (or “other loss of ecosystem services”), provided that these are quantified and valued with an approach which is consistent with the methods listed above, and no double counting occurs.

[13] Potentially Disappeared Fractions of species (PDF), from ReCiPe (Huijbregts et al., 2017)

5. Guidance for the scoping phase of a true price assessment

All agricultural processes that require the use of land are material when assessing land use. Land use change is most material when farming occurs on land that has been recently converted from natural ecosystems.[14] Non-agricultural processes such as processing, transport, and logistics can typically be considered non-material.

Existing Life Cycle Assessment (LCA) studies for similar products as the studied one, or databases that provide information on Land use and Biodiversity for economic activity, can be used to assess materiality in a more quantitative way.

6. Footprint indicators

Land use corresponds to two footprint indicators, presented in Table 1, valued using different monetisation factors (see Section 8). The distinction between land use and land use change is in line with UNEP-SETAC LCA guidelines (Milà i Canals et al., 2007; Koellner et al., 2013a; Koellner et al., 2013b; Frischknecht & Jolliet, 2016). The impact is split into the two indicators to capture different time effects. While land use change covers the loss of natural habitats in *past* years, land use covers *current* displacement of ecosystem services on an annual basis, which is an opportunity cost of land use.

The current method furthermore splits the footprint indicators in six biomes[15] to account for differences in communities of plants and animals that have common characteristics.

[14] Note that different frameworks often have different interpretations of what is considered 'recent'. The GHG protocol, for example, considers 'recent land use change' to be within 20 years.
[15] The largest unit of ecological classification that is convenient to recognise below the entire globe. Terrestrial biomes are typically based on dominant vegetation structure (e.g., Forest grassland). Ecosystems within a biome function in a broadly similar way, although they may have very different species composition (Potschin et al., 2014).

Table 1: Overview of Land use and Land use change indicators

Footprint indicator(s)	Unit	Suggested modelling approach
1. Land use (by biome) adjusted for biodiversity loss:		
Occupation tropical forest	MSA.ha.yr	See Section 7.1
Occupation other forest		
Occupation woodland/shrubland		
Occupation grassland/savannah		
Occupation inland wetland		
Occupation coastal wetland		
2. Land use change (by biome):		
Transformation tropical forest	MSA.ha	See Section 7.2
Transformation other forest		
Transformation woodland/shrubland		
Transformation grassland/savannah		
Transformation inland wetland		
Transformation coastal wetland		

7. Modelling approach

7.1. Land use

Land use (by biome) adjusted for biodiversity loss represents the amount of land used to produce a product. It is adjusted for the level of biodiversity lost due to the intensity of land use type and split by type of natural biome that is local in the place where cultivation takes place. It is calculated for each process in scope using the following formula:

(1) $$\text{LAND-O}_b = \text{USE} * \text{BIOME}_b * (1\text{-MSA})$$

Where LAND-O_b is land use adjusted for biodiversity loss for a unit of product for biome *b* [in MSA.ha.yr/unit product]; the footprint indicator. USE is land use per unit of product (in ha.yr/unit), or the ratio between land area occupied in a year and number of products produced. For agriculture this is equivalent to the inverse of annual crop yield (unit/ha/yr). $BIOME_b$ is the share (%) of biome cover of biome b in that region in the pristine nature state, where the sum of $BIOME_b$ for all biomes is 100 percent. Table 2 provides global and Dutch biome share values, based on OECD data (OECD, 2019). Box 1 provides more information on biomes.

Table 2: Share of biomes (%) globally and in the Netherlands.

Biome	Global share (%)	NL share
Coastal wetlands	4%	4%
Inland wetlands	10%	8%
Tropical forest	19%	0%
Temperate forest	27%	14%
Woodlands	26%	6%
Grasslands	14%	68%

MSA is the percentage of biodiversity in the original vegetation that remains intact, so 1-MSA is the percentage of biodiversity that is lost. The biodiversity loss coefficient (1-MSA) (loss of Mean Species Abundance [MSA][16]) represents the share of species abundance that is lost in the current type of land use, compared to the pristine natural state (ten Brink, 2006). 1-MSA values are taken from the framework for the Biodiversity Impact Metric by CISL (CISL, 2020). These values depend on the type of original biome and the intensity of the current land use. 1-MSA default values are provided in Table 3 and they represent the degree of biodiversity loss for forests, cropland and pasture, and varying levels of intensity of human impacts relating to land use. They can range from 0 to 1, showcasing no to complete loss, respectively[17]. In case primary data can be collected on biodiversity loss coefficients, these could replace the default values proposed in this module.

