Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe

S2Biom Project Grant Agreement n°608622

D5.1
Methodology for life-cycle based environmental sustainability assessment of non-food biomass value chains

June 2014

About S2Biom project

The S2Biom project - Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe - supports the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies, and roadmaps that will be informed by a "computerized and easy to use" toolset (and respective databases) with updated harmonized datasets at local, regional, national and pan European level for EU28, Western Balkans, Moldova, Turkey and Ukraine. Further information about the project and the partners involved are available under www.s2biom.eu.

Project coordinator

FNR
Fachagentur Nachwachsende Rohstoffe e.V.

Scientific coordinator

Imperial College London

Project partners

About this document

This report corresponds to deliverable 5.1 – Methodology for life-cycle based environmental sustainability assessment of non-food biomass value chains - of S2Biom.

Due date of deliverable:	February 2015
Actual submission date:	June 2014
Start date of project:	2013-01-09
Duration:	36 months

Work package	5
Task	5.1
Lead contractor for this deliverable	JRC
Editor	n.a.
Authors	S. Manfredi (JRC)
Quality reviewer	B. Kavalov (JRC)

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services):	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Version	Date	Author(s)	Reason for modification	Status
0.1	03/06/2014	S. Manfredi	Version defining request for input from partners	

This project is co-funded by the European Union within the 7th Frame Programme. Grant Agreement n°608622. The sole responsibility of this publicati on lies with the author. The European Union is not responsible for any use that may be made of the information contained therein.

Abstract

The proposed methodology provides a user friendly tool to assess the environmental sustainability of non-food bio-based products[1] and their supply chains, using a life-cycle perspective. It is largely based on the Product Environmental Footprint (PEF) method developed by the Joint Research Centre (JRC) of European Commission (EC) in close cooperation with the Directorate General for the Environment (DG ENV).

The methodology represents a comprehensive, science-based method able to provide quantitative understanding of a wide range of environmental aspects. It can be used to conduct comparative environmental assessments of non-food bio-based products along their supply chains. Applying the methodology can help identifying existing gaps in data and/or information availability, thus bringing useful insights to the understanding of the product-system being assessed.

The methodology is structured into six phases: (1) definition of the goals of the assessment, (2) definition of the scope of the assessment, (3) development of the assessment inventory, (4) development of the impact assessment, (5) interpretation and reporting of the results of the assessment, (6) critical review of the assessment.

When assessing the environmental sustainability performance of a given bio-based product-system following this methodology, it is recommended to consider a broad range of environmental aspects. For this purpose, a default list of 14 impact categories, related indicators and impact assessment models is provided. However, it is also recognised that relevant potential environmental impacts may go beyond these default options, or be different. For this reason, the methodology is open to the application of additional impact categories or other quantitative indicators, or even additional qualitative criteria / descriptions. This is intended to help interpreting the results of the assessment and, at the same time, ensure a higher flexibility and adaptability of the methodology to different contexts.

[1] Bio-based products are products that are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilized (CEN – Report on Mandate M/429)

Table of contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

C	Completeness (in data quality evaluation)
CF	Characterisation Factor
CFCs	Chlorofluorocarbons
CPA	Statistical Classification of Products by Activity
CTU	Comparative Toxic Unit
DG ENV	Directorate General for Environment
DQR	Data Quality Rating
EC	European Commission
EF	Environmental Footprint
EMAS	Eco-Management and Audit Schemes
EoL	End-of-Life
GR	Geographical Representativeness
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCT	Life Cycle Thinking
M	Methodological appropriateness and consistency (in data quality evaluation)
OEF	Organisation Environmental Footprint
P	Precision/Uncertainty (in data quality evaluation)
PEF	Product Environmental Footprint
SOM	Soil Organic Matter
TeR	Technological Representativeness (in data quality evaluation)
TiR	Time-related representativeness (in data quality evaluation)

1. Background and Introduction

The proposed methodology is meant to provide a user friendly tool to assess the environmental sustainability of non-food bio-based products[2] and their supply chains, using a life-cycle perspective.

This methodology represents a comprehensive, science-based method able to provide quantitative understanding of a wide range of environmental aspects. It can thus be used to conduct comparative environmental assessments of non-food bio-based products along their supply chains, i.e. from primary production of biological resources to end-of-life (EoL) processes. Applying the methodology can help identifying existing gaps in data and/or information availability and/or accessibility, thus bringing useful insights to the understanding of the product-system being assessed. In practice, its applicability may be constrained by the actual extent of availability and/or accessibility of data and information.

This methodology is largely based on the Product Environmental Footprint (PEF) method developed by the Joint Research Centre (JRC) of European Commission (EC) in close cooperation with the Directorate General for the Environment (DG ENV). The EC PEF method has undergone extensive testing and consultation phases and, ultimately, the 2013 Recommendation of the European Commission “on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations” supports its use when undertaking environmental footprint studies of products and organisations (EC, 2013a and 2013b).

In line with the EC PEF method, this methodology supports multi-criteria assessment of the environmental performance of a product (i.e. a good or service, as from ISO14040:2006) throughout its life cycle (ISO, 2006). It can be used for in-house applications (e.g., support to environmental management, identification of environmental hotspots and environmental performance improvement, tracking) and external applications (e.g., marketing, benchmarking, environmental labelling, supporting eco-design throughout supply chains, green procurement, or responding to the requirements of environmental policies at European or Member State level). It aims at providing for a greater degree of methodological consistency and establishes unambiguous requirements, hence facilitating increased comparability and reproducibility of results. Key principles that were considered for advancing the methodology include:

1. Relevance: all accounting models used and data collected should be as relevant to the study as possible;
2. Completeness: all environmentally relevant material/energy flows should be considered, as well as all relevant impact categories and impact assessment methods;
3. Accuracy: all reasonable efforts should be taken to reduce uncertainties in product system modelling and the reporting of results;

[2] Bio-based products are products that are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilized (CEN – Report on Mandate M/429)

4. Transparency: information should be disclosed in such a way as to provide intended users with the necessary basis for decision-making, and for stakeholders – to assess its robustness and reliability.

The next section presents the methodology for environmental sustainability assessment elaborated for the S2Biom project. It is adapted from the general EC PEF method to the specific context of non-food biomass supply chains.

2. Methodological Guidelines

The methodology for environmental assessment of bio-based products is structured into six phases: (1) definition of the goals of the assessment, (2) definition of the scope of the assessment, (3) development of the assessment inventory, (4) development of the impact assessment, (5) interpretation and reporting of the results of the assessment, (6) critical review of the assessment (Figure 1).

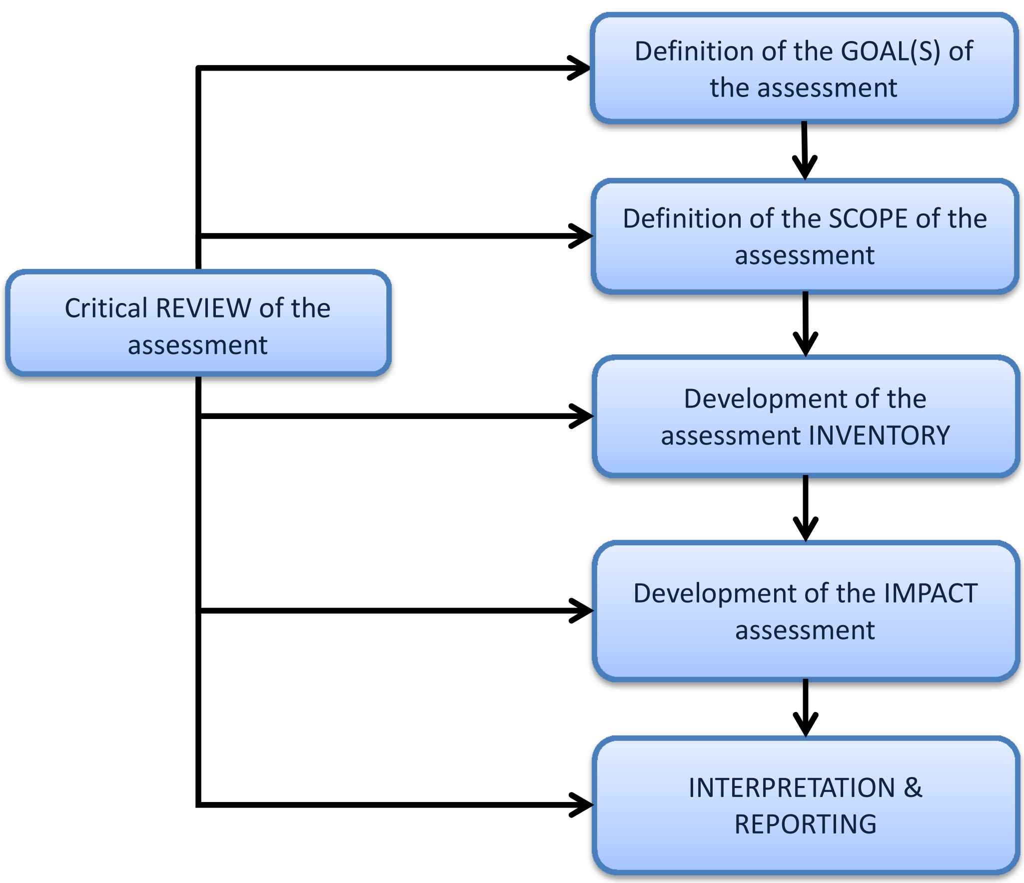

Figure 1: Phases of the methodology for environmental assessment of bio-based products

2.1. Phase 1: Definition of the goals of the environmental sustainability assessment

The definition of the goals of the assessment is the first methodological phase, aiming at unambiguously identifying the general context of the evaluation. The purpose of clearly defining goals is to ensure that the analytical aims, methods, results and intended applications are optimally aligned, and that a shared vision is in place to guide participants in the study. In defining goals, it is important to identify the intended applications and the degree of analytical depth and rigour of the study. This should be reflected in the defined study limitations, which is part of the subsequent "scope definition phase".

