STAR-ProBio

Sustainability Transition Assessment and Research of Bio-based Products

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Report summarizing the findings of the literature review on environmental indicators related to bio-based products

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Abstract

This report reviews 83 scientific articles assessing bio-based products, retained for their relevance in the framework of the STAR-ProBio project. The review presents in quantitative terms the environmental indicators used by this sample of literature, grouped by "clusters", which are groups of similar indicators.

The clusters found are compared with those suggested by the key literature sources, such as the PEFCR guidance or the EN 16751 norm.

There is an avoerall good convergence between the clusters found in the reviewed articles and those that are recommended. However, the indicators belonging to the following clusters are considered highly relevant by the key literature and are not used in the reviewed articles as frequently as they should:
- Water availability
- Land use
- Ecosystem quality

Finally, the impacts of wastes are not really addressed by the reviewed articles neither by the key literature sources, mostly because of the lack of methodology for the assessment of the risk that the presence of plastic in the environment represents.

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1 Introduction and Background

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

The aim of Work Package (WP) 2 is to develop an LCA approach for strategic and policy decision support that is compliant with the ILCD and PEF frameworks; and to perform upstream LCA for the case studies identified in WP1. This report is the deliverable (D2.1) of task 2.1 which objective is to carry out a detailed literature review focusing on available peer-reviewed studies based on environmental indicators of bio-based products obtained from residues/wastes and/or renewable sources and available LCA software. Although special attention was paid to European case studies, the review covers other studies available worldwide in order to obtain a broad overview of current practices.

The most representative environmental indicators and impact categories are identified. This literature review will serve as the basis for the selection of impact categories and indicators, which will be carried out in Task 2.3.

2 Relevant types of studies targeted by the review

2.1 Introduction

This literature review targets several types of studies, which are described in the following sections.

2.2 Life Cycle Assessment

Environmental Life Cycle Assessment (E-LCA), normally referred to as Life Cycle Assessment (LCA), is a technique that aims at addressing the environmental aspects of a product and their potential environmental impacts throughout that product's life cycle. The term "product" refers to both goods and services. A product's life cycle includes all stages of a product system, from raw material acquisition or natural resource production to the disposal of the product at the end of its life, including extracting and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal (i.e., cradle-to-grave).

The technique now called E-LCA was originally developed in the late 1960's and throughout the 1970's to address the desire of enterprises and policy makers to understand the relative environmental impacts of alternative packaging options. The scope of environmental impacts grew with time as more studies were performed for more audiences. Initially, the impacts of interest were energy consumption and the production of solid wastes; thus, the inventory data focused on these impacts as well. Emissions of regulated air pollutants were soon added, as were releases of water pollutants.

During the 1970's, 1980's and early 1990's this LCA technique was applied to an increasing variety of product types, and methods for life cycle environmental impact assessment began to be developed. At the end of the 1980's and the early 1990's, a series of workshops were convened by the Society of Environmental Toxicology and Chemistry (SETAC) in order to generate documents, including the initial LCA Code of Practice, published by SETAC in 1993, which promoted consistency and awareness of best practices in E-LCA.

As a means of consolidating LCA procedures and methods, standards were developed as part of ISO's standards on environmental management. Four ISO standards (ISO 14040-14043) were published in the years 1997-2000, all of which were replaced in 2006 with two standards, ISO 14040[1] and ISO 14044[2]. These standards describe the required and recommended elements of E-LCAs.

The ISO standards identify four phases (illustrated in Figure 1) for conducting an LCA:

1. Goal and Scope--where the reasons for carrying out the study and its intended use are described and where details are given on the approach taken to conduct the study. Notably, it is in this phase of the study that the functional unit (see 4.2.4) is defined, and that modelling approaches are specified.

[1] ISO, "ISO 14040:2006(E) Environmental Management — Life Cycle Assessment — Principles and Framework".
[2] ISO, "ISO 14044:2006(E) Environmental Management — Life Cycle Assessment — Requirements and Guidelines".

2. Life Cycle Inventory (LCI)--where the product system (or systems) and its constituent unit processes are described, and exchanges between the product system and the environment are compiled and evaluated. These exchanges, called elementary flows, include inputs from nature (e.g. extracted raw materials, land used) and outputs to nature (e.g. emissions to air, water and soil). The amounts of elementary flows exchanged by the product system and the environment are in reference to one functional unit, as defined in the Goal and Scope phase.
3. Life Cycle Impact Assessment (LCIA)--where the magnitude and significance of environmental impacts associated with the elementary flows compiled during the previous phase are evaluated. This is done by associating the life cycle inventory results with environmental impact categories and category indicators. LCI results, other than elementary flows (e.g. land use), are identified and their relationship to corresponding category indicators is determined. LCIA has a number of mandatory elements: selection of impact categories, category indicators, and characterization models as well as assignment of the LCI results to the various impact categories (classification) and calculation of category indicator results (characterization). This can then be followed by optional elements such as normalization, grouping and weighting.
4. Life Cycle Interpretation, where the findings of the previous two phases are combined with the defined goal and scope in order to reach conclusions or recommendations.

It is important to note that E-LCA provides an assessment of potential impacts on the basis of a chosen functional unit.