[16] MSA is an indicator of the intactness of biodiversity. It is defined by GLOBIO as the mean abundance of original species relative to their abundance in undisturbed ecosystems. An area with a coefficient (1-MSA) of 0 means a biodiversity that is similar to the natural situation. A coefficient of 1 means a completely destructed ecosystem, with no original species remaining (CISL, 2020).

[17] The original source used by CISL (i.e., GLOBIO) provides opposite MSA factors where 0 represents complete loss of biodiversity, and 1 represents no loss. There, MSA factors are used as biodiversity loss coefficients, rather than 1-MSA factors. Formula 1 can then be used accordingly.

Table 3: Types of land use and biodiversity loss coefficients (1-MSA factors). Source: CISL (2020)

Land Use	Intensity	Description	Coefficient
Natural forest	Minimal	Any human disturbances identified are very minor (e.g., a trail or path) or very limited in the scope of their effect (e.g., hunting of a particular species of limited ecological importance).	0.15
	Light	One or more human disturbances of moderate intensity (e.g., selective logging) or breadth of impact (e.g., bushmeat extraction), which are not severe enough to markedly change the nature of the ecosystem. Primary sites in suburban settings are at least Light use.	0.3
	Intense	One or more human disturbances that is severe enough to markedly change the nature of the ecosystem; this includes clear-felling. Primary sites in fully urban settings should be classed as Intense use.	0.5
Plantation forest	Minimal	Extensively managed or mixed timber, fruit/coffee, oil-palm or rubber 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.	0.7
	Light	Monoculture fruit/coffee/rubber plantations with limited pesticide input, or mixed species plantations with significant inputs. Monoculture timber plantations of mixed age with no recent (< 20 years) clear-felling. Monoculture oil-palm plantations with no recent (< 20 years) clear-felling.	0.75
	Intense	Monoculture fruit/coffee/rubber plantations with significant pesticide input. Monoculture timber plantations with similarly aged trees or timber/oil-palm plantations with extensive recent (< 20 years) clear-felling.	0.8
Cropland	Minimal	Low-intensity farms, 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.	0.6
	Light	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.	0.7
	Intense	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.	0.9
Pasture	Minimal	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).	0.2
	Light	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).	0.4
	Intense	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).	0.7

There is a variety of indicators to measure biodiversity and biodiversity loss, that can be adopted for the purposes of environmental and agricultural assessments. MSA demonstrates similarities to other common indices that measure biodiversity, such as the Biodiversity Integrity Index, the Biodiversity Intactness Index, and the Living Planet Index, while it is considered a proxy for the CBD[18] indicator for trends in species abundance

[18] '*During the sixth meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD), the parties committed themselves to achieve, by 2010, a significant reduction in the current rate of biodiversity loss […] Later that year, governments […] recognized the same target and endorsed the CBD as the key instrument for the conservation and sustainable use of biological diversity.*' (Alkemade et al., 2009)

(Alkemade et al., 2009). The validity of this indicator is further highlighted through its application to multiple assessments from leading organisations, like FAO, UNEP and OECD, among others (ten Brink, 2006).

MSA can be utilised to calculate directly the relative change between a land use type and a reference (De Baan et al., 2013), while it can be applied to global and regional assessments in which models estimate different scenarios in the past, present and future (ten Brink, 2006). Additionally, MSA is easy to link to socioeconomic activities, and to estimate the share per environmental pressure and sector (ten Brink, 2006). Finally, it should be noted that MSA represents the average response of the total set of species present in the ecosystem, and it should be combined with complementary indicators when an extensive biodiversity assessment is taking place. The indicator is considered sufficient for the purposes of a true pricing assessment. Box 1 provides more information about MSA factors.