In practice, all of the aspects listed in Table 1 should be specified in the goal definition.

Table 1: Definition of the goal(s) of the environmental sustainability assessment

Aspect of goal definition	Definition / Specifications / Examples
Intended applications	Specification of the way(s) the results of the assessment are intended to be used. Examples: • Identify opportunities for improvements of the overall environmental performance of e.g. a wooden table; • Respond to a request about the environmental friendliness of the use on land of compost produced from biodegradable waste; • Provide environmental information to be used for eco-labelling of a certain bio-based product;
Reasons for carrying out the study	Specification of the reason(s) for carrying out the assessment that will allow using the results of the assessment for its intended applications. Examples: • Identify the life cycle stages of e.g. a given wooden table that influence the most the environmental performance; • Quantify the impact on certain impact categories (e.g. Climate Change and Ozone Depletion) arising along the life cycle of e.g. 1 tonne of oranges. • Identify some key pollutants in the compost produced from biodegradable waste that may lead to soil pollution when compost is used on land as fertiliser.
Whether comparisons and/or comparative assertions are to be	A comparative assertion is an environmental claim regarding the superiority or equivalence of one product versus another competing product that performs the same

disclosed to the public	function. Whether or not the study will contain comparisons / comparative assertions to be disclosed to the publics should be clarified in the goal definition phase. Examples: • The assessment will be made publicly available but it will not contain comparisons or comparative assertions; • The assessment will contain comparative assertions intended to be made publicly available.
Target audience	Specification of the person(s) / group(s) that are intended to use the assessment, its results and conclusions in order to fulfil its intended applications. Examples: • The assessment is meant for any potential consumer of a given bio-based product; • The assessment is intended to be used by company “X” and company “Y”; • The assessment is intended to be used by a regulatory body that can use results of the assessment to define relevant product parameters used as objectives in product policies (e.g. Ecodesign, Ecolabel, etc.).
Review procedure, if any	Whether or not the study will undergo a critical review, and who will perform it. Example: • Yes, the study will undergo a third party critical review conducted by reviewers “A”, “B”, and “C”.
Client of the study	Specification of the person / entity / group that has mandated the assessment. Example: • Directorate General for Environment (DG ENV) of the European Commission (EC); • Company “X”; • University “Y”.

2.2. Phase 2: Definition of the scope of the environmental sustainability assessment

The definition of the scope of the assessment is the second methodological phase, aiming at unambiguously describing the system being assessed, especially in terms of the function(s) /service(s) that the system is expected to provide, the boundary of the evaluation (i.e. which processes are included and which are not), the type/nature of environmental aspects that will be evaluated.

In practice, the scope definition should address all of the aspects listed in Table 2:

Table 2: Definition of the scope of the environmental sustainability assessment.

Aspect of scope definition	Definition / Specifications / Examples
Unit of analysis and reference flow	The **unit of analysis** represents the function/service that the system being assessed is meant to provide. The entire assessment depends on the choice of the functional unit, which should thus be carefully defined. The functional unit should be defined according to the following aspects[3]: the functions(s) / service(s) provided ("what"), the extent of each function/service ("how much"), the expected level of quality ("how well"), the duration / life-time of the bio-product ("how long"). Examples: • Assessment of one table made of red-pine wood and used for 30 years after which it is incinerated in a municipal solid waste incinerator with high-efficiency energy recovery; • Assessment of compost produced from municipal biodegradable waste by in-vessel composting technique, and used on land as replacement of generic chemical fertilizers. The **reference flow** is the amount of bio-based product that is needed to provide the defined unit of analysis. The reference flow is used as a reference for the subsequent phases of "inventory" and "impact assessment", in that any input/output flow and any estimated impact will be expressed "per reference flow". For instance, with respect to the two above examples of unit of analysis, potential reference flows could be, respectively: • 100 kg of red-pine wood; • 1 tonne of compost.
Boundary of the system	The system boundary defines which parts of the life-cycle of the bio-based product and which associated processes belong to the

[3] Depending on the specific bio-based product system, not all of these aspects may always be specified.

assessed	product-system being assessed, i.e. are needed for carrying out the function(s) defined by the unit of analysis. It is recommended to include a system boundary diagram to help visualize and structure the system being assessed. The system boundary should be defined following the general cradle-to-grave supply-chain logic, thus including all stages along the life cycle, from primary production of resources through processing, production, distribution, storage, use stage and EoL treatment. It is recommended to divide the processes included in the system boundaries into **foreground processes** (i.e. core processes in the product life cycle for which direct access to information/data is available[4]) and **background processes** (i.e. those processes in the product life cycle for which no direct access to information/data is possible[5]). In order to better visualize the boundary of the system being assessed and help identify any missing process, it is recommended to develop a "system boundary diagram", i.e. a schematic representation of the analysed system. It details which parts of the product life cycle are included or excluded from the analysis. A system boundary diagram can be a useful tool in defining the system boundary and organising subsequent data collection activities.
Impact categories & impact assessment models/methods	**Impact categories** refer to specific categories of impacts considered in an environmental assessment study. These are generally related to resource use, emissions of environmentally damaging substances (e.g., greenhouse gases and toxic chemicals), which may as well affect human health. These categories refer to specific **impact assessment methods** used for quantifying the causal relationships between the material/energy inputs and emissions associated with the product life cycle (assessment inventory) and each impact category considered. Each category, hence, refers to a certain stand-alone **impact assessment model**. The list of recommended environmental impact categories and related impact assessment models for inclusion in the assessment is provided by Table 5 in Annex 1. Depending on the product system and the intended application of the assessment (as reported under "goal definition"), it may be possible to narrow the suite of impact categories considered. Such exclusions should be supported by appropriate documents,

[4] For example, the producer's site and other processes operated by the producer or its contractors such as goods transport, head-office services, etc.

[5] For example, e.g. most of the upstream life cycle processes – such as infrastructures, buildings - and generally all processes further downstream

	such as (non-exhaustive list): • International consensus process; • Independent external review; • Multi-stakeholder process; • Life Cycle Assessment (LCA) studies which have been peer reviewed;
Additional environmental information	Relevant potential environmental impacts of a product (including of course bio-products) may go beyond the life-cycle based impact categories listed in Table 5 (Annex 1). It is important to consider these environmental impacts whenever feasible. For example, biodiversity impacts due to land use changes may occur in association with a specific site or activity. This may involve the application of additional impact categories or other quantitative indicators that are not included in the default list provided here, or even additional qualitative criteria/descriptions where impacts cannot be linked to the product supply-chain in a quantitative manner. Such **additional environmental information** should be viewed as optional, complementary information to the default list of impact categories and is intended to help interpreting the results of the assessment and deriving conclusions. Additional environmental information should be: • Based on data and/or information that is substantiated and has been reviewed or verified; • Specific, accurate and not misleading; • Relevant to the particular type of bio-based product. For the purpose of environmental assessment of bio-based products, the following relevant aspects may be considered for inclusion as “additional environmental information”: • Indicators on the content of bio-based materials in typical product groups; • Temporary carbon storage and delayed carbon emissions; • Recoverability rates indicators (i.e. recyclability rate and energy recoverability rates) for typical bio-based products groups (wholly or partly derived from materials of biological origin); • Content of recycled materials (including recycled fibres) in the product; • Environmentally based life cycle indicators associated to the content of bio-based materials in the product (including the content of recycled fibres), compared to the non-bio-based materials;

	• Environmentally based life cycle indicators associated to the recoverability rates, compared to the option when the materials are landfilled; • Presence of hazardous substances in the product (type, quantity); • Indicators for biomass resources availability[6] • Indicators for biomass provision and costs[7] • Indicators for biomass demand[8] • Indicators for the proportion of biomass issue from organic agriculture and / or processed via certified organic processors. These aspects are presented and elaborated in Annex 1
Assumptions and limitations	Several limitations to carrying out the analysis may arise and therefore assumptions need to be made. All assumptions should be justified and transparently documented. For instance, accessible site-specific data typically do not fully cover the need of data to conduct the assessment, thus generic, site-unspecific data (not representing the reality of the product analysed) may need to be identified and adapted for better representation before they can be used in the assessment. Examples: • In a bio-based product system such as “production of wooden table”, several types of chemicals may be used, but for some of these chemicals not all the necessary information is known/accessible (e.g. amount used, concentrations). Other comparable bio-based product systems are thus looked at to extrapolate the missing information. • In a bio-based product system such as “production of compost from biodegradable waste”, no information is available / accessible on the type of chemical fertilizer that the compost produced within the analysed system will replace. This may be approached in a conservative way by neglecting the benefits arising from replacement of the chemical fertilizer, or by accounting for these benefits making an assumption on the type of chemical compost that would likely be replaced.