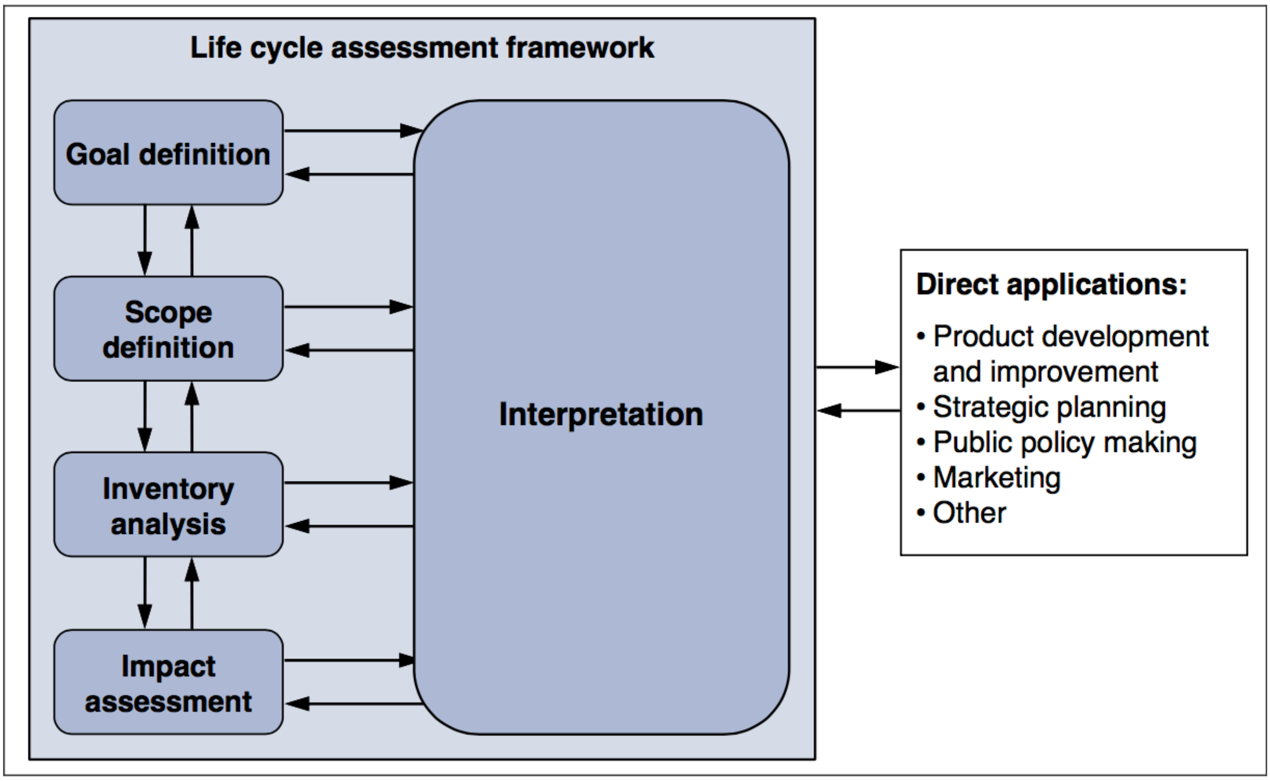

Figure 1: Framework for LCA (from ISO 14040:2006[3]; modified)

[3] ISO, "ISO 14040:2006(E) Environmental Management — Life Cycle Assessment — Principles and Framework".

2.3 Input-output analysis

Input-output analysis is a branch of econometrics used to analyse inter-industry relationship in order to understand the inter-dependencies and complexities of the economy and thus the conditions for maintaining equilibrium between supply and demand.

2.4 Life Cycle Costing

Life cycle costing, or LCC, is a compilation and assessment of all costs related to a product, over its entire life cycle, from production to use, maintenance and disposal. It was first developed and used by the U.S. military in the 1960's in order to assess the costs of long living goods such as tanks and tractors[4]. The motivation is that, for many products, the purchase price reflects only a minority of the costs that will be caused by the product. Since its early beginnings, LCC is applied in many different industrial sectors and use cases, especially for investment goods (transport – railways, air, sea; building sector; general machinery, chemical industry). A number of industry guidelines and references have been developed but an ISO standard does not exist yet. Products can range from complete office buildings, trains or train carriages to one square meter of carpet[5].

LCC can address the economic impact of a product whose environmental performance is scrutinized in a E-LCA. Since both LCC and E-LCA build on a network of interlinked material flows over the whole life cycle of the product, such a combination is inviting. However, it bears particular modelling pitfalls in order to obtain an "as best as possible" and consistent assessment, without double counting.

A SETAC guideline is under preparation at the moment. Environmental Life Cycle Costing is meant to be applied in parallel to an E-LCA, and is defined as:

An assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle (e.g., supplier, manufacturer, user or consumer, or End of Life actor) with complementary inclusion of externalities that are anticipated to be internalized in the decision-relevant future[6].

System boundaries of the environmental LCC need to be equivalent to E-LCA. They will often not be identical, since research and development, planning and managerial overhead will have decision-relevant costs (and will therefore be considered) even without a significant share of environmental impacts.

The text of this section is from UNEP[7].

[4] Sherif and Kolarik, "Life Cycle Costing: Concept and Practice".
[5] Ciroth, "Cost Data Quality Considerations for Eco-Efficiency Measures".
[6] Ciroth et al., *Environmental Life Cycle Costing*. Page 173.
[7] UNEP 2009, *Guidelines for Social Life Cycle Assessment of Products*

2.5 Social Life Cycle Assessment

A social and socio-economic Life Cycle Assessment (S-LCA) is a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal. S-LCA complements E-LCA with social and socio-economic aspects. It can either be applied on its own or in combination with E-LCA.

S-LCA assesses social and socio-economic impacts found along the life cycle (supply chain, including the use phase and disposal) with generic and site-specific data. It differs from other social impacts assessment techniques by its objects: products and services, and its scope: the entire life cycle. Social and socioeconomic aspects assessed in S-LCA are those that may directly affect stakeholders positively or negatively during the life cycle of a product. They may be linked to the behaviours of enterprises, to socio-economic processes, or to impacts on social capital. Depending on the scope of the study, indirect impacts on stakeholders may also be considered.

S-LCA does not have the goal nor pretends to provide information on the question of whether a product should be produced or not. S-LCA documents the product utility but does not have the ability nor the function to inform decision making at that level. It is correct that information on the social conditions of production, use and disposal may provide elements for thoughts on the topic, but will, in itself, seldom be a sufficient basis for decision.