Figure 3 shows a graphical representation of the land use formula. The formula should be applied for each biome that is relevant as an original biome in the region under study. The sum of the parameters $BIOME_b$ for each of the considered biomes, should be 1.

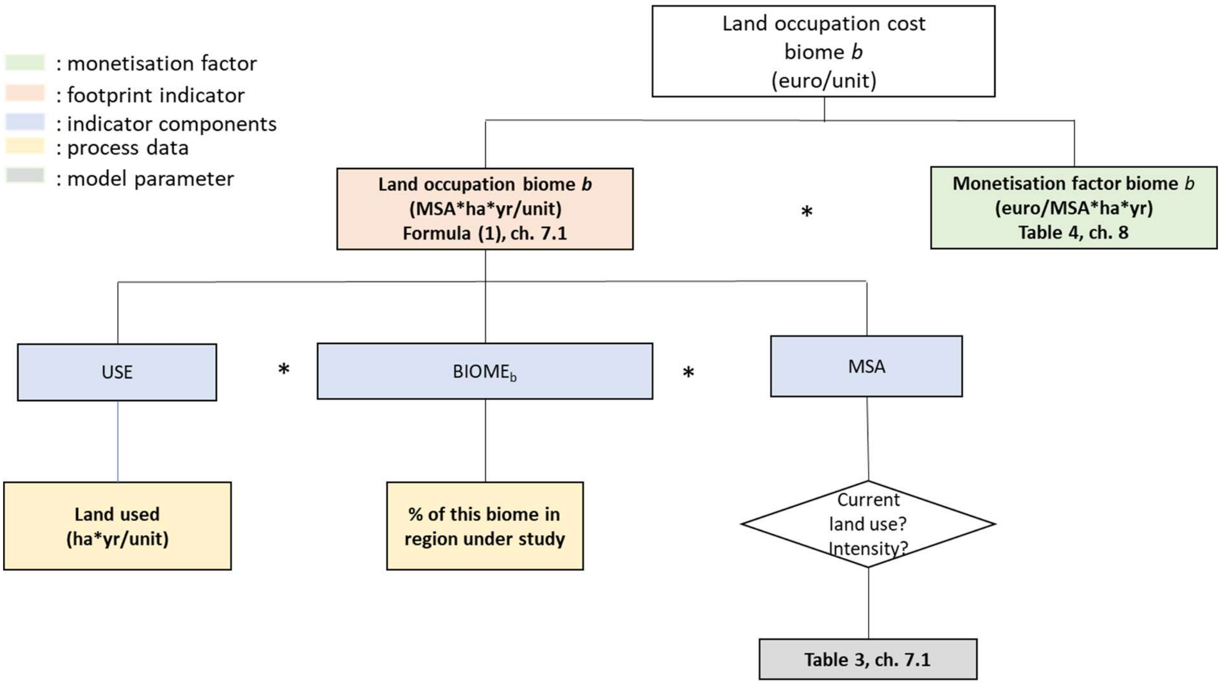

Figure 3: Modelling approach and monetisation to derive the cost of land use by biome.

7.2. Land use change

Land use change (by biome) represents the share of original ecosystem conversion that can be attributed to the amount of land used to produce the product under study. It is calculated for each process in scope using the following formula:

(2) $$\text{LAND-C}_b = \text{LAND-O}_b \,/\, \text{YEAR}$$

Where LAND-C_b is land use change for a unit of product for biome b (in MSA.ha/unit). LAND-O_b is land use for a unit of product for biome *b* (in MSA.ha.yr/unit product). YEAR is the number of years since the conversion from a ‘natural’ ecosystem to another.

The focus is on conversion from natural ecosystems to human land use. Land use change from various types of land use is not considered here. Its impact is captured by the (1-MSA) factor and other impacts such as soil degradation. It is possible that the land is converted into a more biodiverse land use. This effect will result in a positive effect that reduces the negative externalities compared to previous land uses. However, in the current method, a small external cost remains present, since the reference land is the natural (pristine) ecosystem. The choice to use pristine land as a reference is common practice in other frameworks such as LCA or Value Balancing Alliance.