[6] This should presumably and partially come as input from the economic and socio-economic assessment conducted within the BISO framework

[7] This should presumably come as input from the economic and socio-economic assessment conducted within the BISO framework

[8] This should presumably come as input from the economic and socio-economic assessment conducted within the BISO framework

2.3. Phase 3: Compilation of the assessment inventory and evaluation of data quality

An inventory of all material/energy resource inputs/outputs and emissions into air, water and soil for the product supply chain has to be compiled as a basis for evaluating the environmental performance. Ideally, the model of the product supply chain should be constructed using product-specific data (i.e. modelling the exact life cycle depicting the supply chain, use, and end-of-life stages as appropriate). In practice, and as a general rule, directly collected, facility-specific inventory data should be used wherever possible. For processes where the company does not have direct access to specific data (i.e. background processes), generic data[9] will typically be used.

2.3.1. Compiling the assessment inventory

All resource use and emissions associated with the life-cycle stages included in the defined system boundaries should be included in the assessment inventory.

The assessment inventory shall adopt the following classifications[10] of the flows included:

- **Elementary flows,** which are (ISO 14040:2006, 3.12) "*material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation."* Elementary flows are, for example, resources extracted from nature or emissions into air, water, soil that are directly linked to the characterisation factors of the impact categories;
- **Non-elementary (or complex) flows**, which are all the remaining inputs (e.g. electricity, materials, transport processes) and outputs (e.g. waste, by-products) in a system that require further modelling efforts to be transformed into elementary flows.

All non-elementary flows in the emission inventory shall be transformed into elementary flows. For example, waste flows shall not only be reported as kg of e.g. household waste, but shall also include the emissions into water, air and soil due to the treatment of the solid waste. The compilation of the emission inventory is therefore completed when all flows are expressed as elementary flows.

In particular, to populate the assessment inventory the elements described in Table 3 should be considered.

[9] Generic data refers to data that is not directly collected, measured, or estimated, but rather sourced from a third-party life cycle inventory database or other source.

[10] Classification is defined as assigning the material/energy inputs and outputs tabulated in the assessment inventory to impact categories according to each substance's potential to contribute to each of the impact categories considered.

Table 3: Key aspects for consideration in the compilation of the assessment inventory

Aspects for consideration	Definition / Specifications / Examples
Raw material acquisition and pre-processing	The raw material acquisition and pre-processing stage starts when resources are extracted from nature and ends when the product components enter (through the gate of) the product's production facility. Processes that may occur in this stage include e.g.: • Mining and extraction of resources; • Pre-processing of all material inputs to the studied product system; • Conversion of recycled material; • Photosynthesis for the biogenic fraction of the bio-based product; • Cultivation and harvesting of trees or crops; • Transportation within and between extraction and pre-processing facilities, and to the production facility.
Capital goods	Examples of capital goods that should be included (if applicable) are: • Machinery used in production processes; • Buildings; • Office equipment; • Transport vehicles; • Transportation infrastructure. Linear depreciation should be used for capital goods. The expected service life of the capital goods should be taken into account (and not the time to evolve to an economic book value of "0").
Production, distribution and storage	Products are distributed to users and may be stored at various points along the supply chain. Examples of processes related to distribution and storage that should be included (if applicable) are e.g.: • Energy inputs for warehouse lighting and heating; • Use of refrigerants in warehouses and transport vehicles; • Fuel use by vehicles.
Use stage	The use stage begins when the consumer or the end-user takes possession of the product and ends when the used product is discarded for transport to a recycling or waste treatment facility. Examples of use-stage processes that should be included (if applicable) are e.g.:

	• Use/consumption patterns, location, time (day/night, summer/winter, week/weekend), and assumed use stage lifespan of products; • Transportation to the location of use; • Refrigeration at the location of use; • Preparation for use (e.g. microwaving); • Resource consumption during use (e.g. energy consumption for microwaving, water use, etc.); • Repair and maintenance of the product during the use stage.
Logistics	Transport parameters that should be taken into account are: • Transport mode: The mode of transport, e.g. by land (road, rail, pipeline), by water (sea, river), or air should be taken into account; • Vehicle type and fuel consumption: The type of vehicle should be taken into account by transport mode, as well as the fuel consumption when fully loaded and empty. An adjustment for the actual load should be made pro-rata based on the consumption of a fully-loaded vehicle[11]; • The ratio of the distance travelled to collect the next load after unloading the product to the distance travelled to transport the product; • Transport distance; • Fuel production. • Any additional transport infrastructure, supporting logistics (e.g. cranes, transporters), resources and tools that may be needed.
End of Life (EoL)	The EoL stage begins when the used product is discarded by the user and ends when the product is returned to nature as a waste product or enters another product's life cycle (i.e. as a recycled input). Examples of EoL-life processes that (if applicable) should be included in the assessment are: • Collection and transport of end-of-life products and packages; • Dismantling of components; • Shredding and sorting; • Conversion into recycled material; • Biological treatment, e.g. composting and anaerobic digestion; • Littering; • Incineration and disposal of bottom ash; • Landfilling and landfill operation and maintenance; • Transport required to all EoL treatment facilities.

[11] The loading rate is the ratio of actual load to the full load or capacity (e.g. mass-based) that a vehicle carries per trip.

	Life cycle inventories for these EoL processes have to be typical of the bio-product groups and of the materials contained in them. A comprehensive source of technical information about management of biodegradable waste and methodological specification on life-cycle modelling is provided by the JRC technical report "Supporting environmentally sound decisions for bio-waste management – A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA)" (EC, 2010).
Accounting for electricity use	For electricity from the grid consumed upstream or within the defined assessment boundary, supplier-specific data should be used. If these are not available, country-specific consumption-mix data should be used of the country/ies where the life cycle stages occur. For electricity consumed during the use stage of the bio-products, the energy mix should reflect that of the country/ies or region(s) where the bio-product is used/consumed. Where such data are not available, the average EU consumption mix should be used.
Accounting for renewable energy (electricity and/or heat) generation	Within the assessed system boundary, energy may be produced from renewable energy sources. If the renewable energy (electricity and/or heat) generated exceeds the amount of energy that is consumed within the defined system boundary, and the excess energy is fed into the grid or consumed elsewhere (e.g. in another nearby facility), this should be credited to the bio-product assessed provided that the credit has not already been taken into account in other schemes. Credits associated with renewable energy generated within the system boundary should be calculated with respect to the corrected average (i.e. by subtracting the externally provided amount of renewable energy), country-level consumption mix of the country where the energy is provided. Where such data is not available, the corrected average EU energy generation mix should be used.
Accounting for removals and emissions of biogenic carbon	Carbon can be removed from the atmosphere due to the growth of trees (characterisation factor[12] of -1 CO_2 eq. for the category Climate Change), while it is released during the burning of wood (characterisation factor of +1 CO_2 eq. for the category Climate Change). Removals and emissions of biogenic carbon sources should be kept separated when compiling the assessment inventory[13].

[12] A characterisation factor is a factor derived from a characterisation model which is applied to convert each inventory flow to the common unit of the impact category indicator (based on ISO 14040:2006).

[13] A separate inventory of emissions/removals of biogenic carbon sources implies that the following characterisation factors should be assigned for the environmental footprint impact category Climate Change: "-1" for removals of biogenic carbon dioxide; "+1" for emissions of biogenic carbon dioxide; "+25" for methane emissions.

Accounting for temporary carbon storage and delayed emissions	Credits associated with temporary (carbon) storage or delayed emissions should not be considered in the calculation of the default impact categories. However, if relevant, these should be included as “additional environmental information”.

2.3.2. Evaluating data quality

In order to obtain reliable results from the environmental assessment it is essential to use high quality data. For this purpose, it is important to evaluate the quality of the data collected in order to verify whether these provide for a robust assessment or whether better data should be identified. In order to evaluate data quality, the following criteria should be considered:

- **Technological representativeness (TeR)**: i.e. the degree to which the dataset reflects the actual technology(ies) of the bio-based system being assessed, including background datasets, if any.

  TeR is assessed via qualitative expert judgment (1 = very good, 2 = good, 3 = fair, 4 = poor, 5 = very poor).

- **Geographical representativeness (GR)**: i.e. the degree to which the dataset reflects the actual geographical context of the bio-based system being assessed (e.g. the exact Country/region), including background datasets, if any.

  GR is assessed via qualitative expert judgment (1 = very good, 2 = good, 3 = fair, 4 = poor, 5 = very poor).

- **Time-related representativeness (TiR)**: i.e. the degree to which the dataset reflects the actual bio-based system being assessed from a time perspective (e.g. a 20 years old dataset may not be representative from a time perspective), including for included background datasets, if any.

  TiR is assessed via qualitative expert judgment (1 = very good, 2 = good, 3 = fair, 4 = poor, 5 = very poor).

- **Completeness (C)**: to be judged with respect to the coverage for each impact category and in comparison to a hypothetical ideal data quality.

  C is evaluated quantitatively (C>90% = very good (1), 80<C<90% = good (2), 70<C<80% = fair (3), 50<C<70% = poor (4), C<50% = very poor (5))[14].

- **Precision/uncertainty (P)**: qualitative expert judgement or relative standard deviation as a % if a Monte Carlo simulation is used.

[14] These ranges are based on the expert-judgment of the authors of the EC EF methodology

If standard deviation is used: P<10% = very low uncertainty (1), 10<P<20% = low uncertainty (2), 20<P<30% = fair uncertainty (3), 30<P<50% = high uncertainty (4), P>50% = very high uncertainty (5)[15].

