Sustainability Transition Assessment and Research of Bio-based Products

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Selection of environmental indicators and impact categories for the life cycle assessment of bio-based products

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1.0	Final version
1.1	Revised version, clarifying that the biodiversity indicator relates to potentially affected species. Corrections are brought to table 15. A clarification on the choice of freshwater eutrophication is added.
1.2	Minor presentation bugs corrected

Abstract

This report describes the outcome from STAR-ProBio Task 2.3 which objective is *to select the life cycle impact assessment (LCIA), standardised environmental indicators and impact categories that are relevant for the environmental life cycle assessment (E-LCA) of bio-based products*. Indicators are made of impact categories (e.g.: eutrophication) coupled with impact assessment methodologies, or models (e.g.: how to quantify eutrophication on an impact scale). A two-step approach is applied: Step 1: Definition of a set of hierarchised criteria for impact categories selection, leading to a list of impact categories within the clusters (categories grouped by similarities regarding impact pathways) determined in the D2.1. Step 2: Definition of a set of hierarchised criteria for the methodologies selection, leading to a choice of a precise methodology to be used for each impact category.

The chosen assessment criteria are 1) ability be used for comparing bio-based materials among them and for comparing bio-based materials against conventional petrochemical products, 2) Scientific relevance, 3) Political and social priority, 4) Reliability and robustness, 5) Representativeness and 6) Stakeholder and market perception. A set of 11 indicators and associated models are recommended to be used for the environmental assessment of bio-based materials and be tested through the STAR-ProBio case studies. These indicators are: Acidification; Particulate matter; Global warming potential BIO; Potentially affected biodiversity; Terrestrial eutrophication; Freshwater eutrophication; Human toxicity, cancer; Land use, soil quality index; Soil erosion; Fossil resources depletion; Water scarcity.

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Abbreviations

GWP	Global warming potential
ILCD	International Reference Life Cycle Data System
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
LU	Land use
LUC	Land use change
PAS	Potentially affected species
PEF	Product environmental footprint
PEFCR	Product environmental footprint category rules
RUSLE	Revised Universal Soil Loss Equation (erosion model)
SDGs	Sustainable development goals (United Nations)
UNCCD	United Nations Convention to combat desertification

1 Introduction and background

The STAR-ProBio project aims to promote a more efficient and harmonized policy regulation framework for the market-pull of bio-based products, through the development of a dedicated sustainability scheme. An integral part of STAR-ProBio is the adoption of life-cycle methodologies to measure environmental, techno-economic and social impacts of bio-based products. The aim of STAR-ProBio is to cover gaps in the existing framework for sustainability assessment of bio-based products, and improve consumer acceptance for bio-based products by identifying the critical sustainability issues in their value chains.

The aim of Work Package (WP) 2 is to develop an LCA approach for strategic and policy decision support that is compliant with the European Commission's ILCD and PEF frameworks; and to perform upstream LCA for the case studies identified in WP1. This report is the deliverable (D2.2) of task 2.3, which objective is *to select the life cycle impact assessment (LCIA), standardised environmental indicators and impact categories that are relevant for the environmental life cycle assessment (E-LCA) of bio-based products*.

This selection uses as a basis the deliverable D2.1: *Report summarizing the findings of the literature review on environmental indicators related to bio-based products*[1]. It is also built on the PEFCR Guidance 6.3[2] and the UN Sustainable Development Goals (SDGs)[3].

The present report is deliverable D2.2 "Selection of environmental indicators and impact categories for the life cycle assessment of bio-based products" with Quantis as lead beneficiary Quantis and due in Month 15 (July 2018).

[1] Deliverable D2.1. STAR-ProBio. 2017.
[2] Product Environmental Footprint Category Rules Guidance - Version 6.3. European Commission. 2017.
[3] Transforming our world: The 2030 agenda for sustainable development. United Nations. 2015.

2 Objective and approach

The objective of the task 2.3 is to select a set of strategic environmental sustainability indicators adapted to bio-based products and enabling the comparison with conventional petrochemical products.

Indicators are made of *impact categories* (e.g.: eutrophication) coupled with *impact assessment methodologies*, or models (e.g.: how to quantify eutrophication on an impact scale).

According to the task description, indicators must:

- Be representative of the production systems
- Enable comparison with petrochemical products
- Be based on the findings from Task 2.1 (*Literature review of environmental indicators considered in related bio-based products studies*)
- Be consistent with the potential environmental issues

Moreover, the selection must consider all kind of methodologies / models:

- Midpoint or endpoint categories
- The ILCD Handbook[4] and the Cumulative Energy Demand (CED)
- The PEF methodology
- Special attention to land use in collaboration with WP7.

Logically, to reach this objective, a two-step approach (Figure 1) is applied:

Step 1: Definition of a set of hierarchised criteria for impact categories selection, leading to a list of impact categories within the *clusters* (categories grouped by similarities regarding impact pathways) determined in the D2.1.

Step 2: Definition of a set of hierarchised criteria for the methodologies selection, leading to a choice of a precise methodology to be used for each impact category.

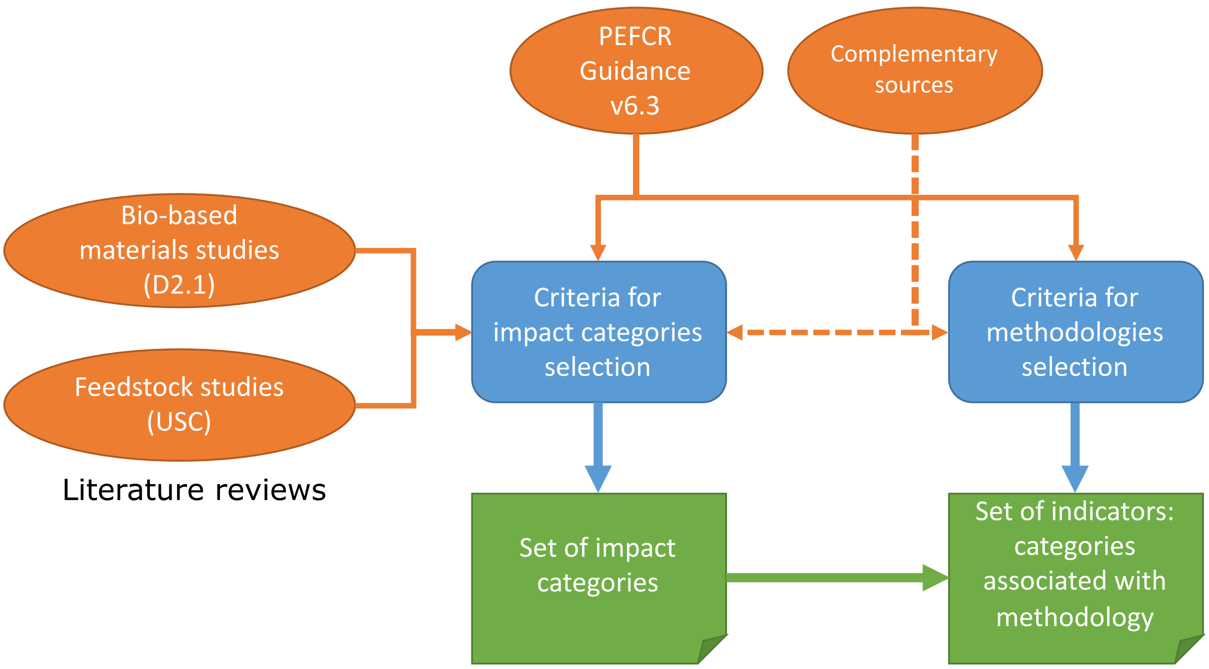

Figure 1: Schematic of the two-step approach and the inputs used in this study.

[4] *ILCD Handbook - Recommendations for Life Cycle Impact Assessment in the European Context*. JRC-IES. 2011.

The two sets of criteria and their resulting choices have been presented to all partners during the April 2018 plenary session in Lausanne and further discussed via conference call (May 2018) to reach consensus.

The complementary sources mentioned in Figure 1 are the SDGs and partners' feedback.

3 Selection of impact categories

3.1 Criteria for the selection of impact categories

A set of criteria has been proposed based on the goals of the STAR-ProBio project and the constraints defined by the task description. These criteria are the following (in decreasing importance):

1) The indicator shall be used for **benchmarking and environmental labelling** to:

- compare bio-based materials among them and
- compare bio-based materials against conventional petrochemical products.

2a) **Scientific relevance**: the indicator captures an acknowledged key issue for bio-based materials, according to the scientific community, experts at large.

2b) **Political / social priority**: the indicator captures an issue on the political agenda (debated at European level, addressed by the UN as an SDG, or heavily advocated by NGOs)

3) **Reliability / robustness**: the indicator can be calculated based on available data and recognized LCIA methods, preferably robust for benchmarking, if not in absolute value.

4) **Representativeness**: the indicator takes part of the complete array of relevant environmental issues ("clusters"), avoiding overlapping.

5) **Stakeholder / market perception**: the indicator meets the expectations of corporate users and final customers, it conveys meaningful, understandable information; it is not misleading.

6) Most used in literature: this criterion refers to D2.1 and is *de facto* considered by points 2a and 3, but is not relevant per se.

These indicators cover the constraints defined by the task description as described in Table 1. The numbering reflects the importance, therefore 2a and 2b are considered of the same importance.

Table 1: Coverage of the task constraints by the chosen criteria for the selection of impact categories

CONSTRAINT: THE INDICATORS MUST…	ADDRESSED BY CRITERIA…
Be representative of the production systems	1 and 2a
Enable comparison with petrochemical products	1 and 5
Be based on the findings from Task 2.1	6, hence 2a and 3
Be consistent with the potential environmental issues	2a, 2b and 4
Consider Midpoint or endpoint categories	3 and 5
Consider the ILCD Handbook and the Cumulative Energy Demand (CED)	2a and 2b
Consider the PEF methodology	2a and 2b
Pay special attention to land use in collaboration with WP7	2a

The impact categories included in the PEFCR guidance v.6.3 are the result of a recent scientific and political consensus made at the European level. As such, it is considered to be a good basis for the selection of the impact categories, which justifies considering the PEF methodology as a reference.

3.2 Criteria discussion

The criteria proposed are discussed and commented in Table 2 below. They are ranked in order of relevance for the purpose of STAR-ProBio.

Table 2: Discussion of the chosen criteria for the selection of impact categories

RANK	CRITERIA	COMMENT
1	**Benchmarking and environmental labelling** to assess and compare bio-based materials among them and against conventional petrochemical products	**Benchmarking and environmental labelling** represent one of the most relevant objectives stated by the PEFCR Guidance and are STAR-ProBio core objectives too. We strongly advise to select indicators that can be used as a benchmark in order to evaluate different bio-based products among them and to compare their performance against their petrochemical counterparts (if existing). Some indicators, such as *land use* and *water use*, might perform better for fossil derived products.
2a	**Scientific relevance**: indicator captures an acknowledged key issue for bio-based materials, according to the scientific community, experts at large	Scientific relevance refers to key issues acknowledged by the scientific community and experts as key aspect for production, processing, use and EoL. The selection should take into consideration a set of relevant environmental issues designed for bio-based products. For instance, and to the best of our knowledge, we expect that *land use*, while being largely neglected in literature (see Deliverable 2.1), should be adopted in first place. We should consider that Star-ProBio selection of indicators can shape the category rules of bio-based products.
2b	**Political / social priority**: indicator captures an issue on the political agenda (debated at European level, addressed by the UN as an SDG, or heavily advocated by NGOs)	We intend as 'political priority' the link to pending legislation, directives and political discussion (e.g. ammonia ceiling limits, iLUC, etc.) or the link to topics debated by NGOs and the civil society, such as bees decline, GMOs or biodiversity loss. In this sense, the Sustainable Development Goals may represent a reference. Concerning *land use*, we may also consider *Land Degradation Neutrality* (UNCCD) as a reference principle, also related to SDG 15.3.1.
3	**Reliability / robustness**: indicator can be calculated based on available data and recognized LCIA methods, preferably robust for benchmarking, if not in absolute value	Being reliable should be top-of-list or a prerequisite. However, benchmarking and environmental labelling are more important than reliability for our goal. We need a *relative* robustness and not an *absolute* one. In this way, when using a specific indicator, a robust ranking will be obtained, in order to accomplish the function of benchmarking and labelling.
4	**Representativeness**: indicator takes part of the complete array of relevant environmental issues, avoiding overlapping	The selection should consider a set of relevant environmental issues designed for bio-based products. *Land use*, *biodiversity, water use, climate change, eutrophication* and *acidification* should be considered among others. Other indicators such as *ionising radiation* may not be that relevant.
5	**Stakeholder / market perception**: indicator meets the expectations of corporate users and final customers, it conveys meaningful**,** understandable information, it is not misleading	We intend as 'stakeholder perception' the way the information provided by the indicators is received by stakeholders. Therefore, it is connected to communication aspects (e.g. human toxicity can be perceived as more urgent aspect by stakeholders than eutrophication). In this sense, endpoint indicators may be preferred by stakeholders because they clearly connect cause-effect

		relationships. However, they are more difficult to be computed and include higher uncertainty. As the main objective are benchmarking, relevance and political priority, following stakeholder's perception might be contradictory. We advise to consider this criterion moderately and to focus on the importance of remaining meaningful and understandable.
6	Most used in literature	Provided that our selection of indicators should be accepted by the scientific community, the criterion of replicating past choices, in this case, does not make too much sense. For instance, following "most used in literature" criterion would imply not including LU impact category, but choosing other commonly used indicators, some of which can be relevant. Therefore, this criterion is *de facto* considered by points 2a and 3, but is not relevant *per se*.