Figure 4 shows a graphical representation of the land use change formula. Land use change is based on the calculation of land use. The formula should be applied for each biome that is relevant as an original biome in the region under study. The sum of the parameters $BIOME_b$ for each of the considered biomes, should be 1.

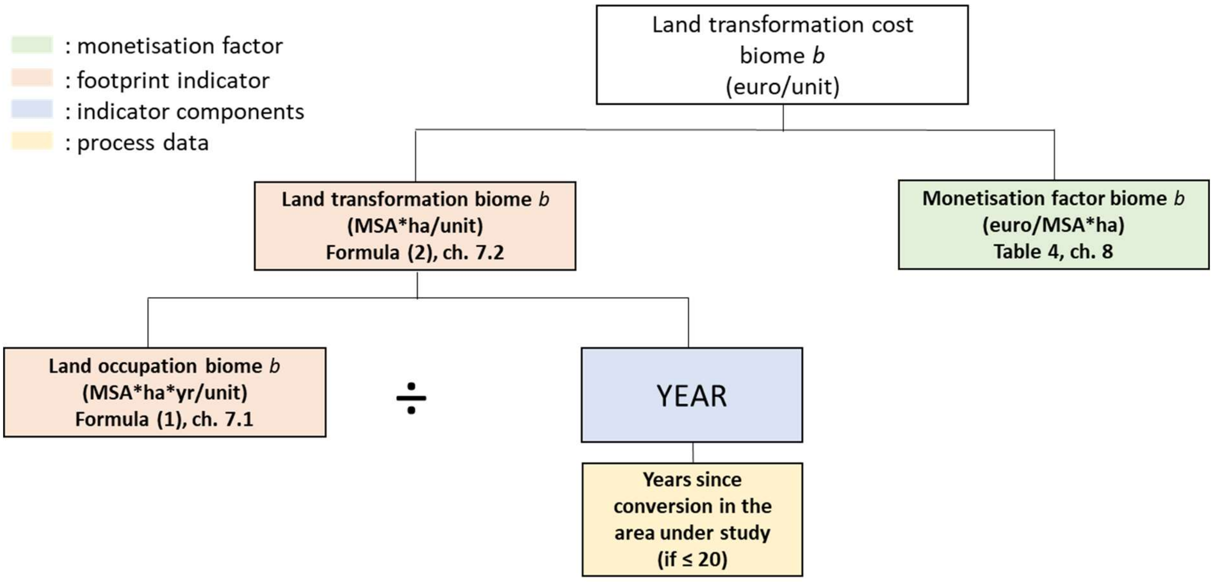

Figure 4: Modelling approach and monetisation to derive the cost of land use change by biome

7.3. Data requirements

Based on the modelling approach described above, the following datapoints are needed for each process in the lifecycle where these impacts have to be quantified.

- For both land use and land use change:
  - Land use per unit of output (ha.yr/unit product). This is equivalent to the inverse of the yield for a year (unit product/ha.yr).
  - Biome cover in the region in the pristine nature state (in percent), for the six considered biomes
  - Mean species abundance (in percent) for current land use in reference to the pristine nature state in that region. Standard factors for various land use types and different intensities are provided in Table 3. In case of uncertainty, regarding the degree of land use intensity, a precautionary 'intense' should be assumed.
- For land use change:
  - Years since conversion from a natural ecosystem (years)

Box 1: Biomes and MSA factors for land use and land use change modelling.

Biomes

A biome is defined by TEEB as the largest unit of ecological classification that is convenient to recognise below the entire globe. Terrestrial biomes are typically based on dominant vegetation structure (e.g., Forest grassland). Ecosystems within a biome, function in a broadly similar way, although they may have a very different species composition. For example, all forests share certain properties regarding nutrient cycling, disturbance, and biomass that are different from the properties of grasslands. Marine biomes are typically based on biogeochemical properties (Potschin et al., 2014).

For each region under study, a list of biomes that are relevant as original biomes is required for the calculation of land use and land use change indicators. For each biome in the list, the parameter BIOME, % biome cover should be determined based on how much they contribute to the original biome composition in that region. The sum of this parameter for all biomes should be 100%. Values at a sub-national level should be used as much as possible. Nonetheless, values representing the country average for The Netherlands are also provided in Table 2, calculated from OECDstat.