- **Methodological Appropriateness and Consistency (M)**: the applied inventory methods and methodological choices (e.g. allocation, substitution, etc.) are in line with the goal and scope of the dataset, especially its intended applications as support to decisions. The methods have also been consistently applied across all data.

  M is assessed via qualitative expert judgment (1 = very good, 2 = good, 3 = fair, 4 = poor, 5 = very poor).

The overall data quality rating (DQR) can be calculated by summing up the achieved quality rating for each of the quality criteria, divided by the total number of criteria (i.e. six):

Formula 1 $$DQR = \frac{TeR + GR + TiR + C + P + M}{6}$$

Formula 1 shall be used to identify the overall data quality level according to the achieved data quality rating[16]:

- DQR <1.6 excellent quality
- 1.6<DQR<2.0 very good quality
- 2.0<DQR<3.0 good quality
- 3.0<DQR<4.0 fair quality
- DQR>4 poor quality

Example for determining the data quality rating:

Component	Achieved quality level	Corresponding rating
Technological representativeness (TeR)	very good	1
Geographical representativeness (GR)	fair	3
Time-related representativeness (TiR)	fair	3
Completeness (C)	poor	4
Parameter uncertainty (P)	good	2
Methodological appropriateness and consistency	very good	1

[15] These ranges reflect the expert-judgments of the authors of the EC EF methodology
[16] These ranges reflect the expert-judgments of the authors of the EC EF methodology

(M)

$$DQR = \frac{TeR + GR + TiR + C + P + M}{6} = \frac{1+3+3+4+2+1}{6} = 2.3$$

A DQR of 2.3 corresponds to an overall "good quality" rating.

2.3.3. Data types and data collection

Specific data are data directly measured or collected representing activities at a specific facility or set of facilities. Specific data can be collected, measured or calculated using activity data[17] and related emission factors. Generic data refers to data that are not based on direct measurements or calculation of the respective processes in the system. Generic data can be either sector-specific, i.e. specific to the sector being considered for the environmental assessment, or multi-sector. Examples of generic data include: data from literature or scientific papers; industry-average life-cycle data from inventory databases, industry association reports, government statistics, etc.

The data should include all known inputs and outputs for the processes. Inputs are, for example: use of energy, water, materials, etc. Outputs are the products, co-products[18] and emissions. Emissions can be divided into four categories: emissions to air, to water, to soil, and emissions as solid waste.

Specific data should be obtained for all foreground processes and for background processes, where appropriate. However, when generic data are more representative or appropriate than specific data for foreground processes (to be justified and reported), generic data should also be used for the foreground processes. Generic data should be used only for processes in the background system, unless they are more representative or appropriate than specific data for foreground processes. When available, sector-specific generic data should be used instead of multi-sector generic data.

The most representative sources of data for specific processes are measurements directly performed on the process or obtained from operators via interviews or questionnaires. The data may need calibration, aggregation or other forms of mathematical treatment to bring them in line with the unit of analysis and reference flow of the process. Typical specific data sources are:

- Process- or plant-level consumption data;
- Bills and stock/inventory changes of consumables;
- Emission measurements (amounts and concentrations of emissions from gas and wastewater);

[17] Activity data are data that are specific to the process being considered, as opposed to generic data.

[18] Co-product – any of two or more products coming from the same unit process or product system (ISO 14040:2006)

- Composition of products and waste;
- Procurement and sale department(s)/unit(s).

Generic data can be either sector-specific, i.e. specific to the sector being considered in the study (e.g. manufacturing of wooden tables), or multi-sector. Examples of generic data include:

- Data from peer-reviewed literature or scientific papers;
- Industry-average life-cycle data from inventory databases, industry association reports, government statistics, etc.
- Databases provided by international governmental organisations (for example FAO, UNEP);
- Country-specific national governmental LCI database projects;

2.3.4. Modelling multi-functional product systems

A typical situation that requires careful consideration is when a bio-based product is part of (or it is produced in) a larger process or facility that provides more than one function, i.e. it delivers several goods and/or services ("co-products"). This situation is called “multifunctionality”. For instance, this happens when a factory produces different pieces of furniture, but the environmental sustainability assessment is to be conducted only for one of them, e.g. only for a specific type of wooden table produced within the factory. How can then the input / output flows, related to the overall process, be assigned to the specific bio-product being considered in the environmental sustainability assessment?

In such situations, all inputs and emissions linked to the overall multifunctional process must be partitioned between the product of interest (e.g. the wooden table) and the other co-products in a coherent manner. Systems involving multi-functionality of processes should be modelled in accordance with the following decision hierarchy (see also Figure 2):

I) Subdivision or system expansion

Wherever possible, subdivision or system expansion should be used to avoid allocation. Subdivision refers to disaggregating multifunctional processes or facilities to isolate the input flows directly associated with each product output. System expansion refers to expanding the system by including additional functions related to the co-products. It shall be investigated first whether the analysed process can be subdivided or expanded. Where subdivision is possible, inventory data should be collected only for those unit processes[19] directly attributable[20] to the product(s) being assessed. Or if the system can be expanded, the additional functions shall be included in the analysis with results communicated for the expanded system as a whole rather than on an individual co-product level.

[19] A unit process is the smallest element considered in the emission inventory for which input and output data are quantified. (based on ISO 14040:2006)

[20] Directly attributable refers to a process, activity or impact occurring within the defined system boundary.

II) Allocation based on a relevant underlying physical relationship

Where subdivision or system expansion cannot be applied, allocation should be applied. The inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects relevant underlying physical relationships between them (ISO 14044:2006).

Allocation based on a relevant underlying physical relationship refers to partitioning the input and output flows of a multi-functional process or facility in accordance with a relevant, quantifiable physical relationship between the process inputs and co-product outputs (for example, a physical property of the inputs and outputs that is relevant to the function provided by the co-product of interest). If a product can be identified that is directly substituted[21], allocation based on a physical relationship can be modelled using direct substitution.

Can a direct substitution-effect be robustly modelled? This can be demonstrated by showing that (1) there is a direct, empirically demonstrable substitution effect, AND (2) the substituted product can be modelled and the resource use and emissions profile data subtracted in a directly representative manner:

- If yes (i.e. both conditions are verified), model the substitution effect.

OR

Can input/output flows be allocated based on other relevant underlying physical relationships that relate the inputs and outputs to the function provided by the system? This can be demonstrated by showing that a relevant physical relationship can be defined by which to allocate the flows attributable to the provision of the defined function of the product-system:

- If yes, allocate based on this physical relationship.

III) Allocation Based on Other Relationship

Allocation based on other relationships may be possible. For example, economic allocation refers to allocating inputs and outputs associated with multi-functional processes to the co-product outputs in proportion to their relative market values. The market price of the co-functions should refer to the specific condition and point at which the co-products are delivered. Allocation based on economic value shall only be applied when allocations I or II are not possible.

Allocation based on other relationships can be approached in the following alternative ways:

Can an indirect substitution[22] effect be identified? AND can the substituted product be modelled and the inventory subtracted in a reasonably representative manner?

- If yes (i.e. both conditions are verified), model the indirect substitution effect.

[21] See below for an example of direct substitution.

[22] Indirect substitution occurs when a product is substituted but the exact product which substitutes the product bein assessed is not known.

OR

Can the input/output flows be allocated between the products and functions on the basis of other relationships (e.g. the economic value of the co-products)?

- If yes, allocate products and functions on the basis of the identified relationship