3.3 Impact categories rating and final choice

The criteria list has been applied to all impact categories identified in the D2.1 using a qualitative method (presented in annexe 7.1) complemented by discussion and expert choice. The following Table 3 shows the list of scrutinized impact categories, grouped by clusters, and their rating obtained by the qualitative method, followed by the final decision of inclusion.

Table 3:Impact categories evaluation summary for inclusion as relevant environmental indicators

D2.1 CLUSTER	SCRUTINIZED IMPACT CATEGORIES	PEFCR GUIDANCE 6.3	RATING	DECISION
Ecosystem quality (biodiv.)	Land occupation * species richness loss		95%	Approved
Ecosystem quality (biodiv.)	Ecosystem services loss		73%	
Ecosystem quality (biodiv.)	Biodiversity endpoint		84%	
Land use	Soil quality index	Yes	86%	Approved
Land use	• Biotic production	Yes	71%	
Land use	• Erosion resistance	Yes	71%	
Land use	• Mechanical filtration	Yes	71%	
Land use	• Groundwater replenishment	Yes	71%	
Land use	Fertile land occupation		84%	Option – Not selected
Land use	Soil carbon deficit		77%	
Land use	Soil erosion / degradation (UNCCD)		78%	Option - Approved
Water availability	Water use: User deprivation potential (deprivation-weighted water consumption)	Yes	100%	Approved
Air quality	Particulate matter	Yes	84%	Approved
Air quality	Photochemical ozone formation, human health	Yes	57%	
Climate change	Radiative forcing as Global Warming Potential (GWP_{100})	Yes	99%	

Climate change	$GWP_{100}+GWP_{bio}$		100%	Approved
Eutrophication	Eutrophication, terrestrial	Yes	61%	Approved
Eutrophication	Eutrophication, freshwater (P)	Yes	61%	Approved
Eutrophication	Eutrophication, marine (N)	Yes	54%	
Mineral and fossil resources	Resource use, minerals and metals: Abiotic resource depletion (ADP ultimate reserves)	Yes	52%	
Mineral and fossil resources	Resources depletion endpoint		76%	
Mineral and fossil resources	Phosphate use		67%	
Mineral and fossil resources	Cumulative energy demand		85%	
Mineral and fossil resources	Resource use, fossils: Abiotic resource depletion – fossil fuels (ADP-fossil)	Yes	84%	Approved
Mineral and fossil resources	Organic carbon content (TOC)		58%	
Wastes	Marine plastic pollution risk / Plastic leakage footprint		73%	Approved
Wastes	Biodegradability		66%	
Wastes	Recyclability (and other EoL options)		68%	Pending (1)
Acidification	Acidification	Yes	75%	Approved
Ecotox	Ecotoxicity, freshwater (USEtox)	Yes	58%	Excluded (2)
Human health	Human toxicity, cancer (USEtox)	Yes	52%	Option - Approved
Human health	Human toxicity, non-cancer (USEtox)	Yes	46%	
Human health	Human health endpoint		54%	
Ionising radiation	Ionising radiation, human health	Yes	48%	Excluded (2)
Ozone layer	Ozone depletion	Yes	63%	Excluded (2)

(1) While plastics pollution is important in the public debate, there is a lack of robust methodology for assessing its effects on the environment. However, progress is being rapidly made and there is a possibility to have a pilot methodology available before the end of the STAR-ProBio project. For this reason the decision is still pending.
(2) Three clusters (ecotoxicity, ionising radiation and ozone layer depletion), are left unrepresented.

The decisions have been taken by considering suggestions brought by Work Package partners and complementary sources:

- USC made a literature review of feedstock studies and suggested some indicators after each of the criterion proposed. This alternative approach ("which indicator would better capture this aspect?") had the advantage of opening the discussion to unconventional indicators.
- UniBo assessed the UN Sustainable Development Goals to identify which ones would suggest an indicator that was not in the list. The output of this assessment is presented in section 3.3.1.
- UoY identified a short-list of indicators to be taken into account.
- The PEF has a selection procedure of the most relevant impact categories in each product category, using a defined weighting scheme. The following product categories have been chosen to represent bio-based and fossil-based products: Feed, Beer, Packed water, Paints and Thermal insulation. The impact categories that were considered relevant by the PEF procedure have been considered in priority in our work. More details are provided in section 3.3.2.

3.3.1 Sustainable Development Goals review

The SDGs indicators that are able to reflect scientific relevance and policy priority are listed below. This includes the indicators for which the cause-effect relationship between LCIA indicator and a state/pressure SDG indicator can be evident.

List of selected SDGs especially concerning WP2, WP3, WP4, WP7 in Star-ProBio:

- 6.3.2 Proportion of bodies of water with good ambient water quality
- 6.4.1 Change in water-use efficiency over time
- 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater 6.6.1 Change in the extent of water-related ecosystems over time
- resources
- 9.4.1 CO2 emission per unit of value added
- 11.3.1 Ratio of land consumption rate to population growth rate
- 12.3.1 Global food loss index (by-products /coproducts recovery)
- 12.4.2 Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment
- 12.5.1 National recycling rate, tons of material recycled
- 14.1.1 Index of coastal eutrophication and floating plastic debris density
- 14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations
- 15.1.1 Forest area as a proportion of total land area
- 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type
- 15.3.1 Proportion of land that is degraded over total land area
- 15.5.1 Red List Index

Table 4: Assessment of the relationship between the UN Sustainable Development Goals and some indicators of the PEFCR Guidance 6.3

SELECTED SDG / PEFCR INDICATOR	6.3.2	6.4.1	6.4.2	6.6.1	9.4.1	11.3.1	12.3.1	12.4.2	12.5.1	14.1.1	14.3.1	15.1.1	15.1.2	15.3.1	15.5.1
Soil quality - Erosion resistance	°		°	X		X	°					X	X	X	°
Soil quality - Groundwater replenishment	X		X	X		X						X	°	X	°
Soil quality - Biotic production	°		°	°		X	°					X	X	X	X
Water use - User deprivation potential	X	X	X	°											°
Climate change - GWP_{100}		°			X		°	°	°	°	X	X	°	°	X
Acidification - Accumulation exceedance							°		°	°	X				°
Particulate matter - Impact on human health								°	°	°					
Aquatic AND marine eutrophication	°	°	°	°			°		°	X					X
Abiotic resource depletion, fossil fuels							X	°	X	°					
Human toxicity, cancer -								X	°	°					

(X) Pointers of direct relationship: can be found in most of the cases – evidence in literature
(°) Suspected relationship: depending on certain conditions (cause-effect relationship between a LCIA indicator (stressor) and pressure/state indicators of the environment not yet demonstrated)

3.3.2 PEF procedure to identify the most relevant impact categories

The PEFCR Guidance (EC-JRC 2017) provides a procedure to identify the most relevant impact categories to be systematically assessed for PEF studies within a specific industry sector: "*The identification of the most relevant impact categories is based on the normalised and weighted results (for the representative products of each product category). The most relevant impact categories shall be identified as all impact categories that cumulatively contribute to at least 80% of the total environmental impact, excluding toxicity-related impact categories*"

The Life Cycle Impact Assessment (LCIA) method promoted under the PEF framework provides normalisation (impact reference per EU inhabitant, for each impact category) and weighting factors. The weighting scheme, a result of a scientific and political consensus, gives proportionally more importance to some impact categories such as *climate change* or *water use* compared to others such as *eutrophication* (Table 5).

Table 5: PEF LCIA weighting scheme

IMPACT CATEGORIES WITHOUT TOX CATEGORIES	AGGREGATED WEIGHTING SET (50:50)	ROBUSTNESS FACTORS (SCALE 1-0.1)	CALCULATION	FINAL WEIGHTING FACTORS
	A	B	C=A*B	C scaled to 100
Climate change	15.75	0.87	13.65	22.19
Ozone depletion	6.92	0.60	4.15	6.75
Particulate matter	6.77	0.87	5.87	9.54
Ionizing radiation, human health	7.07	0.47	3.3	5.37
Photochemical ozone formation, human health	5.88	0.53	3.14	5.1
Acidification	6.13	0.67	4.08	6.64
Eutrophication, terrestrial	3.61	0.67	2.4	3.91
Eutrophication, freshwater	3.88	0.47	1.81	2.95
Eutrophication, marine	3.59	0.53	1.92	3.12
Land use	11.1	0.47	5.18	8.42
Water use	11.89	0.47	5.55	9.03
Resource use, minerals and metals	8.28	0.60	4.97	8.08
Resource use, fossils	9.14	0.60	5.48	8.92

Quantis scrutinised how this approach has been applied in five different sectorial PEFCRs that could relate to bio-based materials (Table 6):

- **Feed for food-producing animals**: many feed ingredients are also used as feedstocks for bio-based materials (e.g. maize starch, sugarcane)
- **Beer:** some ingredients involved in beer production are also used as feedstocks for bio-based materials
- **Packed water:** bottled water is often packed in PET, and could be packed in bio-based plastics
- **Paints:** several paints use bio-based materials in their formulation
- **Thermal insulation**: several insulation materials can be made of bio-based feedstocks

Table 6: Most relevant impact categories selected in key PEFCRs related to bio-based materials

MOST RELEVANT IMPACT CATEGORIES	FEED	BEER	PACKED WATER	PAINTS	THERMAL INSULATION
Climate change	✓	✓	✓	✓	✓
Ozone depletion					
Particulate matter	✓	✓	✓	✓	✓
Ionising radiation, human health					
Photochemical ozone formation, human health			✓	✓	
Human toxicity, non-cancer					
Human toxicity, cancer					
Acidification	✓	✓	✓	✓	
Eutrophication, terrestrial	✓				
Eutrophication, freshwater					
Eutrophication, marine					
Freshwater ecotoxicity					
Land use	✓				✓
Water use (water scarcity)	✓	✓			
Resource use, minerals and metals		✓	✓		✓
Resource use, fossils		✓	✓	✓	✓

3.4 Discussion of the impact categories choice

The chosen impact categories cover all the clusters identified in deliverable D2.1 except ecotoxicity[5], ionising radiation and ozone layer depletion, which have been considered of lower priority in the context of bio-based material environmental assessment and comparison with their fossil counterparts. The cluster related to waste is however still pending: it might be included later if a methodology is developed to assess the topic of marine plastic pollution risk.

Table 7 : Impact categories chosen and discussion of this choice

D2.1 CLUSTER	COMMENT
Acidification	Acidification is related to the emission of acids into the environment, leading to a decrease of the pH in water bodies or soil, which is in general harmful to biotopes. It is in general related to industrial activities which can be involved in the production of electricity or fertilisers. It is therefore relevant for both bio-based and fossil materials. This indicator is included in the PEFCR Guidance 6.3.
Air quality	Particulate matter is the indicator selected for this cluster. It is mostly related to the combustion of fuels but is also related to ammonia emissions from agricultural activities. It is therefore relevant for both bio-based and fossil materials. This indicator is included in the PEFCR Guidance 6.3

[5] The adverse effects of pesticides in the environment are not considered irrelevant, but there are weaknesses that cannot be remediated in the short term. See comments in the table for more details.