S-LCA is a technique that helps inform incremental improvements but does not in itself provide a breakthrough solution for sustainable consumption and sustainable living. Those topics go well beyond the scope of the tool.

S-LCA provides information on social and socio-economic aspects for decision making, instigating dialogue on the social and socio-economic aspects of production and consumption, in the prospect to improve performance of organizations and ultimately the well-being of stakeholders.

The text of this section is taken from UNEP[8] and Fontes[9].

[8] UNEP, 2009, *Guidelines for Social Life Cycle Assessment of Products*
[9] Fontes, *Handbook for Product Social Impact Assessment 3.0*.

3 Critical aspects considered in the review

3.1 Elements related to LCA scope

3.1.1 Attributional versus Consequential LCA

3.1.1.1 Attributional LCA

Attributional LCA involves the determination of burdens associated with a product (including production and use), service or process at a specific point in time.

For attributional LCAs, there is no perfect allocation system because the desire to attribute impacts or benefits to a specific system is a purely human need that varies case-by-case. Thus, the allocation rules can be modified according to the nature of the study to avoid un-realistic results.

3.1.1.2 Consequential LCA

Consequential LCAs involve the identification of environmental consequences of a decision or change in a particular system. Both market and economic implications may require consideration.

3.1.2 Allocation procedure

A common methodological decision point in LCA occurs when the system being studied is directly connected to a past or future system, or produces co-products. When systems are linked in this manner, the boundaries of the system of interest must be widened to include the adjoining system, or the impacts of the linking items must be distributed—or allocated—across the systems. While there is no clear scientific consensus regarding an optimal method for handling this in all cases[10], many possible approaches have been developed, and each may have a greater level of appropriateness in certain circumstances.

ISO 14044 prioritizes the methodologies related to applying allocation. It is best to avoid allocation through system subdivision or expansion. If that is not possible, then one should perform allocation using an underlying physical relationship. If using a physical relationship is not possible or does not makes sense, then one can use another relationship.

3.1.3 Functional unit

Life cycle assessment relies on a “functional unit” (FU) for comparison of alternative products that may substitute each other in fulfilling a certain function for the user or consumer. The FU describes this function in quantitative terms and serves as an anchor point of the comparison ensuring that the compared alternatives do indeed fulfil the same function. It is therefore critical that this parameter is clearly defined and measurable.

[10] Reap et al., “A Survey of Unresolved Problems in Life Cycle Assessment - Part 1: Goal and Scope and Inventory Analysis”.

3.1.4 System boundaries and cut-off criteria

The system boundaries identify the life cycle stages, processes, and flows considered in the LCA and should include all activities relevant to attaining the study objectives.

The system boundaries identify the life cycle stages, processes and flows considered in the LCA and should include all activities necessary to provide the specified function and therefore relevant to attaining the abovementioned study objectives, as illustrated by Figure 2.

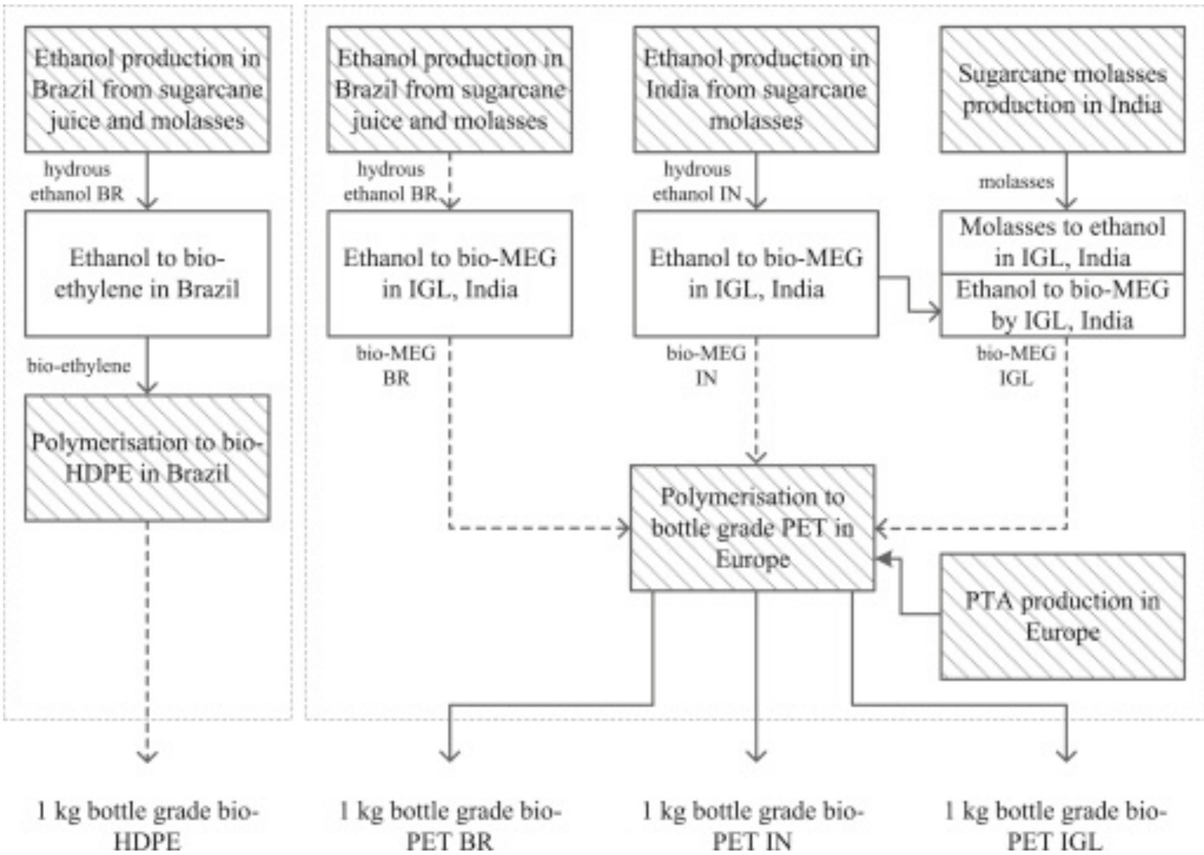

Figure 2: Example of system boundaries describing the main process steps in bio-HDPE (left) and bio-PET (right) production (source: Tsiropoulos et al[11])

Processes may be excluded if their contributions to the total system's environmental impact are less than 1%. All product components and production processes are included when the necessary information is readily available or a reasonable estimate can be made.