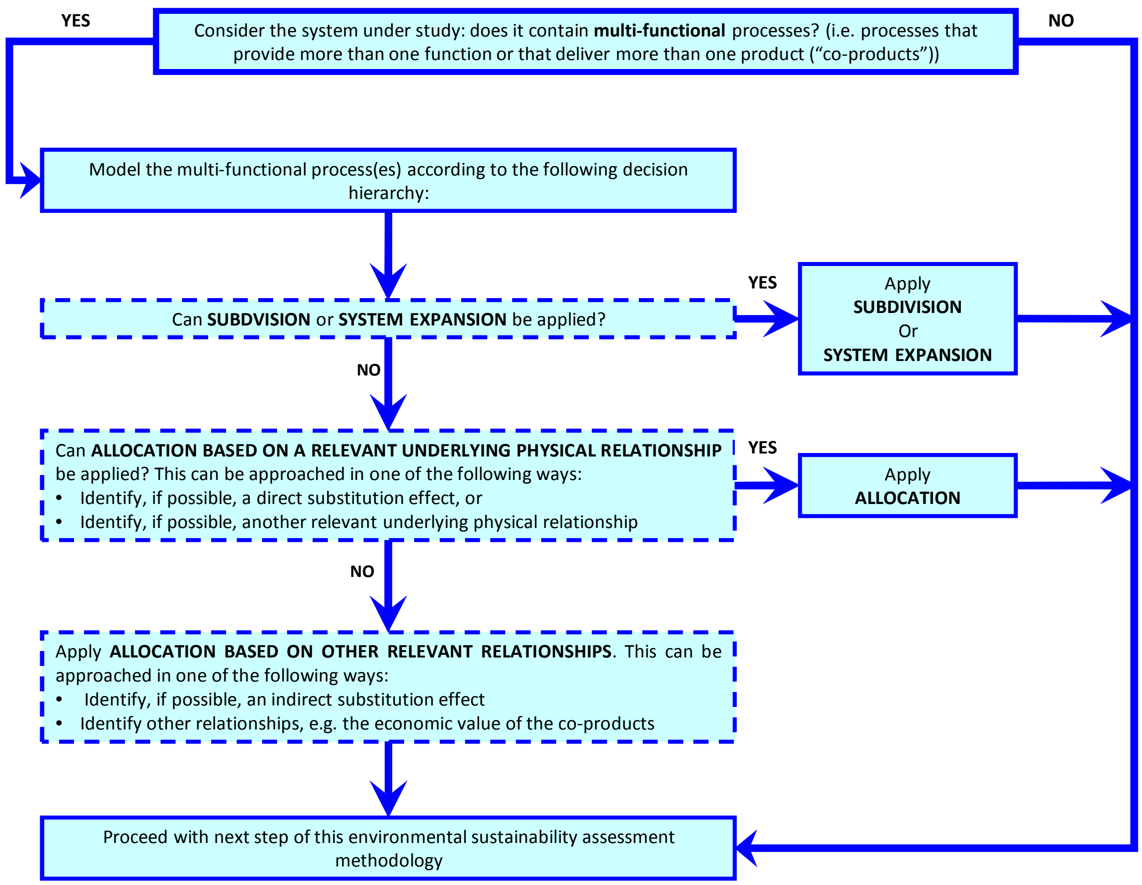

Figure 2: Decision hierarchy for modelling of multi-functional product-systems

2.4. Phase 4: Calculation of the Impact Assessment

Once the assessment inventory has been compiled, the impact assessment phase should be undertaken to calculate the environmental performance of the bio-based product, using the selected impact categories and models, listed in Annex 1, Table 5. The impact assessment phase quantifies the existing pressures on the environment, resource consumption and human health. It includes two mandatory steps - classification and characterisation, and two optional steps - normalisation and weighting.

2.4.1. Mandatory steps: classification and characterisation

Classification requires assigning the material and energy inputs and outputs from the assessment inventory to the relevant impact categories. For example, during the classification phase, all inputs and outputs that result in greenhouse gas emissions are assigned to the Climate Change category. Those that result in emissions of ozone-depleting substances are classified in the Ozone Depletion category. In some cases, an input or output may contribute to more than one impact category. For example, chlorofluorocarbons (CFCs) contribute to both Climate Change and Ozone Depletion.

Example:

Classification of data in the Climate Change impact category:

CO_2	Yes
CH_4	Yes
SO_2	No
NO_x	No

Classification of data in the acidification impact category:

CO_2	No
CH_4	No
SO_2	Yes
NO_x	Yes

Characterisation refers to the calculation of the contribution magnitude of each classified input / output to their respective impact categories, and aggregation of the contributions within each category. This is carried out by multiplying the values in the assessment inventory by the relevant characterisation factor for each impact category. The characterisation factors (CFs) are substance- or resource- specific. They represent the impact intensity of a substance relative to a common reference substance for a given impact category. For example, in the case of calculating climate change impacts, all greenhouse gas emissions are weighted in terms of their impact intensity relative to carbon dioxide, which is the reference substance for this category. This allows for the aggregation of impact potentials and expression in terms of a single equivalent substance (in this case, CO_2 equivalents) for each impact category. For example, the CF expressed as global warming potential for methane equals 25 CO_2 – equivalents and its impact on global warming is thus 25 times higher than of CO_2 (i.e. CF of 1 CO_2-equivalent).

Example:

Climate Change

			CF			
CO_2	g	5,132	x	1	=	5.132 kg CO_2eq
CH_4	g	8.2	x	25	=	0.205 kg CO_2eq
SO_2	g	3.9	x	0	=	0 kg CO_2eq
NO_x	g	26.8	x	0	=	0 kg CO_2eq
			Total	=	5.337 kg CO_2eq	

Acidification

			CF			
CO_2	g	5,132	x	0	=	0 Mol H^+ eq
CH_4	g	8.2	x	0	=	0 Mol H^+ eq
SO_2	g	3.9	x	1.31	=	0.005 Mol H^+ eq
NO_x	g	26.8	x	0.74	=	0.019 Mol H^+ eq
			Total	=	0.024 Mol H^+ eq	

2.4.2. Optional steps: normalization and weighting

Following the two mandatory steps of classification and characterisation, the impact assessment phase may be complemented with normalisation and weighting.

Normalisation is a recommended step, where the impact assessment results are multiplied by normalisation factors (NFs) in order to calculate and compare the magnitude of their contributions to the impact categories relative to a reference unit (typically the pressure related to that category caused by the emissions over one year of a whole country or an average citizen). As a result, normalised results are obtained. These reflect the burdens attributable to a product relative to the reference unit, such as per capita for a given year and region. This allows the relevance of the contributions made by individual processes to be compared to the reference unit of the impact categories considered. For example, impact assessment results may be compared for a given region such as the EU-27 and on a “per-person” basis. In this case they would reflect person-equivalents relative to the emissions associated with the EU-27. Normalised impact assessment results do not, however, indicate the severity or relevance of the respective impacts.

Weighting is an optional step that supports the interpretation and communication of the results from the analysis. In this step, the impact assessment results are multiplied by a set of weighting factors. The factors reflect the perceived relative importance of the respective impact categories. The weighted impact assessment results can then be compared to assess their relative importance. They can also be aggregated across impact categories to obtain combined values or a single overall impact indicator. Weighting requires making value judgements about the importance of the impact categories.

2.5. Phase 5: Interpretation and Reporting of the Results of the Assessment

2.5.1. Interpretation of results

The interpretation of the results of an environmental assessment study serves two purposes:

- To ensure that the performance of the assessment exercise corresponds to the scope and goals of the study. In this sense, the interpretation phase may identify improvements for the assessment until all goals and scope are met;
- To derive robust conclusions and recommendations from the analysis, for example in support of environmental improvements.

To meet these objectives, the interpretation phase should include four key steps: (1) evaluation of robustness, (2) identification of hotspots, (3) estimation of uncertainty, and (4) formulation of conclusions and recommendations (Table 4).

Table 4: Key steps of the interpretation phase

Step	Definition / Specifications / Examples
Evaluation of robustness	The robustness of the environmental assessment can be evaluated by assessing the extent to which methodological choices made for e.g. system boundaries, data sources, and coverage of the impact categories, influence the analytical outcomes. Tools that can be used for this purpose include: • **Completeness check:** evaluates the extent to which the assessment inventory is complete in relation to the defined goal(s), scope, and system boundaries. This includes completeness of process coverage (i.e. all processes at each supply-chain stage considered have been included) and input/output coverage (i.e. all material or energy inputs and emissions associated with each process have been included). • **Sensitivity checks**: assesses the extent to which the results are determined by specific methodological choices and the impact of implementing alternative choices where these are identifiable. It is useful to structure sensitivity checks for each phase of the assessment, including goal and scope definition, the compilation of the assessment inventory, etc. • **Consistency check**: assesses the extent to which

	assumptions, methods, and data quality considerations have been applied consistently throughout the environmental assessment. Any issue identified in this evaluation can then be used to conduct iterative improvements of the assessment.
Identification of hotspots	Once it has been ensured that the environmental assessment is robust and conforms to all aspects defined in the goal and scope definition phases, the next step is to identify the main elements of the calculated results. This step may also be referred to as “hotspot” or “weak point” analysis. Contributing elements may be specific life-cycle stages, processes, or individual material/energy inputs/outputs associated with a given stage or process in the bio-based product supply chain. These are identified by systematically reviewing the calculated results. Such analyses provide the necessary basis to identify environmental improvement potentials along the supply chains of the considered bio-based system.
Estimation of uncertainty	Estimating the uncertainties of the final assessment results supports iterative improvement of the studies. It also helps the target audience to assess the robustness and applicability of the assessment results. There are two key sources of uncertainty in environmental assessment studies: • **Stochastic uncertainties** for assessment inventory. Stochastic uncertainties (both parameter and model) refer to statistical descriptions of variance around a mean/average. For normally distributed data, this variance is typically described in terms of an average and standard deviation. Assessment results that are calculated using average data (i.e. the mean of multiple data points for a given process) do not reflect the uncertainty associated with such variance. However, uncertainty may be estimated and communicated using appropriate statistical tools. • **Choice-related uncertainties**. Choice-related uncertainties arise from methodological choices including modelling principles, system boundaries, choice of impact assessment methods and other assumptions related to time, technology, geography, etc. These are not readily amenable to statistical description, but rather can only be characterised via scenario model assessments (e.g. modelling worst- and best-case scenarios for significant processes) and sensitivity analyses.
Formulation of conclusions and	The final aspect of the interpretation phase is to draw conclusions based on the analytical results, answer the

recommendations	questions posed at the outset of the assessment study, and advance recommendations appropriate to the intended audience and context whilst explicitly taking into account any limitations to the robustness and applicability of the results. Potential improvements should be identified such, as for example, cleaner technology techniques, changes in product design, environmental management systems (e.g. Eco-Management and Audit Scheme (EMAS), or other systematic approaches.

2.5.2. Summary of results

A summary of the environmental assessment should be developed in order to provide a relevant, comprehensive, consistent, accurate and transparent account of the study and of the calculated environmental impacts associated with the bio-based product. It reflects the best possible information in such a way as to maximise its usefulness to users, whilst honestly and transparently communicating limitations. The environmental assessment summary should include the following elements:

- Key elements of the goal and scope of the study with relevant limitations and assumptions;
- A description of the system boundary;
- The main results from the assessment inventory;
- Information about data quality, assumptions and value judgements;
- The main results from the impact assessment;
- A description of what has been achieved by the study, conclusions and recommendations;
- Overall appreciation of the limitations, including the uncertainties of the results.