D2.1 CLUSTER	COMMENT
Climate change	While climate change is almost always used as an environmental indicator, the question was how to account for the biogenic carbon embedded in bio-based materials. Biogenic carbon is commonly considered as carbon neutral, but in certain cases with slow regrowth of the biomass (such as ligno-cellulose, which is used in widespread bio-based materials) there is a delay that affects the climate neutrality of biogenic carbon. Without entering the question of the methodology at this stage, it has been decided that this indicator should be able to differentiate carbon-neutrality and climate-neutrality. This is why the chosen indicator is called here GWP_{100}+GWP_{bio}. This indicator is relevant for both bio-based and fossil materials. The GWP_{100} is included in the PEFCR Guidance 6.3, but the GWP_{bio} part is **NOT** and is recommended as an addition.
Ecosystem quality (biodiv.)	Land occupation * species richness loss is the indicator selected for this cluster. It is a simple indicator made of inventory data (land occupation) and an empirical weighting value representing the potential species richness of the occupied land (if the land was not occupied). It is mostly related agricultural practices, which have the largest land occupation, therefore is relevant to bio-based materials. This indicator is **NOT** in the PEFCR Guidance.
Eutrophication	Eutrophication, terrestrial is related to the emission of nutrients into the environment (in the case of terrestrial eutrophication: nitrogen). Overabundance of this nutrient leads to decrease of oxygen in soils, which is in general harmful to biotopes. It is in general related to agricultural activities. It is therefore relevant to bio-based materials. This indicator is included in the PEFCR Guidance 6.3.
Eutrophication	Eutrophication, freshwater (P) is related to the emission of nutrients into the environment (in the case of freshwater: phosphorus). Overabundance of this nutrient leads to decrease of oxygen in water bodies, which is in general harmful to biotopes. It is in general related to agricultural activities. It is therefore relevant to bio-based materials. This indicator is included in the PEFCR Guidance 6.3.
Human health	Human toxicity, cancer is the indicator selected for this cluster. It is related to the emissions of chemicals reaching the human body via air, food or skin contact. It is in general related to industrial activities and is expected to be principally relevant for fossil materials. This indicator is included in the PEFCR Guidance 6.3.
Land use	Soil quality index is the first indicator selected for this cluster. It relates to the ability of the soil to sustain four essential function: biotic production, erosion resistance, mechanical filtration and groundwater replenishment. It is therefore relevant to bio-based materials. This indicator is included in the PEFCR Guidance 6.3.
Land use	Soil erosion is the second indicator selected for this cluster. It differs from the first one in the sense that it does not measure the state of the soil but the trend of the state, by indicating the soil loss by erosion. It is therefore relevant to bio-based materials. This indicator is **NOT** in the PEFCR Guidance
Mineral and fossil resources	Resource use, fossils is the indicator selected for this cluster. It relates to the use of non-renewable resources, targeting especially fossil fuels, hence it is mostly relevant to fossil-based materials. This indicator is included in the PEFCR Guidance 6.3.

D2.1 CLUSTER	COMMENT
Water availability	Water use: User deprivation potential (deprivation-weighted water consumption), also called Water scarcity, is the indicator selected for this cluster. It measures the deprivation of water by considering water availability versus water requirements in a given area. It is therefore mostly relevant to bio-based materials, especially when irrigation is involved. This indicator is included in the PEFCR Guidance 6.3.
Wastes	Marine plastic pollution risk / Plastic leakage footprint: this indicator would be the representative for this cluster, if it becomes available. It relates to the risk of contributing to ocean pollution, in particular at the end-of-life of the product, but also on the whole supply chain. Because bio-based products are generally more easily biodegradable than fossil-based ones and also are based on mostly biodegradable raw materials, this indicator might be relevant to address the differences between bio-based and fossil materials. This indicator is **NOT** in the PEFCR Guidance and is under development.
Ecotoxicity	Not used - While this cluster could cover debated aspects such as bees dying and more generally the problems related to pesticides on biodiversity, it is not retained for this project for the following reasons: • Many characterization factors related to pesticides are currently not available, hence the capture of environmental issues related to their use could be inconsistent, depending on which pesticides are used. This would make comparisons irrelevant, which fails the first criterion (benchmarking). • Existing methodologies are mostly oriented on ecotoxicity in water, which typically excludes the effects on pollinator insects. The dying of bee colonies cannot be captured by known indicators and must be addressed separately. • The scientific community currently lacks a consensus on how applied pesticides should be modelled with respect to the emission fractions ending in different natural compartments (air, water and soil). • Pesticides toxicity are also covered, when known and to some extent, by human health indicators.
Ionising radiation	Not used – This cluster is mostly related to the use of nuclear power, which is not specifically relevant to either bio-based or fossil materials.
Ozone layer	Not used – This cluster is mostly related to industrial processes and refrigeration, which are not specifically relevant to either bio-based or fossil materials.

4 Selection of assessment methodologies / models

4.1 Criteria for the selection of assessment methodologies

A set of criteria has been proposed based on the goals of the STAR-ProBio project and the constraints defined by the task description. These criteria are the following (in decreasing importance):

1) Scientific acceptance

2a) Overlap/double-counting among indicators

2b) Operability

2c) Consistency among indicators

3a) Compliance in end-point assessment

3b) Precision and accuracy

Again, the PEFCR Guidance[6] v.6.3 is used as a primary reference, because the impact categories and the methodologies included in this guidance are the result of a scientific and political consensus. This work made at the European level need not to be repeated unnecessarily.

The main drawback relies in the fact that indicators of this guidance have been taken from various impact assessment methods, so that they may not be always consistent one with each other. This eliminates almost certainly the possibility to work at endpoint level, hence the **criterion 3a cannot be met**. However, this opens the door to the inclusion of other indicators as proposed in the former section, which is an added-value the goal of the project.

Table 8: Coverage of the task constraints by the chosen criteria for the selection of assessment methodologies

CONSTRAINT: THE INDICATORS MUST...	ADDRESSED BY CRITERIA...
Consider Midpoint or endpoint categories	1, 2b, 2c (and 3a) It is recognized that endpoint categories cannot be used, so criterion 3a is *de facto* purposeless
Consider the ILCD Handbook and the Cumulative Energy Demand (CED)	1
Consider the PEF methodology	1, 2b and 2c
Pay special attention to land use in collaboration with WP7	1

[6] Product Environmental Footprint Category Rules Guidance - Version 6.3. European Commission. 2017.

4.2 Criteria discussion

The criteria proposed are discussed and commented in Table 9 below. They are ranked in order of relevance for the purpose of STAR-ProBio.

Table 9: Discussion of the chosen criteria for the selection of assessment methodologies

RANK	CRITERIA	COMMENT
1	Scientific acceptance	Fundamental: the methodology must be scientifically accepted. This is why the PEFCR Guidance 6.3 is used whenever possible. For other indicators, published references should be used.
2a	Avoidance of overlap/double-counting among indicators	Very important, otherwise all the assessment would not be reliable and it would overestimate the overall impact. This is fine-tuned at methodology level but was already addressed by the selection of impact categories. However, small double-counting among some indicators is somehow inevitable.
2b	Operability	Very important, otherwise LCIA would be hardly applicable (specifically for the STAR-ProBio project, we would face difficulties when assessing case studies). Indicators must be operable and take into consideration: • Data availability (inventories) and quality • Require a reasonable effort as for collection
2c	Consistency among indicators	Very important
3a	Compliance in end-point assessment	Very important if end-point indicators are included. However, we do not consider end-point indicators as priorities. In this sense, PEFCR approach is adopting a clear midpoint approach.
3b	Precision and accuracy	Important, but not that much. Our aim is to provide schemes for certification of bio-based products. Recommendations need to be broad enough to include all possible scenarios related to bio-based products, and this might limit LCA's precision and accuracy.

4.3 Synthesis of the selected indicators and models

There is a vast diversity of methodologies available in the LCA scientific domain. It is not relevant to describe them all and to detail how each assessment criteria applies to them. The selection has been driven by the application of the 1st criterion of scientific acceptance, hence the choice of a set of indicators selected and recognised by the European Commission, wherever possible: the PEFCR Guidance 6.3, which also complies to most other criteria.

However, for certain chosen impact categories, a different or complementary methodology was needed. Table 10 shows the selected and proposed methodologies to be applied in the STAR-ProBio project. Each indicator is described in more details in section 4.4.

Table 10: Summary of the selected assessment methodologies

IMPACT CATEGORY	UNIT	METHOD	MODEL / COMMENT
Acidification	mol H^+_{eq}	PEFCR Guidance 6.3[7] EF-Acidification terrestrial and freshwater	Accumulated Exceedance[8, 9]
Particulate matter	disease incidence	PEFCR Guidance 6.3 EF-Respiratory inorganics	UNEP recommended model[10]
Global warming potential BIO	kg $CO_{2\text{-eq}}$	IPCC (2013) + Guest (2013)	IPCC GWP_{100} model[11] complemented with GWP_{bio} model[12] for biogenic carbon
Potentially affected biodiversity	m^2.year*PAS (Potentially affected species)	Inventory data + recognized weighting factor for biodiversity	Inventory data weighted by species richness as reported by the 2005 Millennium Ecosystem Assessment[13]. In line with LCIA recommendation.[14]
Terrestrial eutrophication	mol N-eq	PEFCR Guidance 6.3 EF-Eutrophication terrestrial	Accumulated Exceedance[8, 9]
Freshwater eutrophication	kg $P_{\text{-eq}}$	PEFCR Guidance 6.3 EF-Eutrophication freshwater	EUTREND[15] model as implemented in ReCiPe 2008
Human toxicity, cancer	CTUh	PEFCR Guidance 6.3 EF-Cancer human health effects	USEtox[16] model
Land use, soil quality index	Dimensionless (Pt)	PEFCR Guidance 6.3 EF-Land Use	LANCA indicators[17, 18]
Soil erosion	kg soil loss	RUSLE 2 + Borrelli (2017)	Revised Universal Soil Loss Equation[19] using C factor specific to crops[20]
Fossil resources depletion	MJ	PEFCR Guidance 6.3 EF-Resource use, energy carriers	Abiotic resource depletion – fossil fuels (ADP-fossil): CML 2002[21, 22]
Water scarcity	m^3 $_{\text{water deprived-eq}}$	PEFCR Guidance 6.3 EF-Water scarcity	Available WAter REmaining (AWARE)[23] : User deprivation potential (deprivation-weighted water consumption)

[7] Product Environmental Footprint Category Rules Guidance - Version 6.3. European Commission. 2017.
[8] Country-Dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator. Seppälä et al. 2006.
[9] The Role of Atmospheric Dispersion Models and Ecosystem Sensitivity in the Determination of Characterisation Factors for Acidifying and Eutrophying Emissions in LCIA. Posch et al. 2008.
[10] Health impacts of fine particulate matter. Fantke et al. 2016.
[11] Anthropogenic and Natural Radiative Forcing. IPCC. 2013.
[12] Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life. Guest et al. 2013.
[13] Ecosystems and Human Well-being: Biodiversity Synthesis. Millennium Ecosystem Assessment. 2005
[14] Ecosystem Quality in LCIA: Status Quo, Harmonization, and Suggestions for the Way Forward. Woods et al. 2017.
[15] Aquatic Eutrophication. Struijs et al. 2009
[16] USEtox - The UNEPSETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity. Rosenbaum et al. 2008
[17] LANCA Land Use Indicator Value Calculation in Life Cycle Assessment – Method Report. Beck et al. 2010.
[18] LANCA ® Characterization Factors for Life Cycle Impact Assessment. Bos et al. 2016.
[19] Revised Universal Soil Loss Equation Version 2 (RUSLE 2). USDA-Agricultural Research Service. 2013.
[20] An Assessment of the Global Impact of 21st Century Land Use Change on Soil Erosion. Borrelli et al. 2017.
[21] Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards. Guinée et al. 2002.
[22] Abiotic Resource Depletion in LCA. Van Oers et al. 2002.
[23] The WULCA Consensus Characterization Model for Water Scarcity Footprints: Assessing Impacts of Water Consumption Based on Available Water Remaining (AWARE). Boulay et al. 2017.

In addition to be above, two more indicators were explored but left aside:

- *Fertile land occupation* (m^2.year). This indicator can be computed at inventory level (i.e. no impact assessment) but has been abandoned for this task T2.3, as it can be provided through task 3.2.
- *Marine plastic pollution risk* is identified as a key indicator to be monitored in the context of bio-based materials and their comparison to fossil-based alternatives. However, no quantitative method currently exists. It is recommended to follow closely ongoing methodological developments, which could be available for use as soon as mid-2019.

4.4 Description of the selected methodologies

4.4.1 Acidification

Indicator name: **Acidification**

Identified in D2.1 cluster: Acidification

Model: Accumulated Exceedance model[24, 25]

Unit: mol H^+_{eq}

This indicator, mandatory under the PEFCR Guidance framework[26], addresses impacts due to acidifying substances in the environment. Emissions of nitrogen oxides (NO_x), ammonia (NH_3) and sulphur oxides (SO_x) lead to releases of hydrogen ions (H^+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification. The impact metric is expressed in mole H^+_{eq} (hydrogen ions to soil and water equivalents).

4.4.2 Particulate matter

Indicator name: **Particulate matter**

Identified in D2.1 cluster: Air quality

Model: PM method recommended by UNEP[27]

Unit: disease incidence

This indicator, mandatory under the PEFCR Guidance framework, measures the potential impact on human health (such as acute and chronic respiratory diseases and asthma attacks) caused by emissions of inorganic particles. It is sometimes called respiratory effects, respiratory inorganics or winter smog. It takes into account the adverse health effects on human health caused by emissions of Particulate Matter (PM) and its precursors (NO_X, SO_X, NH_3) into the air. The impact metric is expressed in deaths per kg $PM_{2.5}$-emitted ($PM_{2.5}$ covers all particles < 2.5 µm).

4.4.3 Global warming potential BIO

Indicator name: **Global warming potential BIO**

[24] Country-Dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator. Seppälä et al. 2006.
[25] The Role of Atmospheric Dispersion Models and Ecosystem Sensitivity in the Determination of Characterisation Factors for Acidifying and Eutrophying Emissions in LCIA. Posch et al. 2008.
[26] Product Environmental Footprint Category Rules Guidance - Version 6.3. European Commission. 2017.
[27] Health impacts of fine particulate matter. Fantke et al. 2016.