3.1.5 Indirect and Direct Land Use Change (iLUC, dLUC)

Land use change (LUC, or land transformation) is a change from one land use type to another as a result of a human activity. Land use change has impacts on soil properties (e.g. carbon content, compaction, nutrients leaching, N_2O emissions among others), on biodiversity, on biotic

[11] Tsiropoulos et al., "Life Cycle Impact Assessment of Bio-Based Plastics from Sugarcane Ethanol".

production[12;13] and on other environmental aspects such as landscape, albedo and evapotranspiration[14].

Direct (dLUC) and indirect (iLUC) land use changes are often distinguished. Direct land use change can be defined as a change directly related to the history of the piece of land occupied. Indirect land use change can be defined as a change that appears in a different area than the direct land use as an indirect consequence. Typical example of iLUC is the increase of soybean production in Brazil that forces cattle production to move to other regions, where deforestation tends to increase as a consequence of increased pressure on land[15]. There is no international consensus on how to consistently and systematically address LUC in life cycle inventory, despite significant research in the LCA community[16;17;18].

The lack of consensus is in no way a reason to ignore iLUC in LCA, as argued by Muñoz et al.[19] in opposition to Finkbeiner[20].

3.2 Elements related to Life Cycle Inventory data

3.2.1 Primary data

Primary data: This term refers to data from specific processes within the supply-chain of the company commissioning the LCA study. Such data may take the form of activity data, or foreground elementary flows. Primary data are site-specific, company-specific (if multiple sites for a same product) or supply-chain-specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain of the company.

3.2.1 Secondary data - Background LCI database

Secondary data: This term refers to data that is not directly collected, measured, or esti-mated by the company commissioning the LCA study, but sourced from a third-party life-cycle-inventory database or other sources. Secondary data includes industry-average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and can also be based on financial data, and contain proxy data, and other generic data.

Primary data that go through a horizontal aggregation step are considered as secondary data.

[12] Brandão and Milà i Canals, "Global Characterisation Factors to Assess Land Use Impacts on Biotic Production".
[13] Koellner and Geyer, "Global Land Use Impact Assessment on Biodiversity and Ecosystem Services in LCA".
[14] Spracklen, Arnold, and Taylor, "Observations of Increased Tropical Rainfall Preceded by Air Passage over Forests".
[15] Lapola et al., "Indirect Land-Use Changes Can Overcome Carbon Savings from Biofuels in Brazil."
[16] Bauen et al., *A Causal Descriptive Approach to Modelling the GHG Emissions Associated with the Indirect Land Use Impacts of Biofuels*.
[17] Fritsche, Sims, and Monti, "Direct and Indirect Land-Use Competition Issues for Energy Crops and Their Sustainable Production - an Overview".
[18] Schmidt, Weidema, and Brandão, "A Framework for Modelling Indirect Land Use Changes in Life Cycle Assessment".
[19] Muñoz et al., "Rebuttal to 'Indirect Land Use Change (iLUC) within Life Cycle Assessment (LCA) - Scientific Robustness and Consistency with International Standards'".
[20] Finkbeiner, *Indirect Land Use Change (iLUC) within Life Cycle Assessment (LCA) – Scientific Robustness and Consistency with International Standards*.

3.2.2 Data quality assessment

The data quality assessment is a process aiming at identifying the data elements that are of low quality and therefore could affect the results in terms of uncertainty if not improved. It relies on four criteria: reliability, temporal representativeness, geographical representativeness and technological representativeness

A data quality rating (DQR) is calculated as the average of the scores attributed to each of the five criteria. A more detailed procedure is described in the PEFCR guidance[21].

3.3 Elements related to Impact Assessment

3.3.1 Life Cycle Impact Assessment methods

This phase is described as follows by ISO 14040[22]: "Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle."

The impact assessment classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment.

Life Cycle Impact Assessment (LCIA) is the phase in an LCA where the inputs and outputs of elementary flows that have been collected and reported in the inventory are translated into impact indicator results related to human health, natural environment, and resource depletion.

It is important to note that LCA and the impact assessment is analysing the potential environmental impacts that are caused by interventions that cross the border between technosphere and ecosphere and act on the natural environment and humans, often only after fate and exposure steps. The results of LCIA should be seen as environmentally relevant impact potential indicators, rather than predictions of actual environmental effects. LCA and LCIA are equally distinct from risk based, substance specific instruments.

According to JRC-IES[23], LCIA is composed of mandatory and optional steps, as reflected also by the subchapters:

Based on classification and characterisation of the individual elementary flows, the LCIA results are calculated by multiplying the individual inventory data of the LCI results with the characterisation factors.

In a subsequent, optional step, the LCIA results can be multiplied with normalisation factors that represent the overall inventory of a reference (e.g. a whole country or an average citizen), obtaining dimensionless, normalised LCIA results.