2.6. Phase 6: Critical Review of the Assessment

The critical review is essential to ensure reliability of the: results from the environmental assessment, conclusions and recommendations. In particular, the critical review should ensure that:

- The methods used to carry out the assessment are scientifically and technically sound and valid;
- The used data are appropriate and of sufficient quality;
- The interpretation of results and the respective conclusion and recommendation take into account the respective limitations;
- Results are reported transparently, accurately and consistently.

A critical review, conducted by at least one independent and qualified external reviewer, is highly recommended for studies whose results, conclusions or comparative claims are to be made public.

Glossary

Acidification – Impact category that addresses impacts due to acidifying substances in the environment. Emissions of NO_x, NH_3 and SO_x lead to releases of hydrogen ions (H^+) when the gases are mineralised. 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.

Allocation – An approach to solving multi-functionality problems. It refers to "*partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems*" (ISO 14040:2006).

Average Data – Refers to a production-weighted average of specific data.

Background processes – Refers to those processes in the product life cycle for which no direct access to information is possible. For example, most of the upstream life-cycle processes and generally all processes further downstream will be considered part of the background processes.

Business to Business (B2B) – Describes transactions between businesses, such as between a manufacturer and a wholesaler, or between a wholesaler and a retailer.

Business to Consumers (B2C) – Describes transactions between business and consumers, such as between retailers and consumers. According to ISO 14025:2006, a consumer is defined as "*an individual member of the general public purchasing or using goods, property or services for private purposes*".

Characterisation – Calculation of the magnitude of the contribution of each classified input/output to their respective impact categories, and aggregation of contributions within each category. This requires a linear multiplication of the inventory data with *characterisation factors* for each substance and impact category of concern. For example, with respect to the impact category "climate change", CO_2 is chosen as the reference substance and kg CO_2-equivalents as the reference unit.

Characterisation factor – Factor derived from a characterisation model which is applied to convert an assigned emission flow to the common unit of the impact category indicator (based on ISO 14040:2006).

Classification – Assigning the material/energy inputs and outputs tabulated in the emission inventory to impact categories according to each substance's potential to contribute to each of the mpact categories considered.

Co-function - Any of two or more functions resulting from the same unit process or product system.

Comparative Assertion – An environmental claim regarding the superiority or equivalence of products, based on the results of a study (based on ISO 14040:2006).

Co-product – Any of two or more products resulting from the same unit process or product system (ISO 14040:2006).

Cradle to Gate – A partial product supply chain, from the extraction of raw materials (cradle) up to the manufacturer's "gate". The distribution, storage, use stage and end-of-life stages of the supply chain are omitted.

Cradle to Grave – A product's life cycle that includes raw material extraction, processing, distribution, storage, use, and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.

Data Quality – Characteristics of data that relate to their ability to satisfy stated requirements (ISO 14040:2006). Data quality covers various aspects, such as technological, geographical and time-related representativeness, as well as completeness and precision of the inventory data.

Downstream – Occurring along a product supply chain after the point of referral.

Ecotoxicity – Environmental footprint impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.

Elementary flows – In the emission inventory, elementary flows include "*material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation"* (ISO 14040, 3.12). Elementary flows include, for example, resources taken from nature or emissions into air, water, soil that are directly linked to the characterisation factors of the impact categories.

Impact Assessment – Phase of the environmental sustainability assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (based on ISO 14044:2006).

Impact Assessment Method – Protocol for quantitative translation of the assessment inventory into contributions to an environmental impact of concern.

Impact Category – Class of resource use or environmental impact to which the emission inventory data are related.

Impact category indicator – Quantifiable representation of an impact category (based on ISO 14000:2006).

Environmental impact – Any change to the environment, whether adverse or beneficial, that wholly or partially results from an organisation's activities, products or services (EMAS regulation).

Eutrophication – Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass.

Foreground Processes – Refer to those processes in the product life cycle for which direct access to information is available. For example, the producer's site and other processes operated by the producer or its contractors (e.g. goods transport, head-office services, etc.) belong to the foreground processes.

Gate to Gate – A partial product's supply chain that includes only the processes carried out on a product within a specific organisation or site.

Gate to Grave – A partial product's supply chain that includes only the distribution, storage, use, and disposal or recycling stages.

Generic Data – Refers to data that is not directly collected, measured, or estimated, but rather sourced from a third-party life-cycle-inventory database or other source.

Global Warming Potential – Capacity of a greenhouse gas to influence radiative forcing, expressed in terms of a reference substance (for example, CO_2-equivalent units) and specified time horizon **(**e.g. GWP 20, GWP 100, GWP 500, for 20, 100, and 500 years respectively)**.** It relates to the capacity to influence changes in the global average surface-air temperature and subsequent change in various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc.

Human Toxicity – cancer – Impact category that 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.

Human Toxicity - non cancer – Impact category that 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 non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.

Input – Product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products (ISO 14040:2006).

Ionising Radiation, human health – Impact category that accounts for the adverse health effects on human health caused by radioactive releases.

Land Use – Impact category related to use (occupation) and conversion (transformation) of land area by activities such as agriculture, roads, housing, mining, etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (changes in quality multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (changes in quality multiplied by the area).

Life cycle – Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal (ISO 14040:2006).

Life-Cycle Approach – Takes into consideration the spectrum of resource flows and environmental interventions associated with a product from a supply-chain perspective, including all stages from raw material acquisition through processing, distribution, use, and end-of-life processes, and all relevant related environmental impacts (instead of focusing on a single issue).

Life-Cycle Assessment (LCA) – Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040:2006).

Loading rate – Ratio of actual load to the full load or capacity (e.g. mass) that a vehicle carries per trip.

Multi-functionality – If a process or facility provides more than one function, i.e. it delivers several goods and/or services ("co-products"), it is “multifunctional”. In these situations, all inputs and emissions linked to the process must be partitioned between the product of interest and the other co-products in a principled manner.

Non-elementary (or complex) flows – In the emission inventory, non-elementary flows include all the inputs (e.g. electricity, materials, transport processes) and outputs (e.g. waste, by-products) in a system that need further modelling efforts to be transformed into elementary flows.

Normalisation – After the characterisation step, normalisation is an optional step in which the mpact assessment results are multiplied by normalisation factors that represent the overall inventory of a reference unit (e.g. a whole country or an average citizen). Normalised impact assessment results express the relative shares of the impacts of the analysed system in terms of the total contributions to each impact category per reference unit. When displaying the normalised impact assessment results of the different impact topics next to each other, it becomes evident which impact categories are affected most and least by the analysed system. Normalised impact assessment results reflect only the contribution of the analysed system to the total impact potential, not the severity/relevance of the respective total impact. Normalised results are dimensionless, but not additive.

Output – Product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases (ISO 14040:2006).

Ozone Depletion – Impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons).

Particulate Matter/Respiratory Inorganics – Impact category that accounts for the adverse health effects on human health caused by emissions of Particulate Matter (PM) and its precursors (NO_x, SO_x, NH_3)

Photochemical Ozone Formation – Impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of Volatile Organic Compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NO_x) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials.

Product – Any goods or services (ISO 14040:2006).

Product system – Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product (ISO 14040:2006).

Reference Flow – Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (based on ISO 14040:2006).

Resource Depletion – Impact category that addresses use of natural resources, either renewable or non-renewable, biotic or abiotic.

Sensitivity analysis – Systematic procedures for estimating the effects of the choices made regarding methods and data on the results of a study (based on ISO 14040: 2006).

Soil Organic Matter (SOM) – Is the measure of the content of organic material in soil. This derives from plants and animals and comprises all of the organic matter in the soil exclusive of the matter that has not decayed.

Specific Data – Refers to directly measured or collected data representative of activities at a specific facility or set of facilities. Synonymous with “primary data.”

Subdivision – Subdivision refers to disaggregating multifunctional processes or facilities to isolate the input flows directly associated with each process or facility output. The process is investigated to see whether it can be subdivided. Where subdivision is possible, inventory data should be collected only for those unit processes directly attributable to the products/services of concern.

System Boundary – Definition of aspects included or excluded from the study. For example, for a “cradle-to-grave” analysis, the system boundary should include all activities from the extraction of raw materials through the processing, distribution, storage, use, and disposal or recycling stages.

Uncertainty analysis – Procedure to assess the uncertainty introduced into the results of a study due to data variability and choice-related uncertainty.

Unit of Analysis – The unit of analysis defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product being evaluated; the unit of analysis definition answers the questions “what?”, “how much?”, “how well?”, and “for how long?”

Upstream – Occurring along the supply chain of purchased goods/services prior to entering the system boundary.

Weighting – Weighting is an additional, but not mandatory, step that may support the interpretation and communication of the results of the analysis. Results of the environmental sustainability assessment are multiplied by a set of weighting factors, which reflect the perceived relative importance of the impact categories considered. Weighted results can be directly compared across impact categories, and also summed across impact categories to obtain a single-value overall impact indicator. Weighting requires making value judgements as to the respective importance of the impact categories considered. These judgements may be based on expert opinion, social science methods, cultural/political viewpoints, or economic considerations.