Identified in D2.1 cluster: Climate change

Model: Bern model – Global Warming potential over a 100-year time horizon (GWP_{100})[28] complemented with the GWP_{bio} model[29] for biogenic carbon.

Unit: kg CO_{2-eq}

This indicator accounts for radiative forcing caused by greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4) or nitrous oxide (N_2O). The capacity of a greenhouse gas to influence radiative forcing is expressed in terms of a reference substance (carbon dioxide equivalents) and considers a time horizon of 100 years following the guidelines from the Intergovernmental Panel on Climate Change[30]. Radiative forcing is the mechanism responsible for global warming.

According to the IPCC[31], new metric concepts such as the proposed method for GWP_{bio}[32] are recognized as being worth testing for bio-based products. This is therefore what is recommended for STAR-ProBio.

The GWP_{bio} concept has been introduced by Cherubini[33] to take into account the delay between the emission of CO_2 when incinerating biomass and the recapture of CO_2 by biomass regrowth. This delay makes carbon neutrality not climate neutral. Instead, there is a climate impact that depends on the delay until recapture. Guest completes this calculation by introducing a storage period, to take into account the fact that biomass is not always instantly incinerated at the moment it is harvested. Table 11 below presents the GWP_{bio} factors to be used in the STAR-ProBio case studies.

Table 11: GWP_{bio} factors as proposed by Guest et al. for a 100-year time horizon

Table 1 Biogenic global warming potential (GWP_{bio}) factor values tabularized for several rotation/storage period combinations using a 100-year time horizon.

	Storage period in the anthroposphere (years)										
Rotation period (years)	0	10	20	30	40	50	60	70	80	90	100
1	0.00	−0.07	−0.15	−0.23	−0.32	−0.40	−0.50	−0.60	−0.71	−0.84	−0.99
10	0.04	−0.04	−0.12	−0.20	−0.28	−0.37	−0.46	−0.57	−0.68	−0.80	−0.96
20	0.08	0.00	−0.08	−0.16	−0.24	−0.33	−0.42	−0.53	−0.64	−0.76	−0.92
30	0.12	0.04	−0.04	−0.12	−0.20	−0.29	−0.38	−0.48	−0.60	−0.72	−0.88
40	0.16	0.09	0.01	−0.08	−0.16	−0.25	−0.34	−0.44	−0.55	−0.68	−0.84
50	0.20	0.13	0.05	−0.03	−0.12	−0.21	−0.30	−0.40	−0.51	−0.64	−0.80
60	0.25	0.17	0.09	0.01	−0.07	−0.16	−0.26	−0.36	−0.47	−0.59	−0.75
70	0.29	0.22	0.14	0.06	−0.03	−0.12	−0.21	−0.31	−0.42	−0.55	−0.71
80	0.34	0.26	0.18	0.10	0.02	−0.07	−0.17	−0.27	−0.38	−0.50	−0.66
90	0.38	0.31	0.23	0.15	0.06	−0.03	−0.12	−0.22	−0.33	−0.46	−0.62
100	0.44	0.37	0.29	0.21	0.12	0.032	−0.06	−0.16	−0.27	−0.4	−0.56

A calculation spreadsheet allowing to calculate any value between the available steps will be made available upon request to the author of this report.

[28] Anthropogenic and Natural Radiative Forcing. IPCC. 2013.
[29] Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life. Guest et al. 2013.
[30] Anthropogenic and Natural Radiative Forcing. IPCC. 2013.
[31] Chapter 8, p. 714 of the report mentioned above.
[32] Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life. Guest et al. 2013.
[33] Bioenergy from Forestry and Changes in Atmospheric CO2: Reconciling Single Stand and Landscape Level Approaches. Cherubini et al. 2013.

4.4.4 Potentially affected biodiversity

Indicator name: **Potentially affected biodiversity**

Identified in D2.1 cluster: Ecosystem quality

Model: Land occupation life cycle inventory data combined with species richness of the biome where the activity takes place[34]

Unit: m^2.year*PAS (potentially affected species)

This indicator was created for STAR-ProBio and combines land occupation life cycle inventory data with a biodiversity weighting factor: the 2005 Millennium Ecosystem Assessment data for species richness[35]. With this biodiversity weighting factor, it follows a recommendation for LCIA development for ecosystem quality[36], which is to "tend towards species-richness-related metrics". It represents a number of species potentially affected by land occupation, meaning it is a risk. It does not represent the real biodiversity loss in the area actually cultivated.

The species richness is evaluated for 14 different terrestrial biomes and categorised through 4 groups of species: amphibians, birds, mammals and reptiles, as presented in Figure 2.

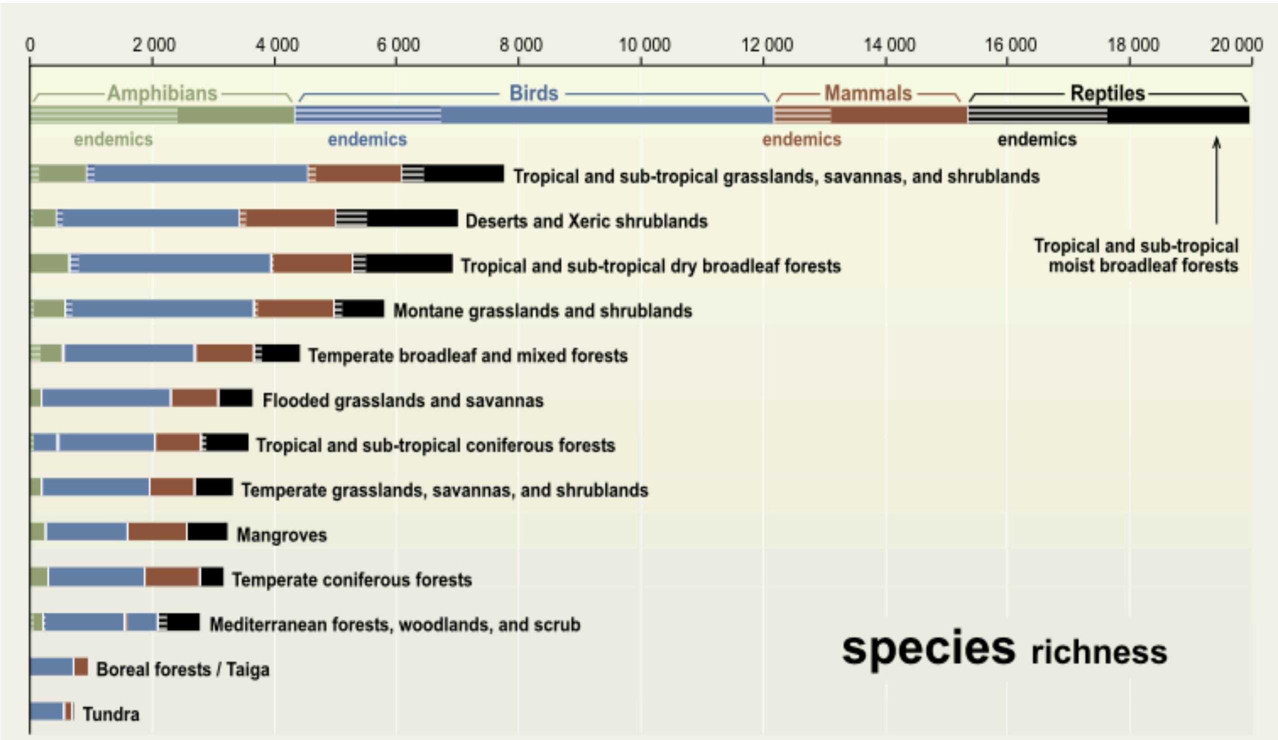

Figure 2: Species richness for 14 terrestrial biomes (as reported by the 2005 Millennium Ecosystem Assessment, figure 1.2)

The Köppen-Geiger Climate Classification[37] can be used to determine which species richness applies to the location where the activity takes place. Best practice is to use this information with the finest granulometry.

[34] Ecosystems and Human Well-being: Biodiversity Synthesis. Millennium Ecosystem Assessment. 2005.
[35] ibid.
[36] Ecosystem Quality in LCIA: Status Quo, Harmonization, and Suggestions for the Way Forward. Woods et al. 2017.
[37] Updated World Map of the Köppen-Geiger Climate Classification. Peel et al. 2007.

If the precise location is not known, the country average species richness can be calculated and used. For this calculation, we used data provided by the Joint Research Centre[38] to obtain the share of the area of ever country that corresponds to each biome. Results are provided in **annex 7.2**. These factors can be used in combination with the land occupation areas needed for feedstock production of bio-based materials on a country-scale.

To enable comparison with fossil-based materials, the potentially affected biodiversity associated to crude oil and natural gas production in main exporting countries was pre-calculated (**annex 7.3**).

4.4.5 Terrestrial eutrophication

Indicator name: **Terrestrial eutrophication**

Identified in D2.1 cluster: Eutrophication

Model: Accumulated Exceedance model[39, 40]

Unit: mol N-eq

This indicator, mandatory under the PEFCR Guidance framework, addresses impacts from nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland which accelerate the growth of vegetation in soil. The degradation of organic material consumes oxygen resulting in oxygen deficiency. With respect to terrestrial eutrophication, only the concentration of nitrogen is the limiting factor and hence important. The impact metric is expressed in mole N-eq (nitrogen equivalents).

4.4.6 Freshwater eutrophication

Indicator name: **Freshwater eutrophication**

Identified in D2.1 cluster: Eutrophication

Model: EUTREND model[41] as implemented in ReCiPe 2008

Unit: kg P-eq

This indicator, mandatory under the PEFCR Guidance framework, addresses impacts from nutrients (mainly phosphorus) from sewage outfalls and fertilized farmland which accelerate the growth of algae and other vegetation in freshwater. The degradation of organic material consumes oxygen resulting in oxygen deficiency. In freshwater environments, phosphorus is considered the limiting factor. The impact metric is expressed in kg P-eq (kg phosphorous to freshwater equivalents).

Note: Freshwater eutrophication has been selected in preference to terrestrial or marine eutrophication. This choice is related to nitrogen. Many indicators are already sensitive to N and help show the difference with fossils based on the emissions of this element. E.g.: acidification or smog. Because freshwater eutrophication is the only indicator sensitive to P, it is a more interesting indicator for impact assessment and it avoids redundancy.

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[38] http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy/, retrieved in 2013.
[39] Country-Dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator. Seppälä et al. 2006.
[40] The Role of Atmospheric Dispersion Models and Ecosystem Sensitivity in the Determination of Characterisation Factors for Acidifying and Eutrophying Emissions in LCIA. Posch et al. 2008.
[41] Aquatic Eutrophication. Struijs et al. 2009.

4.4.7 Human toxicity, cancer

Indicator name: **Human toxicity, cancer**

Identified in D2.1 cluster: Human health

Model: USEtox model[42]

Unit: CTUh

This indicator, optional under the PEFCR Guidance framework, accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer. The impact metric is expressed in CTUh (i.e. comparative toxic units for humans in terms of cases, the estimated increase in morbidity in the total human population). The USEtox model[43] is a scientific consensus model endorsed by the UNEP/SETAC Life Cycle Initiative for characterizing human and ecotoxicological impacts of chemicals.

4.4.8 Land use, soil quality index

Indicator name: **Land use, soil quality index**

Identified in D2.1 cluster: Land use

Model: Soil quality index based on LANCA model EC-JRC, based on LANCA indicators[44, 45]

Unit: points (dimensionless)

This indicator, mandatory under the PEFCR Guidance framework, is an aggregation of four indicators assessed through the LANCA (Land Use Indicator Value Calculation in Life Cycle Assessment) model: biotic production, erosion resistance, mechanical filtration and groundwater replenishment. The aggregation scheme was defined by the European Commission Joint Research Centre (JRC). The impact metric is expressed in Pt (points, i.e. dimensionless).

4.4.9 Soil erosion

Indicator name: **Soil erosion**

Identified in D2.1 cluster: Land use

Model: Revised Universal Soil Loss Equation[46] using C factor specific to crops[47]

Unit: kg soil loss

This indicator assesses soil erosion based on the RUSLE model[48], a revised version of the Universal Soil Loss Equation (USLE) documented by Wischmeier and Smith in 1978.

Soil erosion describes the process of removing and transporting soil particles by means of water or wind, which occurs if the inherent resistance of the soil against mechanical influences is not given anymore. The loss of soil affects the water and nutrient cycles as well as the general soil productivity.

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[42] USEtox - The UNEPSETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity. Rosenbaum et al. 2008.
[43] http://www.usetox.org/
[44] LANCA Land Use Indicator Value Calculation in Life Cycle Assessment – Method Report. Beck et al. 2010.
[45] LANCA ® Characterization Factors for Life Cycle Impact Assessment. Bos et al. 2016.
[46] Revised Universal Soil Loss Equation Version 2 (RUSLE 2). USDA-Agricultural Research Service. 2013.
[47] An Assessment of the Global Impact of 21st Century Land Use Change on Soil Erosion. Borrelli et al. 2017.
[48] Revised Universal Soil Loss Equation Version 2 (RUSLE 2). USDA-Agricultural Research Service. 2013.