MSA factors

The 1-MSA factors are another parameter in the calculation, which represents the extent to which the studied type of (agricultural) land use leads to a loss in biodiversity. The coefficient values calculated by the University of Cambridge Institute for Sustainability Leadership (CISL), presented in Table 3, can be used. They are based mainly on the mean abundance of original species (MSA) coefficients taken from the factors used by the GLOBIO global biodiversity model (Schipper et al., 2016). MSA indicates the biodiversity intactness and illustrates the abundance of original species relative to their abundance in undisturbed ecosystems.

The biodiversity loss coefficients are also informed by the PREDICTS (Hudson et al., 2017) database and by refined species-area models (combination of land use maps with the IUCN habitat-use classification scheme) that identify '*taxon affinity*' (a measure of the proportion of species remaining in transformed habitats) (CISL, 2020). To be able to use the coefficients, information on land use and production practices is required. CISL (2020) recommends creating a questionnaire to determine the appropriate intensity coefficient. In case of uncertainty regarding the degree of land use intensity, a precautionary 'intense' should be assumed.

It is also possible to calculate MSA loss for a specific site, by doing primary measurements. This allows to increase the specificity of the land use and land use change results.

8. Monetisation

The monetisation factors for the footprint indicators land use and land use change for different types of biomes are presented in Table 4[19]. Values are expressed at 2020 price level.

- For **land use** the monetisation factors represent the opportunity cost of using the land, derived from the ecosystem services supplied when the land would be in its native state. The cost is based on the median annual value per hectare of ecosystem services of the six biomes. These values are based on a meta-analysis of the TEEB database (De Groot et al., 2012). These costs represent compensation costs, or the value of the foregone value of nature by using land for agriculture.
  To calculate the 2020 monetisation factors presented in this document, the median values, provided in the original source, are adjusted for inflation and the exchange rate (from US dollars to euros). For example, the monetisation factor for tropical forest is calculated as follows: the original median value is 2,355 Int.$/ha/year in 2007 (De Groot et al., 2012 p. 55). This value is then inflated to Int.$ in the year 2016 with inflation 1.17. Adjusting that value for the exchange rate (i.e., 0.73 EUR/Int.$ in 2016) and for inflation from 2016 to 2019 (i.e. 1.04), we get a value of 2,118 €/MSA.ha/year in 2020. Inflation and exchange rate data are retrieved from the World Bank (World Bank, n.d.)
- For **land use change**, restoration cost factors are used that express the typical cost of ecosystem restoration projects in different biomes based on an analysis of relevant case studies (TEEB, 2009). These costs include capital investment and maintenance of the restoration projects.

Table 4: Monetisation factors per biome. Sources: De Groot et al, 2012 (land use); TEEB, 2009 (land use change). Values are corrected for inflation and exchange rate.

Indicator per biome	Monetisation unit	Monetisation factor
Land use tropical forest	EUR_{2020}/MSA.ha.yr	2,118
Land use other forest	EUR_{2020}/MSA.ha.yr	1,014
Land use woodland/shrubland	EUR_{2020}/MSA.ha.yr	1,369
Land use grassland/savannah	EUR_{2020}/MSA.ha.yr	2,427
Land use inland wetland	EUR_{2020}/MSA.ha.yr	14,871
Land use coastal wetland	EUR_{2020}/MSA.ha.yr	10,939
Land use change tropical forest	EUR_{2020}/MSA.ha	3,595
Land use change other forest	EUR_{2020}/MSA.ha	2,491
Land use change woodland/shrubland	EUR_{2020}/MSA.ha	1,032
Land use change grassland/savannah	EUR_{2020}/MSA.ha	271
Land use change inland wetland	EUR_{2020}/MSA.ha	34,392
Land use change coastal wetland	EUR_{2020}/MSA.ha	3,001

For both impacts, region- and country-specific factors can be derived based on the original biome cover. This leads to different monetisation factors, since each region has a different mix of original biomes. In practice the

[19] Please refer to the Valuation Framework for True Price Assessment of Agri-food Products (Galgani et al, 2021b, p.11-12) for a detailed discussion on the concept of remediation and the cost types to carry out remediating activities - restoration cost, compensation cost, prevention cost and retribution cost.

value of ESS of a specific biome is different per location. However, for simplicity, the global median value provided in the meta-analysis of the TEEB database is used (De Groot et al, 2012).