In a second optional step these normalised LCIA results can be multiplied by a set of weighting factors, that indicate the different relevance that the different impact categories (midpoint level related weighting) or areas-of-protection (endpoint level related weighting) may have, obtaining

[21] European Commission, *Product Environmental Footprint Category Rules Guidance - Version 6.2*.
[22] ISO, "ISO 14040:2006(E) Environmental Management — Life Cycle Assessment — Principles and Framework".
[23] JRC-IES, *ILCD Handbook - General Guide for Life Cycle Assessment - Detailed Guidance*.

normalised and weighted LCIA results that can be summed up to a single-value overall impact indicator. Note that a weighting set always involves value choices.

The LCIA phase prepares additional input for the interpretation phase of the LCI/LCA study.

3.3.2 Midpoint versus Endpoint methods

The midpoint method is a characterisation method that provides indicators for comparison of environmental interventions at a level of cause-effect chain between emissions/resource consumption and the endpoint level.

The category endpoint is an attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern. Hence, endpoint method (or damage approach)/model is a characterisation method/model that provides indicators at the level of Areas of Protection (natural environment's ecosystems, human health, resource availability) or at a level close to the Areas of Protection level.

Midpoint and endpoint level impact assessment - requirements

LCIA methods exist for midpoint and for endpoint level, and for both in integrated LCIA methodologies (see Figure 3). Both levels have advantages and disadvantages. In general, on midpoint level a higher number of impact categories is differentiated and the results are more accurate and precise compared to the three Areas of Protection at endpoint level that are commonly used for endpoint assessments.

Common environmental impact categories (midpoint):

Climate change, (Stratospheric), Ozone depletion, Human toxicity, Respiratory inorganics, Ionizing radiation, (Ground-level), Photochemical ozone formation, Acidification (land and water), Eutrophication (land and water), Ecotoxicity (land and water), Land use, Resource depletion (minerals, fossil and renewable energy resources, water).

Most commonly used environmental areas of protection (damage categories, endpoint):

Human health, Natural environment, Natural resources

By default, all the above impact categories should be covered by the combination of selected LCIA methods. If available and eligible, it is recommended to use them together with coherent impact factors on the endpoint level.

JRC-IES[24] has published and in-depth analysis of different methodologies and indicators.

[24] JRC-IES, *ILCD Handbook - Analysis of Existing Environmental Impact Assessment Methodologies for Use in Life Cycle Assessment*.

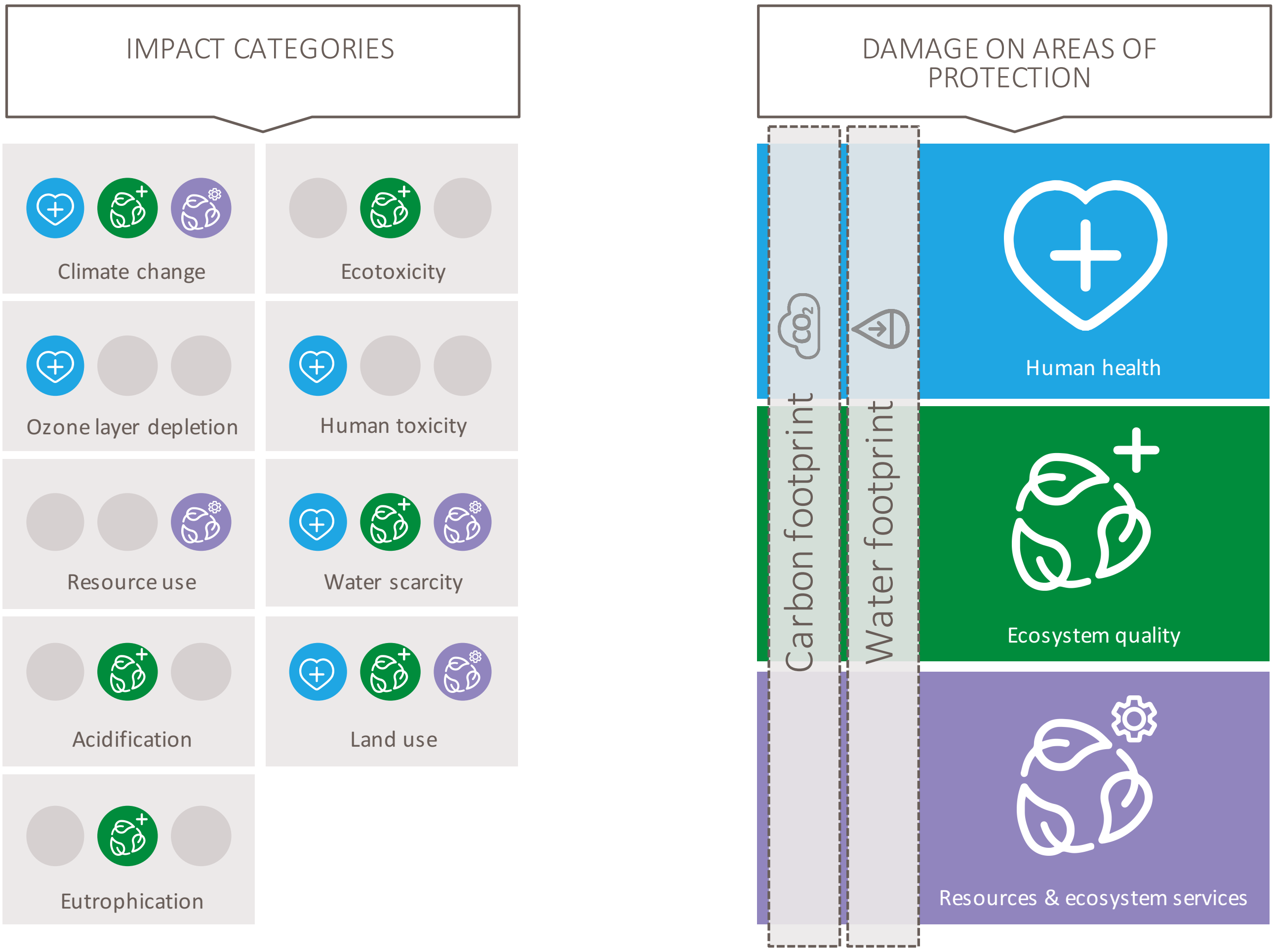

Figure 3: example of impact assessment method including midpoint impact categories (left) and endpoint damage categories (right). In addition, areas of concern, frequently subject to footprinting, are defined and are displayed across the areas of protection. This example is IMPACT World+ [25]

3.3.3 Environmental indicators

The environmental indicators are the main focus of the present review.