Soil losses are represented by the following equation:

$$A = R \cdot L \cdot S \cdot K \cdot C \cdot P \quad \text{Equation 1}$$

where:

A ($Mg\ ha^{-1}\ yr^{-1}$) is the annual average soil erosion,

R ($MJ\ mm\ h^{-1}\ ha^{-1}\ yr^{-1}$) is the rainfall-runoff erosivity factor,

K ($Mg\ h\ MJ^{-1}\ mm^{-1}$) is the soil erodibility factor,

L (dimensionless) is the slope length factor,

S (dimensionless) is the slope steepness factor,

C (dimensionless) is the land cover and management factor,

P (dimensionless) is the soil conservation or prevention practices factor.

The parameters R, K, L and S are specific to the location where the activity takes place. Parameter C is specific to the vegetation, that is the crop cultivated in the cases of our interest. Finally, P depends on management practices adopted by the farmers. Default values for these factors, for a few important countries, are provided in annex 7.4.

A good example with default values is provided by the Ontario Ministry of Agriculture, Food and Rural Affairs[49].

4.4.10 Fossil resources depletion

Indicator name: **Fossil resources depletion**

Identified in D2.1 cluster: Mineral and fossil resources

Model: CML 2002 model (Guinée et al., 2002 and van Oers et al. 2002)

Unit: MJ

This indicator, mandatory under the PEFCR Guidance framework, measures the potential impact on non-renewable resources depletion from fossil fuels. The impact metric is expressed in MJ (megajoules).

4.4.11 Water scarcity

Indicator name: **Water scarcity**

Identified in D2.1 cluster: Water availability

Model: Available WAter REmaining (AWARE)[50]

Unit: m^3 water deprived-eq

This indicator, mandatory under the PEFCR Guidance framework, assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived. It is based on the AWARE 100 model, the recommended method from WULCA for water consumption impact assessment in LCA. The impact metric is expressed in m^3 of water deprived equivalents.

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[49] http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm, accessed July 2018.
[50] The WULCA Consensus Characterization Model for Water Scarcity Footprints: Assessing Impacts of Water Consumption Based on Available Water Remaining (AWARE). Boulay et al. 2017.

5 Interpretation and final conclusions

5.1 Interpretation

The two-steps selection process allowed for a transparent evaluation of the relevant impact indicators and models to be used for the environmental assessment of bio-based materials. Special attention was paid to make sure the selected indicators can be used for comparisons with fossil-based alternatives.

It was however noted that the risk of marine pollution from macro and micro-plastics (bio- or fossil-based) is an important indicator lacking from the current proposed framework. One should also note that iLUC as a quantitative indicator was deliberately kept out of scope, since a dedicated work package (WP7) aims to address this crucial topic for bio-based feedstocks.

5.2 Conclusion

The 11 selected environmental indicators shall be applied in the STAR-ProBio case studies, looking as a wide array of possible feedstocks, which should demonstrate their applicability in all situations.

Would new metrics or methodologies be published in the course of the project, we would recommend re-assessing whether the proposed selection should be revised. This particularly applies to risk of plastics leakage into the environment, for which several initiatives attempt to define sound metrics usable with an LCA framework.

6 Reference list

Beck, T., Bos, U., Wittstock, B., Baitz, M., Fischer, M., Sedlbauer, K., "LANCA Land Use Indicator Value Calculation in Life Cycle Assessment – Method Report", Fraunhofer Institute for Building Physics, 2010.

Borrelli, Pasquale, David A. Robinson, Larissa R. Fleischer, Emanuele Lugato, Cristiano Ballabio, Christine Alewell, Katrin Meusburger, et al., "An Assessment of the Global Impact of 21st Century Land Use Change on Soil Erosion", *Nature Communications*, Vol. 8, No. 1, 2017, p. 2013.

Bos, Ulrike, Rafael Horn, Tabea Beck, Jan Paul Lindner, and Matthias Fischer, *LANCA ® Characterization Factors for Life Cycle Impact Assessment*, Fraunhofer Institute for Building Physics IBP, Stuttgart, Germany, 2016.

Boulay, Anne-marie, Jane Bare, Lorenzo Benini, Markus Berger, Alessandro Manzardo, Manuele Margni, Masaharu Motoshita, and Michael Lathuillière, "The WULCA Consensus Characterization Model for Water Scarcity Footprints: Assessing Impacts of Water Consumption Based on Available Water Remaining (AWARE)", *The International Journal of Life Cycle Assessment*, 2017, pp. 1–23.

Cherubini, Francesco, Geoffrey Guest, and Anders H Strømman, "Bioenergy from Forestry and Changes in Atmospheric CO2: Reconciling Single Stand and Landscape Level Approaches.", *Journal of Environmental Management*, Vol. 129, November 15, 2013, pp. 292–301.

European Commission – Joint Research Centre, Product Environmental Footprint Category Rules Guidance - Version 6.3, Publications Office of the European Union, Ispra , Italy, 2017.

European Commission – Joint Research Centre – IES, ILCD Handbook - Recommendations for Life Cycle Impact Assessment in the European Context, First edit., Publications Office of the European Union, Ispra, Italy, 2011.

Fantke, P., Evans, J., Hodas, N., Apte, J., Jantunen, M., Jolliet, O., McKone, T.E., "Health impacts of fine particulate matter". In: Frischknecht, R., Jolliet, O. (Eds.), Global Guidance for Life Cycle Impact Assessment Indicators: Volume 1. UNEP/SETAC Life Cycle Initiative, Paris, 2016, pp. 76-99. Retrieved Jan 2017 from www.lifecycleinitiative.org/applying-lca/lcia-cf/.

Guest, Geoffrey, Francesco Cherubini, and Anders H. Strømman, "Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at End of Life", Journal of Industrial Ecology, Vol. 17, No. 1, February 8, 2013, pp. 20–30.

Guinée, J.B. (Ed.), Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., Van Oers, L., Wegener Sleeswijk, A., Suh, S.,. Udo de Haes, H.A, De Bruijn, J.A., Van Duin R., Huijbregts, M.A.J., "Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards". Series: *Eco-efficiency in industry and science*. Kluwer Academic Publishers, Dordrecht, 2002.

IPCC, Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, "Anthropogenic and Natural Radiative Forcing". In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

Millennium Ecosystem Assessment, *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington DC, USA, 2005.

Panagos, Panos, Pasquale Borrelli, Katrin Meusburger, Emma H. van der Zanden, Jean Poesen, and Christine Alewell, "Modelling the Effect of Support Practices (P-Factor) on the Reduction of Soil Erosion by Water at European Scale", *Environmental Science and Policy*, Vol. 51, 2015, pp. 23–34.

Panagos, Panos, Pasquale Borrelli, and Katrin Meusburger, "A New European Slope Length and Steepness Factor (LS-Factor) for Modeling Soil Erosion by Water", *Geosciences*, Vol. 5, No. 2, 2015, pp. 117–126.

Peel, M. C., B. L. Finlayson, and T. A. McMahon, "Updated World Map of the Köppen-Geiger Climate Classification", *Hydrology and Earth System Sciences*, Vol. 11, July 10, 2007, pp. 1633–1644.

Posch, Maximilian, Jyri Seppälä, Jean-Paul Hettelingh, Matti Johansson, Manuele Margni, and Olivier Jolliet, "The Role of Atmospheric Dispersion Models and Ecosystem Sensitivity in the Determination of Characterisation Factors for Acidifying and Eutrophying Emissions in LCIA", The International Journal of Life Cycle Assessment, Vol. 13, No. 6, August 21, 2008, pp. 477–486.

Renard, KG, GR Foster, GA Weesies, DK McCool, and DC Yoder, coordinators. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*. US Department of Agriculture, Agriculture Handbook No. 703, 404 pp, 1997.

Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, M.A.J., Jolliet, O., Juraske, R., Köhler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., van de Meent, D., Hauschild, M.Z., "USEtox - The UNEPSETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity" in Life Cycle Impact Assessment. International Journal of Life Cycle Assessment, 13(7): 532-546, 2008

Seppälä, Jyri, Maximilian Posch, Matti Johansson, and Jean-paul Hettelingh, "Country-Dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator", The International Journal of Life Cycle Assessment, Vol. 11, No. 6, November 11, 2006, pp. 403–416.

Struijs, J., Beusen, A., van Jaarsveld, H. and Huijbregts, M.A.J., "Aquatic Eutrophication". Chapter 6 in: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., De Schryver, A., Struijs, J., Van Zelm, R. *ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors*, first edition, 2009.

United Nations. "Transforming our world: The 2030 agenda for sustainable development." Resolution adopted by the General Assembly, 2015.

USDA-Agricultural Research Service, *Revised Universal Soil Loss Equation Version 2 (RUSLE 2)*, Washington DC, USA, 2013.

van Oers, Lauren, Arjan de Koning, Jeroen B Guinée, and Gjalt Huppes, *Abiotic Resource Depletion in LCA*, Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam, 2002.

Woods, John S., Mattia Damiani, Peter Fantke, Andrew D. Henderson, John M. Johnston, Jane Bare, Serenella Sala, et al., "Ecosystem Quality in LCIA: Status Quo, Harmonization, and Suggestions for the Way Forward", *International Journal of Life Cycle Assessment*, 2017, pp. 1–12.

7 ANNEXES

7.1 Full rating of the impact categories

The qualitative rating of the impact categories is displayed in the table below. It shows the relative score, based on the weighting attributed to each criterion (see bottom line). These results are very much dependant on value choices (the given score and weight are subjective) so they have been used as a guidance for the discussion and the final selection decision.

Table 12: Qualitative rating of the impact categories (before discussion and selection decision)

		Benchmarking and environmental labelling								
D2.1 Cluster	**Scrutinized impact categories**	**compare BB materials among them**	**compare against conventionals**	**Scientific relevance**	**Political / social priority**	**Reliability / robustness**	**Representativeness**	**Stakeholder / market perception**	**Score**	**Relative score**
Ecosystem quality (biodiv.)	Land occupation * species richness	4	4	3	4	3	2	3	75	95%
Ecosystem quality (biodiv.)	Ecosystem services loss	2	4	3	3	1	2	3	58	73%
Ecosystem quality (biodiv.)	Biodiversity endpoint	2	4	4	3	2	2	3	66	84%
Land use	Soil quality index	1	4	4	4	2	2	3	68	86%
Land use	•Biotic production	1	4	4	2	2	2	1	56	71%
Land use	•Erosion resistance	1	4	4	2	2	2	1	56	71%
Land use	•Mechanical filtration	1	4	4	2	2	2	1	56	71%
Land use	•Groundwater replenishment	1	4	4	2	2	2	1	56	71%
Land use	Fertile land occupation	3	4	2	3	4	2	4	66	84%
Land use	Soil carbon deficit	2	4	3	3	2	2	3	61	77%
Land use	Soil erosion / degradation	2	4	3	4	1	2	2	62	78%
Water availability	Water use: User deprivation potential (deprivation-weighted water consumption)	3	4	4	4	2	4	4	79	100%
Air quality	Particulate matter	1	3	4	3	4	2	3	66	84%
Air quality	Photochemical ozone formation, human health	1	2	2	2	3	2	3	45	57%
Climate change	Radiative forcing as Global Warming Potential (GWP100)	2	4	4	4	4	2	4	78	99%
Climate change	GWP bio	3	4	4	4	4	2	2	79	100%
Eutrophication	Eutrophication, terrestrial	2	4	2	1	3	2	2	48	61%
Eutrophication	Eutrophication, freshwater (P)	2	4	2	1	3	2	2	48	61%
Eutrophication	Eutrophication, marine (N)	2	4	1	1	3	2	2	43	54%

Mineral and fossil resources	Resource use, minerals and metals: Abiotic resource depletion (ADP ultimate reserves)	1	2	2	2	2	2	2	41	52%
Mineral and fossil resources	Resources depletion endpoint	3	4	3	2	2	2	4	60	76%
Mineral and fossil resources	Phosphate use	2	4	3	1	3	2	2	53	67%
Mineral and fossil resources	Cumulative energy demand	2	4	3	3	4	2	3	67	85%
Mineral and fossil resources	Resource use, fossils: Abiotic resource depletion – fossil fuels (ADP-fossil)	2	4	4	3	2	2	3	66	84%
Mineral and fossil resources	Organic carbon content (TOC)	2	4	1	1	4	2	2	46	58%
Wastes	Marine plastic pollution risk	3	3	2	4	1	2	3	58	73%
Wastes	Biodegradability	4	2	1	2	4	2	3	52	66%
Wastes	Recyclability (and other EoL options)	4	2	1	3	3	2	3	54	68%
Acidification	Acidification	2	3	4	1	3	4	2	59	75%
Ecotox	Ecotoxicity, freshwater (USEtox)	2	3	1	2	2	4	2	46	58%
Human health	Human toxicity, cancer (USEtox)	2	3	1	2	2	2	1	41	52%
Human health	Human toxicity, non-cancer (USEtox)	2	3	1	1	2	2	1	36	46%
Human health	Human health endpoint	2	3	1	2	2	2	3	43	54%
Ionising radiation	Ionising radiation, human health	1	2	1	1	3	4	2	38	48%
Ozone layer	Ozone depletion	1	3	1	2	4	4	3	50	63%
			6							
Weight		**3**	**3**	**5**	**5**	**3**	**2**	**1**		

7.2 Average species richness by country

The following table shows the country climates as provided by the Joint Research Centre in 2013 (http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy).