The choice between compensation and restoration cost is based on the principles introduced by the **Valuation Framework for True Price Assessment of Agri-food Products** (Galgani et al., 2021b), according to which reversible impacts should be monetised using restoration cost and irreversible impacts should be monetised using a compensation cost approach. Land use is considered irreversible since the occupation of land has happened already, and so has the foregone value of ecosystem services for that period. Land use change is taken to be reversible considering that ecosystems are restorable.

9. Limitations and items for further research

9.1. Limitations

1. De Groot et al. (2012) evaluate ecosystem services and provide a very large range of values. The valuation seems very location dependent. A median value per biome is used now, but accuracy could be improved.
2. No distinction is made between reversible loss of species (local disappearance) and irreversible loss of species (extinction).
3. Dividing land use change cost by the number of years is very much ad hoc, but signals that the more recent the land use change is, the more important the costs generated by it. Standard LCA practice is to distribute the biodiversity cost of the last 20 years equally over these years.
4. It is common practice to differentiate between land use and land use change. However, Searchinger et al. (2018) argue that land use implies land conversion somewhere else through indirect land use.
5. The reference ecosystem used in this method is pristine nature. This reference choice is relevant to have global comparability and aligned with common practices in LCA. A downside of this choice is that in some geographical decision contexts, this reference scenario can be less relevant. For example, in The Netherlands, agricultural nature and landscape are included as goals in nature policies, so true pricing in relation to local goals may also take the implementation of policy goals as a reference scenario. In other contexts, other ecosystems, for example high biodiversity agricultural land, or a reference derived from planetary boundaries, could be used as a reference instead.
6. Land use is calculated relative to the natural situation in a biome where the activities happen. However, for example agricultural biodiversity has a value in itself. Therefore, it would be optimal to take this specifically into account.
7. The applied footprint indicators of land use and land use change come with a significant degree of uncertainty. For example, systems with higher levels of agrochemical usage might appear more favourable as land use (m^2 per kg of product) decreases, despite the detrimental effects on biodiversity (van der Werf et al., 2020). However, there is no consensus in the LCA community on how to account for biodiversity and all current methods have their limits.
8. MSA is an indicator that accounts for abundance of biodiversity that is part of the reference ecosystem that one wishes to conserve. However, the current approach takes as a reference value a pristine ecosystem, overlooking the biodiversity of anthropogenic origin, such as semi-natural grasslands. MSA is a good indicator when the aim is to preserve the originally occurring species of the ecosystem under study (Kok et al., 2020).
9. MSA as an indicator doesn't account for an increase in total abundance in case of multiple land uses. A mixture of naturally occurring forest and grassland would result in greater total diversity in reality but would not improve the MSA value compared with having only the habitat with better biodiversity value according to the indicator (Kok et al., 2020).
10. The global and Dutch biome share values included in this module are based on OECD data. OECDstat is based on land use rather than original biome. Biome maps can also be used to identify the biome share of a region. However, the resolution of the maps can be quite low, for example, the Netherlands is

classified as 100% forest. For this reason, OECD data are chosen over biome maps in this module. If maps with higher resolution are available in the future, they should replace the OECD classification.