There is a large diversity of midpoint indicators, as outlined in the previous section. Many of these indicators can carry similar names while being calculated differently, by different LCIA methodologies or by the same LCIA methodology but in several versions, due to scientific evolution or due to characterization choices (e.g., using a hierarchist approach or another).

The number of published individual midpoint indicators must range in the hundreds. For the sake of the analysis required for this report, a grouping of all found indicators is realised and presented in the results, section 6.6.

[25] Bulle et al., "IMPACT World+: A Globally Regionalized Life Cycle Impact Assessment Method".

4 Key documents - International standards and guidelines

4.1 ISO 14040 and ISO 14044

The ISO 14040[26] and 14044[27] norms are the reference standards for environmental life cycle assessment (LCA). They define the terms agreed internationally, the methodological framework, key principles for life cycle inventory (LCI) and life cycle impact assessment (LCIA), as well as interpretation and reporting requirement for state-of-the-art LCA.

4.2 International Reference Life Cycle Data System (ILCD) Handbook

The ILCD Handbook[28;29] is the first methodological reference for Life Cycle Assessment developed by the European Commission. It provides general guidance on LCA and Impact Assessment (LCIA), and standardises nomenclature and data quality requirements following the ILCD framework. The method presented in the ILCD Handbook is updated in the PEF Guide and PEFCR Guidance (see below), which serve as new references for all LCA studies conducted in the EU context.

4.3 Product Environmental Footprint (PEF) Guide and Product Environmental Footprint Category Rules (PEFCR) Guidance

The Product Environmental Footprint (PEF) Initiative provides a standardised framework for the assessment of the environmental footprint of products in the European Union. The PEF Guide[30] defines the general framework while the PEFCR Guidance[31] defines the technical and methodological instructions to be applied when defining Product Environmental Footprint Category Rules (PEFCR).

The current version of the PEFCR Guidance, v6.2, is the result of 4 years of collaboration between the European Commission DG-Environment, the European Commission Joint Research Centre, multiple industry sectors and dozens of LCA specialists. It builds on the experience from the PEF Pilot Phase where 22 sectors tested the PEF Guide and PEFCR Guidance in drafting PEFCR for a wide array of consumer and intermediate products.

The PEFCR Guidance not only builds on the PEF Guide, but also on several existing standards such as:

[26] ISO, "ISO 14040:2006(E) Environmental Management — Life Cycle Assessment — Principles and Framework".
[27] ISO, "ISO 14044:2006(E) Environmental Management — Life Cycle Assessment — Requirements and Guidelines".
[28] JRC-IES, *ILCD Handbook - General Guide for Life Cycle Assessment - Detailed Guidance*.
[29] JRC-IES, *ILCD Handbook - Recommendations for Life Cycle Impact Assessment in the European Context*.
[30] Manfredi et al., *Product Environmental Footprint (PEF) Guide*.
[31] European Commission, *Product Environmental Footprint Category Rules Guidance - Version 6.2*.

- ISO 14025:2006 - Environmental labels and declarations – Type III environmental declarations – Principles and procedures (ISO)
- BP X30-323-0:2011 - Principes généraux pour l'affichage environnemental des produits de grande consommation (AFNOR, France)
- Greenhouse Gas Product Accounting and Reporting Standard (GHG Protocol, 2011)
- PAS 2050 - Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (BSI, 2011)
- ISO 14020:2000 Environmental labels and declarations – General principles
- ISO 14021:1999 Environmental labels and declarations — Self-declared environmental claims (Type II environmental labelling)
- ISO 14040:2006 Environmental management — Life cycle assessment —Principles and framework
- ISO 14044:2006 Environmental management — Life cycle assessment —Requirements and guidelines
- ISO 14050:2006 Environmental management — vocabulary
- ISO/TS 14067:2013 Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification and communication
- ISO 17024:2003 Conformity assessment – General requirements for bodies operating certification of persons.
- ISO/TS 14071:2014 Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006
- ISO 14046:2014 Environmental management -- Water footprint -- Principles, requirements and guidelines
- ENVIFOOD PROTOCOL - Food SCP RT (2013), ENVIFOOD Protocol, Environmental Assessment of Food and Drink Protocol, European Food Sustainable Consumption and Production Round Table (SCP RT), Working Group 1, Brussels, Belgium.

Among the issues covered by the PEFCR Guidance, the following are of particular interest to STAR-ProBio:

- List of impact categories
- Handling multi-functional processes
- Climate change modelling, including land use and land use change
- Agricultural modelling
- Electricity modelling
- End-of-life modelling
- Data requirements and quality requirements

The impact categories recommended by the PEF Guidance are reported in section 6.7.3.

4.4 EN 16751 Bio-based products – Sustainability criteria

Acknowledging the need for common standards for bio-based products, the European Commission initiated a series of standards developed by CEN/TC 411, with a focus on bio-based products other than food, feed and biomass for energy applications.

The standard EN 16751[32] is part of this series and sets horizontal sustainability criteria applicable to the bio-based part of all bio-based products, excluding food, feed and energy, covering all three pillars of sustainability; environmental, social and economic aspects.

This European Standard can be used for two applications; either to provide sustainability information about the biomass production only or to provide sustainability information in the supply chain for the bio-based part of the bio-based product. This European Standard sets a framework to provide information on management of sustainability aspects and can be used for business-to-business communication or for developing product specific standards and certification schemes.