Table 13: Country climates as provided by the Joint Research Centre in 2013

Country	Boreal, dry	Boreal, moist	Cold temperate, dry	Cold temperate, moist	Tropical, dry	Tropical, moist	Tropical montane	Tropical, wet	Warm temperate, dry	Warm temperate, moist
Afghanistan	0.4%	2.0%	26.6%	6.6%	19.7%	0.0%	6.1%	0.0%	38.4%	0.2%
Albania	0.0%	0.0%	0.0%	33.0%	0.0%	0.0%	0.0%	0.0%	0.2%	66.8%
Algeria	0.0%	0.0%	0.0%	0.0%	80.7%	0.0%	6.4%	0.0%	12.7%	0.2%
American Samoa	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
Angola	0.0%	0.0%	0.0%	0.0%	14.0%	13.0%	72.6%	0.0%	0.2%	0.1%
Antigua and Barbuda	0.0%	0.0%	0.0%	0.0%	16.7%	83.3%	0.0%	0.0%	0.0%	0.0%
Argentina	0.0%	0.0%	21.1%	3.9%	18.0%	9.0%	0.2%	0.0%	47.5%	0.4%
Armenia	0.0%	1.4%	40.4%	38.5%	0.0%	0.0%	0.0%	0.0%	19.7%	0.0%
Australia	0.0%	0.0%	0.0%	0.7%	73.9%	5.9%	0.0%	0.1%	16.7%	2.7%
Austria	0.0%	0.0%	8.9%	90.2%	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%
Azerbaijan	0.0%	0.0%	12.2%	8.9%	0.0%	0.0%	0.0%	0.0%	78.1%	0.8%
Bahamas	0.0%	0.0%	0.0%	0.0%	37.3%	62.7%	0.0%	0.0%	0.0%	0.0%
Bahrain	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bangladesh	0.0%	0.0%	0.0%	0.0%	0.0%	40.5%	0.0%	59.5%	0.0%	0.0%
Barbados	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Belarus	0.0%	0.0%	2.4%	97.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Belgium	0.0%	0.0%	0.0%	65.4%	0.0%	0.0%	0.0%	0.0%	0.0%	34.6%
Belgium-Luxembourg	0.0%	0.0%	0.0%	65.4%	0.0%	0.0%	0.0%	0.0%	0.0%	34.6%
Belize	0.0%	0.0%	0.0%	0.0%	0.0%	47.6%	0.0%	52.4%	0.0%	0.0%
Benin	0.0%	0.0%	0.0%	0.0%	19.5%	80.5%	0.0%	0.0%	0.0%	0.0%
Bermuda	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
Bhutan	0.0%	0.0%	7.4%	34.9%	0.0%	0.0%	4.8%	13.7%	0.0%	39.2%
Bolivia (Plurinational State of)	0.0%	0.0%	16.0%	1.5%	12.1%	47.4%	6.7%	6.3%	9.1%	0.8%
Bosnia and Herzegovina	0.0%	0.0%	0.0%	62.0%	0.0%	0.0%	0.0%	0.0%	0.6%	37.4%
Botswana	0.0%	0.0%	0.0%	0.0%	41.5%	0.0%	58.5%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	11.3%	50.4%	1.1%	34.0%	0.0%	3.1%
British Virgin Islands	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
Brunei Darussalam	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	98.6%	0.0%	0.0%
Bulgaria	0.0%	0.0%	17.0%	15.3%	0.0%	0.0%	0.0%	0.0%	67.7%	0.0%
Burkina Faso	0.0%	0.0%	0.0%	0.0%	85.4%	14.6%	0.0%	0.0%	0.0%	0.0%
Burundi	0.0%	0.0%	0.0%	0.0%	6.0%	9.0%	67.7%	0.0%	0.9%	16.5%
Cambodia	0.0%	0.0%	0.0%	0.0%	0.0%	73.0%	0.5%	26.5%	0.0%	0.0%
Cameroon	0.0%	0.0%	0.0%	0.0%	10.1%	64.8%	11.0%	13.8%	0.0%	0.3%
Canada	12.9%	55.7%	8.1%	23.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Cape Verde	0.0%	0.0%	0.0%	0.0%	88.6%	0.0%	2.9%	0.0%	8.6%	0.0%
Cayman Islands	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Central African Republic	0.0%	0.0%	0.0%	0.0%	6.6%	91.9%	1.6%	0.0%	0.0%	0.0%
Chad	0.0%	0.0%	0.0%	0.0%	88.6%	5.3%	5.0%	0.0%	1.0%	0.0%
Chile	0.0%	0.0%	18.4%	42.5%	0.2%	0.0%	0.0%	0.0%	26.9%	12.0%
China	4.4%	4.8%	38.6%	10.1%	0.0%	7.1%	1.0%	0.3%	19.5%	14.2%
Colombia	0.0%	0.0%	0.0%	1.9%	1.5%	10.1%	8.3%	69.9%	0.6%	7.7%
Comoros	0.0%	0.0%	0.0%	0.0%	0.0%	40.0%	13.3%	40.0%	0.0%	6.7%
Congo	0.0%	0.0%	0.0%	0.0%	0.0%	97.4%	0.0%	2.6%	0.0%	0.0%
Cook Islands	0.0%	0.0%	0.0%	0.0%	0.0%	66.7%	0.0%	33.3%	0.0%	0.0%
Costa Rica	0.0%	0.0%	0.0%	0.2%	0.0%	14.2%	12.1%	64.0%	0.0%	9.6%
Côte d'Ivoire	0.0%	0.0%	0.0%	0.0%	0.0%	98.5%	0.0%	1.5%	0.0%	0.0%
Croatia	0.0%	0.0%	0.0%	25.0%	0.0%	0.0%	0.0%	0.0%	11.7%	63.3%
Cuba	0.0%	0.0%	0.0%	0.0%	3.3%	96.4%	0.2%	0.2%	0.0%	0.0%
Cyprus	0.0%	0.0%	0.0%	0.0%	58.5%	0.0%	0.0%	0.0%	40.7%	0.8%
Czechia	0.0%	0.0%	24.2%	75.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Czech Republic	0.0%	0.0%	24.2%	75.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Democratic People's Republic of Korea	0.0%	7.3%	0.5%	82.8%	0.0%	0.0%	0.0%	0.0%	0.1%	9.3%
Democratic Republic of the Congo	0.0%	0.0%	0.0%	0.0%	1.8%	75.8%	15.7%	6.0%	0.0%	0.8%
Denmark	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Djibouti	0.0%	0.0%	0.0%	0.0%	96.0%	0.0%	4.0%	0.0%	0.0%	0.0%
Dominica	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Dominican Republic	0.0%	0.0%	0.0%	0.0%	15.7%	69.7%	5.9%	1.7%	0.0%	7.1%
Ecuador	0.0%	0.0%	0.4%	6.9%	12.0%	11.0%	11.9%	40.9%	6.3%	10.5%
Egypt	0.0%	0.0%	0.0%	0.0%	97.8%	0.0%	0.3%	0.0%	1.9%	0.0%
El Salvador	0.0%	0.0%	0.0%	0.0%	0.0%	83.0%	5.7%	11.3%	0.0%	0.0%
Equatorial Guinea	0.0%	0.0%	0.0%	0.0%	0.0%	18.6%	0.6%	79.4%	0.0%	1.3%
Eritrea	0.0%	0.0%	0.0%	0.0%	71.0%	0.0%	26.6%	0.0%	2.5%	0.0%
Estonia	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ethiopia	0.0%	0.0%	0.0%	0.3%	37.8%	5.0%	43.3%	0.0%	5.4%	8.1%
Ethiopia	0.0%	0.0%	0.0%	0.3%	37.8%	5.0%	43.3%	0.0%	5.4%	8.1%
Faroe Islands	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fiji	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	0.0%	96.0%	0.0%	0.0%
Finland	0.0%	31.4%	0.0%	68.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
France	0.0%	0.0%	0.5%	29.6%	0.0%	0.0%	0.0%	0.0%	19.9%	50.0%
French Guiana	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	99.7%	0.0%	0.0%
French Polynesia	0.0%	0.0%	0.0%	0.0%	0.0%	53.8%	0.0%	46.2%	0.0%	0.0%
Gabon	0.0%	0.0%	0.0%	0.0%	0.0%	72.8%	0.0%	27.2%	0.0%	0.0%
Gambia	0.0%	0.0%	0.0%	0.0%	96.2%	3.8%	0.0%	0.0%	0.0%	0.0%
Georgia	0.0%	0.0%	2.2%	59.3%	0.0%	0.0%	0.0%	0.0%	18.0%	20.4%
Germany	0.0%	0.0%	18.4%	79.2%	0.0%	0.0%	0.0%	0.0%	0.3%	2.1%
Ghana (FAO data)	0.0%	0.0%	0.0%	0.0%	7.6%	91.9%	0.0%	0.4%	0.0%	0.0%
Ghana (FAO 2013 data)	0.0%	0.0%	0.0%	0.0%	7.6%	91.9%	0.0%	0.4%	0.0%	0.0%
Greece	0.0%	0.0%	1.9%	7.6%	2.5%	0.0%	0.0%	0.0%	71.7%	16.2%
Grenada	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%	50.0%	0.0%	0.0%