References

Dreicer M., Tort V. and Manen P. (1995): ExternE, Externalities of Energy, Vol. 5 Nuclear, Centre d'étude sur l'Evaluation de la Protection dans le domaine nucléaire (CEPN), edited by the European Commission DGXII, Science, Research and development JOULE, Luxembourg.

European Commission (2010). JRC Technical Report - Supporting environmentally sound decisions for bio-waste management – A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA). ISBN 978-92-79-21019-8 (PDF), doi: 10.2788/53942. Luxembourg: Publications Office of the European Union. Available online at http://lct.jrc.ec.europa.eu/assessment/publications.

European Commission (2013a). RECOMMENDATION (2013/179/EU) on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations, Annex II (Product Environmental Footprint (PEF) Guide).

European Commission (2013b). RECOMMENDATION (2013/179/EU) on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations, Annex III (Organisational Environmental Footprint (OEF) Guide).

Frischknecht R., Steiner R. and Jungbluth N. (2008): The Ecological Scarcity Method – Eco-Factors 2006. A method for impact assessment in LCA. Environmental studies no. 0906. Federal Office for the Environment (FOEN), Bern. 188 pp.

Intergovernmental Panel on Climate Change (IPCC) (2007): IPCC Climate Change Fourth Assessment Report: Climate Change 2007. http://www.ipcc.ch/ipccreports/assessments-reports.htm

ISO 14040:2006 (2006b). International Standard – Environmental management – Life cycle assessment – Principles and framework. International Organization for Standardization. Geneva, Switzerland.

Milà i Canals L., Romanyà J. and Cowell S.J. (2007): Method for assessing impacts on life support functions (LSF) related to the use of ‘fertile land’ in Life Cycle Assessment (LCA). *Journal of Cleaner Production* 15: 1426-1440.

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. and Hauschild M.Z. (2008): USEtox - The UNEP-SETAC 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 J., Posch M., Johansson M. and Hettelingh J.P. (2006): Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator. *International Journal of Life Cycle Assessment* 11(6): 403-416.

Struijs J., Beusen A., van Jaarsveld H. and Huijbregts M.A.J. (2009): Aquatic Eutrophication. Chapter 6 in: Goedkoop M., Heijungs R., Huijbregts M.A.J., De Schryver A., Struijs J., Van Zelm R. (2009): 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.

Van Oers L., de Koning A., Guinee J.B. and Huppes G. (2002): Abiotic Resource Depletion in LCA. Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam.

Van Zelm R., Huijbregts M.A.J., Den Hollander H.A., Van Jaarsveld H.A., Sauter F.J., Struijs J., Van Wijnen H.J. and Van de Meent D. (2008): European characterisation factors for human health damage of PM10 and ozone in life cycle impact assessment. *Atmospheric Environment* 42, 441-453.

World Meteorological Organization (WMO) (1999): Scientific Assessment of Ozone Depletion: 1998. Global Ozone Research and Monitoring Project - Report No. 44, ISBN 92-807-1722-7, Geneva.

Humbert, S., Margni, M., Charles, R., Torres Salazar, O.M., Quirós, A.L. Jolliet, O. (2007). Toxicity Assessment of the most used Pesticides in Costa Rica. Agriculture, Environment and Ecosystems, 118 (2007) 183–190.

Annex I – Complements

A – Default List of Impact Categories, Impact Assessment Models, and Indicators

Table 5: Default list of impact categories, models and indicators for inclusion in the environmental sustainability assessment

Impact Category	Impact Assessment Model	Impact Category indicators	Source
Climate Change	Bern model - Global Warming Potentials (GWP) over a 100 year time horizon.	kg CO_2 equivalent	Intergovernmental Panel on Climate Change, 2007
Ozone Depletion	EDIP model based on the ODPs of the World Meteorological Organization (WMO) over an infinite time horizon.	kg CFC-11 equivalent	WMO, 1999
Ecotoxicity for aquatic fresh water	USEtox model	CTUe (Comparative Toxic Unit for ecosystems)	Rosenbaum et al., 2008
Human Toxicity - cancer effects	USEtox model	CTUh (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008
Human Toxicity – non-cancer effects	USEtox model	CTUh (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008
Particulate Matter/Respiratory Inorganics	RiskPoll model	kg PM2.5 equivalent	Humbert, 2007
Ionising Radiation – human health effects	Human Health effect model	kg U^{235} equivalent (to air)	Dreicer et al., 1995
Photochemical Ozone Formation	LOTOS-EUROS model	kg NMVOC equivalent	Van Zelm et al., 2008 as applied in ReCiPe
Acidification	Accumulated Exceedance model	mol H+ eq	Seppälä et al.,2006;
Eutrophication – terrestrial	Accumulated Exceedance model	mol N eq	Seppälä et al.,2006;

Eutrophication – aquatic	EUTREND model	fresh water: kg P equivalent marine: kg N equivalent	Struijs et al., 2009 as implemented in ReCiPe
Resource Depletion – water	Swiss Ecoscarcity model	m^3 water use related to local scarcity of water	Frischknecht et al., 2008
Resource Depletion – mineral, fossil	CML2002 model	kg antimony (Sb) equivalent	van Oers et al., 2002
Land Use	Soil Organic Matter (SOM) model	Kg (deficit)	Milà i Canals et al., 2007

CFC-11 = Trichlorofluoromethane, also called freon-11 or R-11, is a chlorofluorocarbon.

CTU = Comparative Toxic Unit

PM2.5 = Particulate Matter with a diameter of 2.5 µm or less.

NMVOC = Non-Methane Volatile Organic Compounds

Sb = Antimony

U = Uranium

B – Recommended Additional Environmental Information for Inclusion in the Environmental Impact Assessment

B.1 Additional indicators on resource efficiency of products

Resource efficiency is considered in the EU policy agenda[23], and it has strong links with other policies such as sustainable production and consumption, and those on product and waste. Although Life Cycle Assessment (LCA) is a powerful tool to address resource efficiency of products, it still falls short of addressing many important aspects of resource efficiency. JRC-IES has developed in recent years a method, entitled Resource Efficiency Assessment of Product (REAPro), which aims to address few of these aspects from a life cycle perspective[24,25,26,27]. The method

[23] European Commission (EC), 2011. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Roadmap to a Resource Efficient Europe. Brussels, 20.9.2011. COM(2011) 571 final.

[24] Ardente, F., Mathieux, F., 2013. Identification and assessment of product's measures to improve resource efficiency of products: the case-study of an Energy Using Product. (Submitted to the Journal of Cleaner Production – 8th January 2013).

[25] Ardente, F., Mathieux, F. Recchioni, M. 2013. Combining five criteria to identify relevant products measures for resource efficiency of an energy using product. 20th CIRP International Conference on Life Cycle Engineering, Singapore, 17-19 April 2013, pp. 111-116.

[26] Allacker K, Mathieux F, Manfredi S, Pelletier N, De Camillis C, Ardente F, Pant R. Allocation solutions for secondary material production and end of life recovery: proposals for policy initiatives. Resources Conservation and Recycling. Submitted in April 2013; 2013.

assesses the performances of products against various criteria, such as recycled content, recyclability and recoverability[28] rates, presence of hazardous substances and durability. For the purpose of this project, the following indicators have been identified as potentially relevant:

- Indicators on the content of bio-based materials in typical product groups;
- Recoverability rates indicators (i.e. recyclability rate and energy recoverability rates) for typical bio-based products groups (fully or partially derived from materials of biological origin);
- Content of recycled materials (including recycled fibres) in the product;
- Environmental life cycle indicators associated to the content of bio-based materials in the product (including the content of recycled fibres), compared to the non-bio-based materials ;
- Environmental life cycle indicators associated to the recoverability rates, compared to landfilling;
- Presence of hazardous substances in the product (type, quantity).

Based on the multi-criteria assessment, the REAPro methodology allows identifying product's hot spots (i.e. product's parts that are relevant for given resource efficiency criteria). Successively, the method identifies potential product's measures for improving resource efficiency and assessing measures at single product or product group level. These measures can be suitable for different policies, including requirements for mandatory policies (e.g. enforced via the EU Ecodesign Directive), and voluntary policies (e.g. environmental labelling schemes or environmental claims).

B.2 Additional indicators on availability, costs and demand of biomass resources

The Land Use Integrated Sustainability Assessment (LUISA) platform[29] is a GIS-based platform that enables dynamic simulation of competing land uses based on pre-defined allocation rules (for example, land demand, neighbourhood characteristics, suitability factors, and scenario/policy-specific decision rules). LUMP is interoperable with numerous existing models/data sources (CBM, CAPRI, EUROP2008, LEITAP/IMAGE, TRANSTOOLS, GEM-E3, RHOMOLO, POLES, etc.) and impact assessment models (LISFLOOD, SOC-TOP, GUIDOS, GREEN/SWAT, EFDM, EDGAR, etc.), and can be used for the purpose of constructing spatially and temporally-specific models that combine environmental, social and economic indicator data[30] [31].

[27] F. Ardente, F. Mathieux. Refined methods and Guidance documents for the calculation of indices concerning Reusability / Recyclability / Recoverability, Recycled content, Use of Priority Resources, Use of Hazardous substances, Durability. JRC Technical Report. September 2012

[28] Intended as "energetic recoverability", i.e. the fraction of the total energy content that can be recovered.

[29] Lavalle, C, Baranzelli, C, Batista e Silva, F, Mubareka, S, Rocha Gomes, C, Koomen E., Hilferink, M., 2011. A high resolution land use/cover modelling framework for Europe. ICCSA 2011, Part I, LNCS 6782, 60–75.