9.2. Items for further development

1. Insight into whether to address and include ‘carbon benefits’ and ‘carbon efficiency’[20]. To illustrate, when a piece of land is converted to agriculture and is made more productive over time, the increase in productivity generates ‘carbon benefits’ - assuming that the extra food that is produced meets the same food demand, it reduces the quantity of land needed elsewhere, which can be used to grow forests or store more carbon. It could be investigated how the current method could be integrated with the Carbon Benefits Index (Searchinger et al., 2018).
2. Feeding society is also one of the basic rights. Therefore, there is a tension between the right on biodiversity and the right for food. This requires an investigation into, among others, what a sustainable level of land use is per product, for instance tied to the concept of planetary boundaries, and what criteria should be considered to determine this level. Also, a comparison of the true price of land use and the true value of produced food should be on the research agenda.
3. It would be interesting to discuss how the approach used to value land use and land use change, which is based on the Valuation Framework for True Price Assessment of Agri-food Products (Galgani et al., 2021b), relates to alternative approaches.
4. Selection of the reference scenario for measuring the external costs of land use. To illustrate, is the reference scenario ‘pristine’ nature, nature as it was 20 years before, or a regional average?
5. Revision and improvement of monetisation factors, including possible inclusion of additional damage cost in land use change as compensation for the time lag of ecosystem restoration.
6. Investigate most suitable data sources on monetisation factors.
7. Possible inclusion in the model of an adjustment for the degree of severity of land use change in the considered region or the presence of rare or threatened ecosystems and species.
8. Reconsideration of the use of restoration cost for land use change.

[20] ‘Carbon efficiency’ is defined by Searchinger et al. (2018) as the efficiency of each hectare in contributing toward the total capacity of global land to reduce atmospheric greenhouse gas levels while meeting the same food demand.

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Annex. Link with internationally accepted agreements on the rights of current and future generations

Relevant rights for Land use and Biodiversity are the right to a clean and healthy environment and the right to have access to the natural resources of the earth for current and future generations. International agreements and goals on sustainable development and biodiversity conservation state this:

- The Declaration of the United Nations Conference on the Human Environment: '*Man has a special responsibility to safeguard and wisely manage the heritage of wildlife and its habitat*' (UN, 1972).
- The Sustainable Development Goals: '*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*' (SDG 15, UN General Assembly, 2015).
- The UN Resolution 37/8 on Human Rights and the Environment: '[…] *loss of biodiversity and the decline in services provided by ecosystems may interfere with the enjoyment of a safe, clean, healthy and sustainable environment,* […] *environmental damage can have negative implications, both direct and indirect, for the effective enjoyment of all human rights*' (UN General Assembly, 2018).

Glossary

Biodiversity	Biodiversity is defined by the Convention on Biological Diversity (CBD) as '*the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems*' (UN, 1992). While this generic definition focuses on genetic diversity, a broader definition may furthermore define biodiversity according to *level* (e.g., world, species, ecosystems, families, etc.), *type* (i.e., alpha, beta, gamma) and *quality* (i.e., functional diversity, trait diversity, phylogenetic diversity, genetic diversity, anthrophiles vs. anthrophobes, rare vs. common, specialist vs. generalist, conservation value).
Biome	The largest unit of ecological classification that is convenient to recognise below the entire globe. Terrestrial biomes are typically based on dominant vegetation structure (e.g., forest grassland). Ecosystems within a biome function in a broadly similar way, although they may have very different species composition. For example, all forests share certain properties regarding nutrient cycling, disturbance, and biomass that are different from the properties of grasslands. Marine biomes are typically based on biogeochemical properties (Potschin et al., 2014).
Ecosystem services	Ecosystem services (ESS) are defined as '*the direct and indirect contributions of ecosystems to human wellbeing*' (Kumar, 2010). ESS are typically divided into four types (Ranganathan, 2008 as cited in Croezen et al., 2011): provisioning services, regulating services, cultural services and supporting services.
Land use	Land use, or land occupation, represents the decreased availability of land for purposes other than the current one, through land occupancy. Land use by agriculture displaces habitats and ecosystems and therefore leads to biodiversity loss and loss of ecosystem services (Milà i Canals et al., 2007; Alkemade et al., 2009; De Groot et al., 2012).
Land use change	Land use change, or land transformation, represents changes in land-cover that can affect ecosystem services and the climate system. This impact includes the number of natural ecosystems – i.e. (tropical) forest, woodland, grassland, and (inland and coastal) wetland - that are transformed in a certain period of time. Land use change reduces the size of habitats and ecosystems and therefore leads to biodiversity loss and loss of ecosystem services.
Mean Species Abundance (MSA)	The share of species abundance that is in the current type of land use compared to the pristine natural state.