Guadeloupe	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%	50.0%	0.0%	0.0%
Guam	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Guatemala	0.0%	0.0%	0.0%	0.3%	2.1%	38.5%	14.7%	29.7%	1.0%	13.6%
Guinea	0.0%	0.0%	0.0%	0.0%	0.0%	67.8%	1.2%	31.0%	0.0%	0.0%
Guinea-Bissau	0.0%	0.0%	0.0%	0.0%	0.0%	81.2%	0.0%	18.8%	0.0%	0.0%
Guyana	0.0%	0.0%	0.0%	0.0%	0.1%	52.4%	1.1%	46.4%	0.0%	0.1%
Haiti	0.0%	0.0%	0.0%	0.0%	7.8%	77.8%	5.3%	7.2%	0.0%	1.9%
Honduras	0.0%	0.0%	0.0%	0.0%	1.3%	53.4%	19.4%	23.6%	0.0%	2.2%
Hungary	0.0%	0.0%	18.2%	3.9%	0.0%	0.0%	0.0%	0.0%	75.2%	2.7%
Iceland	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
India	0.0%	0.0%	0.0%	0.9%	50.2%	37.5%	1.4%	8.2%	0.0%	1.9%
Indonesia	0.0%	0.0%	0.0%	0.2%	0.1%	11.8%	7.0%	78.2%	0.0%	2.8%
Iran (Islamic Republic of)	0.0%	0.0%	8.4%	0.0%	31.7%	0.0%	11.4%	0.0%	48.2%	0.4%
Iraq	0.0%	0.0%	0.3%	0.1%	93.3%	0.0%	0.0%	0.0%	6.2%	0.1%
Ireland	0.0%	0.0%	0.0%	91.8%	0.0%	0.0%	0.0%	0.0%	0.0%	8.2%
Israel	0.0%	0.0%	0.0%	0.0%	94.3%	0.0%	0.0%	0.0%	5.7%	0.0%
Italy	0.0%	0.0%	0.0%	19.0%	0.0%	0.0%	0.0%	0.0%	50.3%	30.6%
Jamaica	0.0%	0.0%	0.0%	0.0%	1.6%	65.3%	3.2%	29.8%	0.0%	0.0%
Japan	0.0%	0.1%	0.0%	42.7%	0.0%	0.0%	0.0%	0.6%	0.0%	56.6%
Jordan	0.0%	0.0%	0.0%	0.0%	59.2%	0.0%	2.5%	0.0%	38.3%	0.0%
Kazakhstan	0.3%	1.3%	84.5%	0.7%	0.0%	0.0%	0.0%	0.0%	13.2%	0.0%
Kenya	0.0%	0.0%	0.0%	0.2%	70.0%	1.0%	19.5%	0.0%	5.6%	3.7%
Kiribati	0.0%	0.0%	0.0%	0.0%	80.0%	0.0%	0.0%	20.0%	0.0%	0.0%
Kuwait	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kyrgyzstan	15.4%	17.6%	45.3%	12.8%	0.0%	0.0%	0.0%	0.0%	8.9%	0.0%
Lao People's Democratic Republic	0.0%	0.0%	0.0%	0.0%	0.0%	50.3%	19.3%	29.4%	0.0%	1.0%
Latvia	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Lebanon	0.0%	0.0%	3.6%	8.6%	21.4%	0.7%	0.0%	0.0%	42.9%	22.9%
Lesotho	0.0%	0.0%	3.6%	26.6%	0.0%	0.0%	0.0%	0.0%	64.6%	5.1%
Liberia	0.0%	0.0%	0.0%	0.0%	0.0%	6.0%	0.0%	94.0%	0.0%	0.0%
Libya	0.0%	0.0%	0.0%	0.0%	98.3%	0.0%	0.5%	0.0%	1.1%	0.0%
Lithuania	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Luxembourg	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Madagascar	0.0%	0.0%	0.0%	0.0%	24.9%	46.4%	11.3%	11.8%	0.2%	5.5%
Malawi	0.0%	0.0%	0.0%	0.0%	20.0%	38.3%	38.8%	0.1%	1.0%	1.7%
Malaysia	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	5.7%	91.3%	0.0%	0.1%
Maldives	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Mali	0.0%	0.0%	0.0%	0.0%	92.5%	7.5%	0.0%	0.0%	0.0%	0.0%
Malta	0.0%	0.0%	0.0%	0.0%	75.0%	0.0%	0.0%	0.0%	25.0%	0.0%
Marshall Islands	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
Martinique	0.0%	0.0%	0.0%	0.0%	0.0%	42.9%	0.0%	57.1%	0.0%	0.0%
Mauritania	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mauritius	0.0%	0.0%	0.0%	0.0%	0.0%	96.0%	0.0%	4.0%	0.0%	0.0%
Mexico	0.0%	0.0%	0.0%	0.1%	27.6%	15.6%	22.3%	3.8%	27.1%	3.4%
Micronesia (Federated States of)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Mongolia	44.8%	4.2%	51.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Montenegro	0.0%	0.0%	6.9%	37.3%	0.0%	0.0%	0.0%	0.0%	43.2%	12.6%
Montserrat	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Morocco	0.0%	0.0%	2.2%	0.3%	38.3%	0.0%	4.0%	0.0%	54.6%	0.6%
Mozambique	0.0%	0.0%	0.0%	0.0%	45.1%	51.3%	3.5%	0.0%	0.0%	0.1%
Myanmar	0.0%	0.0%	0.0%	0.9%	9.6%	34.8%	14.5%	33.5%	0.0%	6.8%
Namibia	0.0%	0.0%	0.0%	0.0%	20.9%	0.0%	63.4%	0.0%	15.7%	0.0%
Nauru	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
Nepal	0.0%	0.0%	1.8%	18.7%	0.0%	33.1%	10.4%	8.1%	1.7%	26.1%
Netherlands	0.0%	0.0%	0.0%	95.1%	0.0%	0.0%	0.0%	0.0%	0.0%	4.9%
New Caledonia	0.0%	0.0%	0.0%	0.0%	0.9%	84.5%	0.0%	14.6%	0.0%	0.0%
New Zealand	0.0%	0.0%	2.1%	45.1%	0.0%	0.0%	0.0%	0.0%	3.9%	48.8%
Nicaragua	0.0%	0.0%	0.0%	0.0%	1.7%	37.3%	2.1%	58.9%	0.0%	0.0%
Niger	0.0%	0.0%	0.0%	0.0%	99.2%	0.0%	0.8%	0.0%	0.0%	0.0%
Nigeria	0.0%	0.0%	0.0%	0.0%	38.8%	51.3%	1.6%	8.3%	0.0%	0.0%
Niue	0.0%	0.0%	0.0%	0.0%	0.0%	33.3%	0.0%	66.7%	0.0%	0.0%
Norway	0.0%	22.3%	0.0%	77.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Occupied Palestinian Territory	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Oman	0.0%	0.0%	0.0%	0.0%	97.6%	0.0%	2.0%	0.0%	0.3%	0.0%
Pakistan	0.1%	0.5%	0.6%	1.7%	73.9%	0.3%	11.3%	0.0%	10.7%	1.0%
Panama	0.0%	0.0%	0.0%	0.0%	0.0%	21.4%	4.7%	71.6%	0.0%	2.3%
Papua New Guinea	0.0%	0.0%	0.0%	0.1%	0.0%	10.5%	13.4%	64.8%	0.0%	11.2%
Paraguay	0.0%	0.0%	0.0%	0.0%	46.9%	53.1%	0.0%	0.0%	0.0%	0.0%
Peru	0.0%	0.0%	3.1%	17.8%	7.2%	12.6%	8.1%	37.2%	11.2%	2.9%
Philippines	0.0%	0.0%	0.0%	0.0%	0.0%	18.3%	6.9%	74.2%	0.0%	0.6%
Poland	0.0%	0.0%	49.4%	50.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Portugal	0.0%	0.0%	0.0%	0.7%	0.1%	0.0%	0.0%	0.0%	60.5%	38.8%
Puerto Rico	0.0%	0.0%	0.0%	0.0%	3.2%	57.0%	0.0%	39.8%	0.0%	0.0%
Qatar	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Republic of Korea	0.0%	0.0%	0.0%	22.9%	0.0%	0.0%	0.0%	0.0%	0.0%	77.1%
Republic of Moldova	0.0%	0.0%	82.8%	0.7%	0.0%	0.0%	0.0%	0.0%	16.5%	0.0%
Réunion	0.0%	0.0%	0.0%	0.0%	0.0%	51.6%	9.7%	0.0%	0.0%	38.7%
Romania	0.0%	0.0%	25.6%	32.8%	0.0%	0.0%	0.0%	0.0%	41.6%	0.0%
Russian Federation	12.8%	61.8%	7.7%	16.8%	0.0%	0.0%	0.0%	0.0%	0.9%	0.1%
Rwanda	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	76.1%	0.0%	4.0%	19.9%
Saint Kitts and Nevis	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Saint Lucia	0.0%	0.0%	0.0%	0.0%	0.0%	25.0%	0.0%	75.0%	0.0%	0.0%
Saint Pierre and Miquelon	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Saint Vincent and the Grenadines	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Samoa	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.4%	92.6%	0.0%	0.0%
Sao Tome and Principe	0.0%	0.0%	0.0%	0.0%	0.0%	45.5%	9.1%	45.5%	0.0%	0.0%
Saudi Arabia	0.0%	0.0%	0.0%	0.0%	84.9%	0.0%	14.4%	0.0%	0.7%	0.0%
Senegal	0.0%	0.0%	0.0%	0.0%	83.4%	16.6%	0.0%	0.0%	0.0%	0.0%
Serbia	0.0%	0.0%	6.9%	37.3%	0.0%	0.0%	0.0%	0.0%	43.2%	12.6%

Serbia and Montenegro	0.0%	0.0%	6.9%	37.3%	0.0%	0.0%	0.0%	0.0%	43.2%	12.6%
Seychelles	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
Sierra Leone	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.1%	94.9%	0.0%	0.0%
Singapore	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Slovakia	0.0%	0.0%	20.9%	70.8%	0.0%	0.0%	0.0%	0.0%	8.3%	0.0%
Slovenia	0.0%	0.0%	0.0%	76.8%	0.0%	0.0%	0.0%	0.0%	0.0%	23.2%
Solomon Islands	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	97.9%	0.0%	0.0%
Somalia	0.0%	0.0%	0.0%	0.0%	90.5%	0.0%	9.2%	0.0%	0.3%	0.0%
South Africa	0.0%	0.0%	0.0%	0.2%	21.7%	1.0%	11.9%	0.0%	64.1%	1.2%
Spain	0.0%	0.0%	4.0%	8.0%	1.5%	0.0%	0.0%	0.0%	73.8%	12.7%
Sri Lanka	0.0%	0.0%	0.0%	0.0%	0.0%	70.6%	3.0%	25.6%	0.0%	0.8%
Sudan	0.0%	0.0%	0.0%	0.0%	89.1%	8.7%	2.2%	0.0%	0.0%	0.0%
Suriname	0.0%	0.0%	0.0%	0.0%	0.0%	14.6%	0.0%	85.4%	0.0%	0.0%
Swaziland	0.0%	0.0%	0.0%	0.0%	64.3%	8.4%	0.9%	0.0%	16.3%	10.1%
Sweden	0.0%	24.0%	0.4%	75.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Switzerland	0.0%	0.0%	0.0%	98.7%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%
Syrian Arab Republic	0.0%	0.0%	0.3%	0.0%	45.3%	0.5%	0.0%	0.0%	52.6%	1.3%
Tajikistan	9.7%	13.8%	8.3%	29.7%	0.0%	0.0%	0.0%	0.0%	38.2%	0.3%
Thailand	0.0%	0.0%	0.0%	0.0%	1.0%	80.9%	3.0%	15.2%	0.0%	0.0%
The former Yugoslav Republic of Macedonia	0.0%	0.0%	20.8%	28.2%	0.0%	0.0%	0.0%	0.0%	47.0%	4.1%
Timor-Leste	0.0%	0.0%	0.0%	0.0%	1.2%	76.4%	10.3%	10.3%	0.0%	1.8%
Togo	0.0%	0.0%	0.0%	0.0%	7.6%	92.4%	0.0%	0.0%	0.0%	0.0%
Tokelau	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
Tonga	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%	50.0%	0.0%	0.0%
Trinidad and Tobago	0.0%	0.0%	0.0%	0.0%	0.0%	40.7%	0.0%	59.3%	0.0%	0.0%
Tunisia	0.0%	0.0%	0.0%	0.0%	71.4%	0.0%	0.0%	0.0%	28.3%	0.3%
Turkey	0.0%	0.0%	27.3%	13.6%	2.1%	0.2%	0.0%	0.0%	52.7%	4.1%
Turkmenistan	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	99.7%	0.0%
Tuvalu	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
Uganda	0.0%	0.0%	0.0%	0.2%	3.3%	10.8%	83.6%	0.0%	0.6%	1.6%
Ukraine	0.0%	0.0%	52.5%	38.2%	0.0%	0.0%	0.0%	0.0%	9.3%	0.0%
United Arab Emirates	0.0%	0.0%	0.0%	0.0%	99.8%	0.0%	0.2%	0.0%	0.0%	0.0%
United Kingdom	0.0%	0.0%	4.4%	89.4%	0.0%	0.0%	0.0%	0.0%	0.9%	5.2%
United Republic of Tanzania	0.0%	0.0%	0.0%	0.1%	15.7%	21.1%	59.4%	0.1%	1.8%	1.7%
United States of America	4.8%	12.0%	21.9%	21.1%	4.0%	4.6%	0.1%	0.0%	14.4%	17.0%
United States Virgin Islands	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Uruguay	0.0%	0.0%	0.0%	0.0%	0.0%	20.9%	0.0%	0.0%	4.6%	74.5%
USSR	12.8%	61.8%	7.7%	16.8%	0.0%	0.0%	0.0%	0.0%	0.9%	0.1%
Uzbekistan	0.0%	0.5%	6.0%	2.5%	0.0%	0.0%	0.0%	0.0%	91.1%	0.0%
Vanuatu	0.0%	0.0%	0.0%	0.0%	0.0%	13.7%	0.8%	85.5%	0.0%	0.0%
Venezuela (Bolivarian Republic of)	0.0%	0.0%	0.0%	0.2%	8.1%	46.1%	6.0%	37.8%	0.8%	1.0%
Viet Nam	0.0%	0.0%	0.0%	0.0%	0.7%	66.5%	6.8%	23.5%	0.0%	2.5%

Wallis and Futuna Islands	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Western Sahara	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Yemen	0.0%	0.0%	0.0%	0.0%	63.7%	0.0%	29.4%	0.0%	6.9%	0.0%
Yugoslav SFR	0.0%	0.0%	20.8%	28.2%	0.0%	0.0%	0.0%	0.0%	47.0%	4.1%
Zambia	0.0%	0.0%	0.0%	0.0%	16.3%	2.0%	81.6%	0.0%	0.0%	0.0%
Zimbabwe	0.0%	0.0%	0.0%	0.0%	45.8%	0.7%	45.4%	0.0%	7.1%	1.0%

The Table 13 has been mapped with Millennium Ecosystem Assessment[51] biomes and species richness as shown in Table 14.

Table 14: Mapping between JRC climate categories and biomes and respective species richness

JRC CLIMATE CATEGORIES	CHOSEN BIOME FOR AGRICULTURE	SPECIES RICHNESS
Boreal, dry	Boreal forests / Taiga	948
Boreal, moist	Boreal forests / Taiga	948
Cold temperate, dry	Temperate coniferous forests	3178
Cold temperate, moist	Temperate coniferous forests	3178
Tropical, dry	Tropical and sub-tropical grasslands, savannas, and shrublands	7749
Tropical, moist	Tropical and sub-tropical moist broadleaf forests	20000
Tropical montane	Tropical and sub-tropical coniferous forests	3568
Tropical, wet	Tropical and sub-tropical moist broadleaf forests	20000
Warm temperate, dry	Mediterranean forests, woodlands, and scrub	2787
Warm temperate, moist	Temperate broadleaf and mixed forests	4404

Finally, the resulting average species richness by country is provided by Table 15.