[30] Lavalle, C., Baranzelli, C., Mubareka,S., Rocha Gomes, C., Hiederer, R., Batista e Silva, F., Estreguil, C., 2011. Implementation of the CAP Policy Options with the Land Use Modelling Platform: A first indicator-based analysis. JRC Scientific and Technical Reports EUR 24909 EN doi: 10.2788/45131.

The added value of such land-use modelling approach is chiefly related to the possibility of simulating dynamically the competition between different land uses. In fact, sectorial macro-economic models provide projections of economic activities and land requirements at national or regional scale, under specific scenarios. These requirements, together with the building pressure generated by the population dynamics, are responsible for a tight competition for land at local level. Therefore, the resulting land use changes might not satisfy completely all these land requirements. Besides, the local land use/cover changes and the resulting patterns (landscapes) affect the performance of several environmental indicators, e.g. related to biodiversity, soil quality[32] [33] and water consumption[34] [35].

The LUMP platform could possibly contribute to the estimation of indicators related to the availability, costs and demand of biomass resources. The environmental impacts of production and consumption systems on the resource 'land' can be identified with a spatially-explicit approach. Indicators of interest are:

<u>Biomass resources availability</u>

1. Dedicated energy crops (i.e. New Energy Crops - NECR)
    a. Total availability of NECR, regional level (Nomenclature of Territorial Units for Statistics, level 2 - NUTS2)[36]:
        Allocated NECR per NUTS2 on available land, expressed in hectares and correspondent biofuel production, taking into account current constraints (e.g. protected areas and certain land use/cover classes must be excluded from the available land).
    b. Availability of NECR, classified by suitability categories:

[31] Batista e Silva, F., Lavalle, C., Jacobs-Crisioni, C., Barranco, R., Zulian, G., Maes, J., Baranzelli, C., Perpiña, C., Vandecasteele, I., Ustaoglu, E., Barbosa, A., 2013. Direct and Indirect Land Use Impacts of the EU Cohesion Policy - Assessment with the Land Use Modelling Platform. JRC Scientific and Policy Reports EUR 26460 EN doi: 10.2788/60631.

[32] Hiederer, R., Barbosa, A., Baranzelli, C., Grassi, G., Lavalle, C., 2013. IPCC Tier 1 Method for Estimating C-Stocks of Mineral Soils Applied to Modeled Land Use Change 2010-2050 - Contribution to JRC AA Nr 070307/2010/585065/A4: Analysis and modeling of energy, transport and climate change scenarios: future GHG emission from agriculture and forestry. JRC Technical Reports. *In publication*.

[33] Hiederer, R., Barbosa, A., Baranzelli, C., Lavalle, C., 2013. Land Use Related Changes in C-Stocks of Mineral Soils Indicator for Resource Efficiency - Contribution to JRC discussion paper: An analytical framework for the assessment of the land milestone proposed in the Roadmap for Resource Efficiency. JRC Technical Reports. *In publication*.

[34] Burek, P. A., Mubareka, S., Rojas Mujica, R. F., De Roo, A., Bianchi, A., Baranzelli, C., Lavalle, C., Vandecasteele, I., 2012. Evaluation of the effectiveness of Natural Water Retention Measures -Support to the EU Blueprint to Safeguard Europe's Waters - EUR 25551 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2012. JRC75938.

[35] De Roo, A., Burek, P. A., Gentile, A., Udias, A., Bouraoui, F., Aloe, A., Bianchi, A., La Notte, A., Kuik, O., Elorza Tenreiro, J., Vandecasteele, I., Mubareka, S., Baranzelli, C., Van Der Perk, M., Lavalle, C.,Bidoglio, G., 2012. A multi-criteria optimisation of scenarios for the protection of water resources in Europe: Support to the EU Blueprint to Safeguard Europe's Waters - EUR 25552 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2012. JRC75919.

[36] For info: http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction

Allocated NECR classified according to the local suitability of the land to grow NECR. The suitability map for NECR is based on climate conditions, topography, soil properties and current land uses. In short, the higher the suitability, the higher the potential productivity level without the need of additional inputs potentially harmful for the environment.

c. Availability of NECR on policy-relevant soil categories (unfavourable agriculture soil conditions):

Allocated NECR classified according to the presence of some location-specific soil categories, e.g. associated with land degradation and contamination issues. The conversion of this land to NECR might have additional positive benefits due to the reclamation and utilization of degraded, marginal and abandoned lands.

2. Provision of primary agricultural residues:
   a. Availability of agricultural land suitable for the provision of primary agricultural residues, based on the CAPRI model projections:

      Allocated land per NUTS2, expressed in hectares, and corresponding quantity of raw residues/produced biofuels.

   b. Availability of agricultural land suitable for the provision of primary agricultural residues, based on additional environmental and bio-physical criteria:

      Allocated land per NUTS2, expressed in hectares, and corresponding quantity of raw residues/produced biofuels.

3. Biomass for energy purposes from forest:
   a. Availability of forest land suitable for the provision of biomass for energy purposes:

      Allocated forest land per NUTS2, expressed in hectares, taking into account environmental and basic technical constraints associated with biomass extraction activities.

   b. Availability of biomass for energy purposes from forest land, taking into account environmental, bio-physical and forest management criteria:

      Biomass from forest land, per NUTS2.

4. Local availability of raw materials:
   c. Distribution of Collection Centres:

      Allocation of local collection facilities for biomass raw material.

<u>Biomass provision and costs</u>

5. Costs associated with some stages of the supply chain (e.g. transport and pre-processing from field to collection point/biorefinery, etc.)

<u>Biomass demand</u>

6. Demand from potential users (e.g. urban settlements, existing power plants, etc.)

B.3 Additional indicators on Ecosystem Services

Ecosystems provide a diverse range of goods and services, including food, timber, clean air and water and recreation opportunities. These so-called ecosystem services are vital to our well-being. The continued and sustainable provision of ecosystem services and the protection of natural capital are increasingly recognized by EU policies as a strategy to cope with potentially changing conditions in the future. Hence, there is substantial overlap between the objectives of a bio-economy and the maintenance or enhancement of ecosystem services under target 2 of the EU Biodiversity Strategy to 2020. Both strategies encompass the sustainable production of renewable biological resources.

Action 5 of the Biodiversity Strategy foresees that Member States will, with the assistance of the Commission, map and assess the state of ecosystems and their services in their national territory by 2014. The Working Group on Mapping and Assessment on Ecosystems and their Services (MAES) is mandated to co-ordinate and oversee Action 5. In 2013, the working group developed ideas for a coherent analytical framework, including a set of common indicators to assess ecosystem services, to ensure consistent approaches are used across Europe.

Table 6 lists the best available indicators to measure the quantity of ecosystem services in Europe based on the CICES classification. This table is the result of the second MAES paper (draft), which provides guidance on the available indicators that can be used at the EU and MS levels for mapping and assessment of ecosystems and their services. In principle, the indicators listed in Table 1 are available for use.

More information on Action 5 and the MAES working group:

- http://biodiversity.europa.eu/ecosystem-assessments/european-level
- http://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/MAESWorkingPaper2013.pdf

Table 6: Best available indicators for assessment of ecosystem services across different ecosystems.

Ecosystem services	**Indicator**
Cultivated crops	• Area and yields of food and feed crops
Reared animals and their outputs	• Livestock
Wild plants, algae and their outputs	• Distribution of wild berries (modelling)
Wild animals and their outputs	• Population sizes of species of interest
Plants and algae from in-situ aquaculture	/

Animals from in-situ aquaculture	● Freshwater aquaculture production
Water (Nutrition)	● Water abstracted
Biomass (Materials)	● Area and yield of fibre crops ● Timber production and consumption statistics
Water (Materials)	● Water abstracted
Plant-based resources	● Fuel wood statistics
Animal-based resources	/
Animal-based energy	/
(Mediation of waste, toxics and other nuisances)	● Area occupied by riparian forests ● N and S removal (forests)
Mass stabilisation and control of erosion rates	● Soil erosion risk or erosion protection
Buffering and attenuation of mass flows	/
Hydrological cycle and water flow maintenance	/
Flood protection	● Floodplains areas (and record of annual floods) ● Area of wetlands located in flood risk zones
Storm protection	/
Ventilation and transpiration	● Amount of biomass
Pollination and seed dispersal	● Pollination potential
Maintaining nursery populations and habitats	● Share of High Nature Value farmland ● Ecological Status of water bodies
Pest and disease control	/
Weathering processes	● Share of organic farming ● Soil organic matter content ● Ph of topsoil ● Cation exchange capacity
Decomposition and fixing processes	● Area of N fixing crops ● Gross nitrogen balance
Chemical condition of freshwaters	● Chemical status
Chemical condition of salt waters	/
Global climate regulation by reduction of greenhouse gas concentrations	● Carbon storage and sequestration by forests

Micro and regional climate regulation	• Forest area
Physical and experiential interactions	• Visitor statistics • Extent of protected areas
Intellectual and representative interactions	/
Spiritual and/or emblematic	/
Other cultural outputs	/
All services at CICES class level except services in italic at CICES group level. CICES Division indicated by brackets. Green indicators are available at national scale, yellow indicator not. This table is based on 3 pilot studies reporting on forests, agro-ecosystems and freshwater ecosystems according to the MAES ecosystem typology.	