4.5 EN 16760 Bio-based products – Life Cycle Assessment

The standard EN 16760[33] is also part of the series developed by CEN/TC 411 (see above). It provides specific life cycle assessment requirements and guidance for bio-based products, excluding food, feed and energy, based on EN ISO 14040 and EN ISO 14044.

This European Standard covers bio-based products, derived wholly or partly from biomass. It provides guidance and requirements to assess impact over the life cycle of bio-based products with the focus on how to handle the specificities of the bio-based part of the product.

[32] CEN, "EN 16751:2016 Bio-Based Products - Sustainability Criteria".
[33] CEN, "EN 16760:2015 Bio-Based Products - Life Cycle Assessment".

5 Relevant literature-review case studies

5.1 Introduction

The literature review targets a wide array of bio-based products. By the goals definition of the STAR-ProBio project, biofuel, feed and food are excluded; however, the remaining possible bio-based products are still very diverse. More importantly, studies available in the literature can be realised at several possible levels of the chemical value chain, depending on the type of feedstock or product: for instance, a final product such as ethanol is also a platform that can be used for further synthesis to other types of products. Figure 4 illustrates this for polymers only.

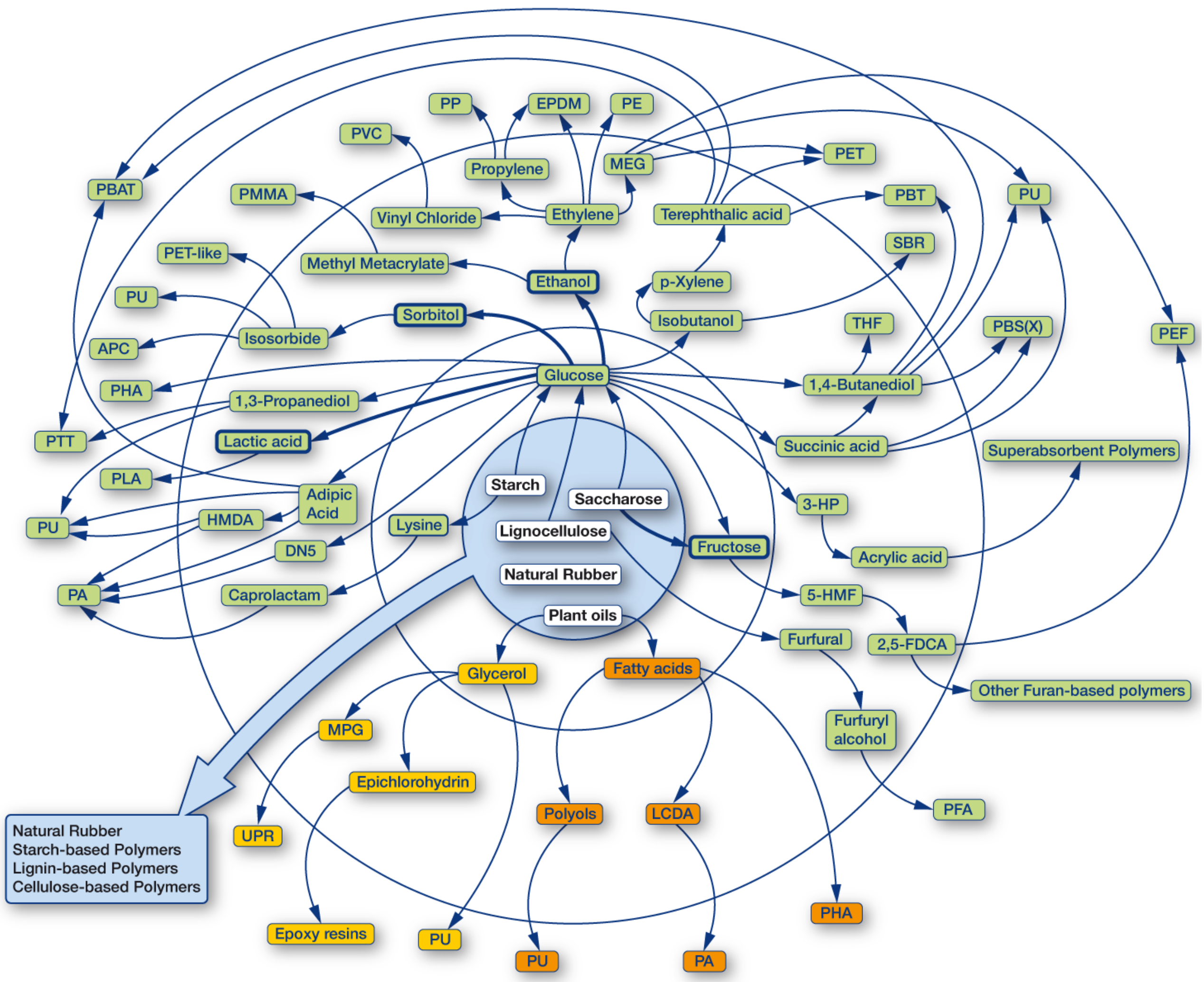

Figure 4: Illustration of the diversity of bio-based products (here: polymers) and their chemical pathways. Source: Carus and Aeschelmann[34].

It is therefore not a simple task to structure a literature review comprehensively covering all products while avoiding overlap. The way it was done for the present report is illustrated in the Table 1: three realisation levels of studied subject have been defined (raw material, platform and product) and each of them contain families defined appropriately to the level. This way of doing

[34] Carus and Aeschelmann, *Bio-Based Building Blocks and Polymers – Global Capacities and Trends Order 2016 - 2021*.

has the advantage of suitably reflecting the real practice found in the variety of available studies. The number of reviewed articles is shown in the same table.

Table 1: Families of bio-based products as defined for the needs of this report.