Table 15: Average species richness by country (potential average in the country)

COUNTRY	AVERAGE SPECIES RICHNESS
Afghanistan	3902
Albania	3996
Algeria	6846
American Samoa	6676
Angola	6289
Antigua and Barbuda	17958
Argentina	5331
Armenia	3071
Australia	7532
Austria	3174
Azerbaijan	2883
Bahamas	15430

[51] Ecosystems and Human Well-being: Biodiversity Synthesis. Millennium Ecosystem Assessment. 2005

COUNTRY	AVERAGE SPECIES RICHNESS
Bahrain	7749
Bangladesh	20000
Barbados	20000
Belarus	3178
Belgium	3602
Belize	20000
Benin	17612
Bermuda	6676
Bhutan	5986
Bolivia (Plurinational State of)	12762
Bosnia and Herzegovina	3634
Botswana	5305
Brazil	17943
British Virgin Islands	6676
Brunei Darussalam	19772
Bulgaria	2914
Burkina Faso	9538
Burundi	5425
Cambodia	19924
Cameroon	16905
Canada	1647
Cape Verde	7204
Cayman Islands	20000
Central African Republic	18940
Chad	8142
Chile	3231
China	4332
Colombia	16840
Comoros	16769
Congo	20000
Cook Islands	20000
Costa Rica	16490
Côte d'Ivoire	20000
Croatia	3909
Cuba	19576
Cyprus	5705
Czechia	3178
Czech Republic	3178
Democratic People's Republic of Korea	3128
Democratic Republic of the Congo	17080
Denmark	3178
Djibouti	7582
Dominica	20000
Dominican Republic	16019
Ecuador	12614
Egypt	7643

COUNTRY	AVERAGE SPECIES RICHNESS
El Salvador	19069
Equatorial Guinea	19694
Eritrea	6516
Estonia	3178
Ethiopia	6003
Faroe Islands	3178
Fiji	20000
Finland	2477
France	3714
French Guiana	20000
French Polynesia	20000
Gabon	20000
Gambia	8213
Georgia	3358
Germany	3202
Ghana	19065
Greece	3211
Grenada	20000
Guadeloupe	20000
Guam	20000
Guatemala	14978
Guinea	19796
Guinea-Bissau	20000
Guyana	19800
Haiti	17878
Honduras	16298
Hungary	2917
Iceland	3178
India	13179
Indonesia	18375
Iran (Islamic Republic of)	4486
Iraq	7422
Ireland	3279
Israel	7466
Italy	3357
Jamaica	19272
Japan	3981
Jordan	5745
Kazakhstan	3090
Kenya	6640
Kiribati	10199
Kuwait	7749
Kyrgyzstan	2407
Lao People's Democratic Republic	16673
Latvia	3178
Lebanon	4391

COUNTRY	AVERAGE SPECIES RICHNESS
Lesotho	2988
Liberia	20000
Libya	7671
Lithuania	3178
Luxembourg	3178
Madagascar	14213
Malawi	10731
Malaysia	19055
Maldives	20000
Mali	8663
Malta	6509
Marshall Islands	6676
Martinique	20000
Mauritania	7749
Mauritius	20000
Mexico	7726
Micronesia (Federated States of)	20000
Mongolia	2086
Montenegro	3164
Montserrat	20000
Morocco	4737
Mozambique	13891
Myanmar	15245
Namibia	4320
Nauru	6676
Nepal	10464
Netherlands	3238
New Caledonia	19885
New Zealand	3761
Nicaragua	19450
Niger	7716
Nigeria	14985
Niue	20000
Norway	2681
Occupied Palestinian Territory	7749
Oman	7648
Pakistan	6600
Panama	18862
Papua New Guinea	16041
Paraguay	14253
Peru	11908
Philippines	18775
Poland	3178
Portugal	3421
Puerto Rico	19605
Qatar	7749

COUNTRY	AVERAGE SPECIES RICHNESS
Republic of Korea	4123
Republic of Moldova	3113
Réunion	12373
Romania	3015
Russian Federation	1513
Rwanda	3704
Saint Kitts and Nevis	20000
Saint Lucia	20000
Saint Pierre and Miquelon	3178
Saint Vincent and the Grenadines	20000
Samoa	18783
Sao Tome and Principe	18506
Saudi Arabia	7114
Senegal	9788
Serbia	3164
Seychelles	6676
Sierra Leone	19980
Singapore	20000
Slovakia	3145
Slovenia	3462
Solomon Islands	19652
Somalia	7349
South Africa	4147
Spain	3112
Sri Lanka	19388
Sudan	8722
Suriname	20000
Swaziland	7590
Sweden	2641
Switzerland	3194
Syrian Arab Republic	5142
Tajikistan	2507
Thailand	19395
The former Yugoslav Republic of Macedonia	3044
Timor-Leste	17875
Togo	19069
Tokelau	6676
Tonga	20000
Trinidad and Tobago	20000
Tunisia	6336
Turkey	3151
Turkmenistan	2789
Tuvalu	6676
Uganda	5482
Ukraine	3141
United Arab Emirates	7740

COUNTRY	AVERAGE SPECIES RICHNESS
United Kingdom	3241
United Republic of Tanzania	7719
United States of America	3908
United States Virgin Islands	20000
Uruguay	7597
Uzbekistan	2812
Vanuatu	19867
Venezuela (Bolivarian Republic of)	17691
Viet Nam	18408
Wallis and Futuna Islands	20000
Western Sahara	7749
Yemen	6175
Yugoslav SFR	3044
Zambia	4587
Zimbabwe	5553

7.3 Pre-calculated potentially affected biodiversity associated to crude oil and natural gas production

To enable comparison between bio-based and fossil-based materials, the potentially affected biodiversity associated to crude oil and natural gas production in main exporting countries has been pre-calculated (Table 16, Table 17).

Table 16: Biodiversity potentially affected by crude oil production

GEOGRAPHY	LAND OCCUPATION (M2.Y/KG CRUDE OIL)	SPECIES RICHNESS (PAS)	AFFECTED BIODIVERSITY IMPACT SCORE (M2.Y.PAS/KG CRUDE OIL)
Canada (Alberta)	8.66E-04	1647	1.43
Great Britain	6.13E-04	3237	1.98
Middle East	4.14E-03	7114	29.44
Nigeria	8.66E-04	14985	12.98
North Africa	4.91E-03	7671	37.67
Norway	4.23E-04	2681	1.13
Russia	7.86E-03	1485	11.67
USA	8.66E-04	2519	2.18

Table 17: Biodiversity potentially affected by natural gas production

GEOGRAPHY	LAND OCCUPATION (M2.Y/M3 NATURAL GAS)	SPECIES RICHNESS (PAS)	AFFECTED BIODIVERSITY IMPACT SCORE (M2.Y.PAS/M3 NATURAL GAS)
Algeria	1.23E-03	6846	8.40
Canada (Alberta)	1.31E-03	1647	2.16
Germany	9.76E-04	3202	3.12
Great Britain	5.15E-04	3237	1.67
Netherlands	1.02E-03	3238	3.31
Norway	6.20E-04	2681	1.66
Russia	8.66E-04	1485	1.29
USA	1.57E-03	2519	3.94

7.4 Default RUSLE factors for the erosion calculation

The soil losses by water erosion are represented by the "RUSLE" equation[52]:

A = R · L · S · K · C · P (see section 4.4.9). Default values for this equation are provided in the sections below.

7.4.1 RUSLE R factor for erosion calculation

R (MJ mm h^{-1} ha^{-1} yr^{-1}) is the rainfall-runoff erosivity factor. The value provided are calculated based on the models described by Bos[53].

Table 18: Default R factors, for a few countries, for the erosion equation

COUNTRY	R		COUNTRY	R
Argentina	2.15E+03		Kenya	1.96E+03
Australia	1.00E+01		Mexico	5.74E-02
Belgium	1.27E+02		Morocco	1.42E+01
Brazil	1.02E+04		Netherlands	7.37E+01
Cameroon	8.64E+03		New Zealand	2.48E+03
Canada	5.26E+02		Nigeria	5.44E+03
Chile	2.28E+02		Paraguay	3.00E+03
China	2.17E+03		Peru	1.24E+03
Colombia	1.66E+04		Philippines	1.44E+04
Costa Rica	2.15E+04		Poland	5.66E+02
Côte D'Ivoire	7.08E+03		Portugal	3.29E+02
Ecuador	1.15E+04		Russian Federation	5.19E+02
Finland	1.98E+02		Serbia	6.08E+02
France	1.07E+02		South Africa	1.02E+01
Germany	5.49E+01		Spain	3.13E+01
Ghana	5.79E+03		Sri Lanka	9.68E+03
Greece	1.01E+03		Switzerland	1.75E+03
Hungary	5.59E+02		Thailand	8.42E+03
India	1.04E-01		Turkey	8.22E+02
Indonesia	1.80E+04		Ukraine	5.56E+02
Israel	N/A		United States	2.31E+03
Italy	1.65E+02		Vietnam	1.07E+04

(a) Default model gives a negative value for Israel, which is impossible.

7.4.2 RUSLE K factor for erosion calculation

K (Mg h MJ^{-1} mm^{-1}) is the soil erodibility factor.

Table 19: Default K factors, for a few countries, for the erosion equation

COUNTRY	K		COUNTRY	K
Argentina	0.0438		Kenya	0.0438
Australia	0.0311		Mexico	0.0438
Belgium	0.0438		Morocco	0.0339
Brazil	0.0339		Netherlands	0.0438

[52] Revised Universal Soil Loss Equation Version 2 (RUSLE 2). USDA-Agricultural Research Service. 2013.
[53] LANCA ® Characterization Factors for Life Cycle Impact Assessment. Bos et al. 2016.

COUNTRY	K
Cameroon	0.0150
Canada	0.0438
Chile	0.0438
China	0.0438
Colombia	0.0339
Costa Rica	0.0339
Côte D'Ivoire	0.0339
Ecuador	0.0438
Finland	0.0438
France	0.0438
Germany	0.0438
Ghana	0.0339
Greece	0.0438
Hungary	0.0438
India	0.0438
Indonesia	0.0339
Israel	0.0438
Italy	0.0438
New Zealand	0.0438
Nigeria	0.0230
Paraguay	0.0200
Peru	0.0438
Philippines	0.0339
Poland	0.0438
Portugal	0.0438
Russian Federation	0.0438
Serbia	0.0339
South Africa	0.0438
Spain	0.0438
Sri Lanka	0.0339
Switzerland	0.0438
Thailand	0.0339
Turkey	0.0438
Ukraine	0.0438
United States	0.0438
Vietnam	0.0339

7.4.3 RUSLE L and S factor for erosion calculation

L (dimensionless) is the slope length factor, S (dimensionless) is the slope steepness factor. As both are related and are based on rough assumptions at country level, only the product L*S is provided.

*Table 20: Default L*S factors for the erosion equation*

COUNTRY	LS
Rice	0.030
Other crops	0.456

In the case specific local information is available, the Ontario Ministry of Agriculture, Food and Rural Affairs provides more detailed values at this link, table 3A:

http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm#5

LS values per country are also available from the literature[54].

7.4.4 RUSLE C factor for erosion calculation

C (dimensionless) is the land cover and management factor. The values proposed by Borrelli[55] (Supplementary Table 2) are reproduced in the Table 21 below.

[54] A New European Slope Length and Steepness Factor (LS-Factor) for Modeling Soil Erosion by Water. Panagos et al. 2015.
[55] An Assessment of the Global Impact of 21st Century Land Use Change on Soil Erosion. Borrelli et al. 2017.

Table 21: Default C factors for the erosion equation

	Crop Group		C-Factor
1	Cereal Grains	Various	0.2
		Maize	0.38
		Rice	0.15
2	Legume Vegetables	Various	0.32
3	Root and Tuber Vegetables	Various	0.34
4	Fruiting Vegetables	Various	0.25
5	Cucurbit Vegetables	Various	0.25
6	Bulb Vegetable	Various	0.3
7	Leafy Vegetables	Various	0.25
		Tobacco	0.5
8	Forage, Fodder and Straw of Cereal Grains Group	Mixed-legumes	0.15
		Mixed-grasses	0.1
9	Grapes and Hops	Grapes	0.35
		Hops	0.42
10	Oilseed Group	Various	0.25
		Cotton	0.4
11	Fibre Crops	Fibre Crops	0.28
12	Berries Group	Various	0.15
		Strawberries	0.2
13	Shrubs Herbs and Spices Group	Shrubs Herbs and Spices	0.15
		Coffee	0.2
14	Trees/Fruit Tree	Various	0.15

7.4.5 RUSLE P factor for erosion calculation

P (dimensionless) is the soil conservation or prevention practices factor.

Table 22: Default P factors for the erosion equation

PREVENTION PRACTICE	P
Up & down slope (no prevention)	1.0
Cross slope	0.75
Contour farming	0.50
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

Source: Ontario Ministry of Agriculture, Food and Rural Affairs
http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm#t5

More detailed information is available from the literature, for instance in Panagos (2015)[56].

[56] Modelling the Effect of Support Practices (P-Factor) on the Reduction of Soil Erosion by Water at European Scale Panagos et al. 2015.