Study realised at the level of…	Defined family	Number of reviewed articles	
Raw material	Oils (non-polymerized)	5	27
	Sugars and starch (non-polymerized)	12	
	Fibres	10	
Platform	Platforms obtained by fermentation route	18	21
	Platforms obtained by other routes	3	
Product	Plastic polymers (non-fibre)	12	35
	Fine and bulk chemicals	6	
	Proteins	10	
	Others	7	
Total		**83**	**83**

Note that some studied subjects could fall in more than one family in this structuration. This has a non-critical influence on the review analysis. However, this overlap is minimised when using the realisation level, therefore the results of the review are presented at the realisation level.

5.2 Raw materials

It is quite frequent that LCAs or other studies focus on the production of the material that is at the start of the transformation process, or that can already be considered as a product at this level. Three main families are identified at this level, based on their fundamental characteristics:

5.2.1 Oils (non-polymerized)

Oils are very often used for fuel or food and therefore often excluded from this review, hence the relatively small number of reviewed articles.

5.2.2 Sugars and starch (non-polymerized)

Sugars and starch can be used for the production of many polymers or other products.

5.2.3 Fibres

Fibres are interesting for their structural properties and are therefore often used directly as a product or within a composite material.

5.3 Platforms

Some studies focus at the intermediate product level, capturing the first steps of the transformation process up to the level at which chemical "bricks" are obtained and can be used in further processing. At this level, the route is the key criterion for the two defined families:

5.3.1 Platforms obtained by fermentation route

Most of the platforms found in the reviewed articles are produced by the fermentation route.

5.3.2 Platforms obtained by other routes

Only a few platforms found are produced by a different route, chemical or thermal. The thermal route is common for fuels that are excluded from this review.

5.4 Products

The majority of the studies are realized at the level of a particular product. At this level, the families are defined based on the type of product, in a large sense:

5.4.1 Plastic polymers (non-fibre)

All bio-based plastic polymers in general.

5.4.2 Fine and bulk chemicals

All other forms of "simple" molecules, mostly obtained via bio-chemical processes, to be used for any type of application.

5.4.3 Proteins

All forms of complex molecules, obtained via biological processes and mostly intended to medical applications or very specific other applications.

5.4.4 Others

Intended to any other type of molecules, this family mostly contains construction materials.

6 Results of the review

6.1 Types of studies

The full list of the 83 reviewed articles is available in annex 9.1. Their short reports and the data aggregation table are available in separate files, annexes 9.2 and 9.3.

The vast majority of the reviewed articles are environmental life-cycle assessments (LCAs) (Table 2). Most of the time, when another type of study is realised, it is in addition to the LCA (combined studies).

Table 2: Quantitative results of the review – number of articles split by type of studies and by level. Some articles are combining several types of studies.

Type of study	Raw material	Platform	Product	All levels
LCA	25	21	35	81
Input-output	2	0	2	4
LCC	3	0	1	4
S-LCA	2	0	1	3
Other	0	1	0	1
Total	**32**	**22**	**39**	**93**

6.2 Approaches

Consequential studies are relatively scarce in the reviewed articles (Table 3). The attributional approach is significantly more frequent, especially considering that when the approach is unspecified or unclear, it is most probably attributional.

Table 3: Quantitative results of the review – number of articles split by approach and by level. In one case, both approaches were compared.

Approach	Raw material	Platform	Product	All levels
Attributional	19	6	20	45
Consequential	3	3	4	10
Unclear	5	13	11	29
Total	27	22	35	84

6.3 System boundaries

Most of the reviewed studies are "cradle-to-gate" assessments, hence not including stages beyond transformation (Table 4). Indeed, only 13% of them include the use stage (which can be passive, explaining this low value) and only 23% of the studies include the end of life (EoL). These rates are even lower for studies realised at platform level.

As expected, all studies at platform and product levels include the transformation stage. In a few cases, no transformation is considered at raw material level, which is understandable.

The rates at which the agricultural activities and logistics and transportation are included in the boundaries are high at raw material and product levels, while relatively low (less than 50%) at platform level. This suggests the following:

- At raw material level, studies tend to include the main subject: the raw material production. When it is not the case, the study focuses on the pre-processing steps and/or uses biomass residues considered to bear no impact.
- At platform level, studies tend to focus only to processing. This is also shown by the low rate of inclusion of the EoL.
- At product level, studies tend to be more comprehensive and have the higher rate of inclusion of the agricultural activities, above 90%.

Table 4: Quantitative results of the review from the perspective of the life cycle stages included in the system boundaries. Values are the number of occurrences that the stage is included relatively to the number of articles of the level.

Life cycle stage	Raw material	Platform	Product	All levels
R&D	7%	14%	3%	**7%**
Agricultural activities	70%	48%	94%	**75%**
Logistics and transportation	85%	43%	80%	**72%**
Transformation	89%	100%	100%	**96%**
Conditioning	33%	5%	54%	**35%**
Packaging and distribution	22%	10%	17%	**17%**
Use	26%	5%	9%	**13%**
End of life	33%	5%	26%	**23%**
Advertising and other overheads	0%	0%	0%	**0%**
Other stage	11%	0%	0%	**4%**

6.4 Land use change (LUC)

The inclusion rate of LUC (complete of direct only) in the reviewed articles is significantly lower (Table 5) than the inclusion rate of the agricultural activities (Table 4). This means that LUC is either considered negligible or simply ignored by most of the reviewed authors.

Table 5: Quantitative results of the review – number of articles including LUC relatively to the number of articles of the level.

Inclusion of LUC	Raw material	Platform	Product	All levels
Yes	22%	10%	14%	**16%**
Direct LUC only	15%	5%	3%	**7%**
No / not mentioned	63%	86%	83%	**77%**

6.5 LCIA methods

There are important disparities in the type of LCIA methods used, depending on the realisation level of the studied subject (Table 6). The CML method is used in 40% of the studies referring to raw materials, 34% for products but is never used, in this sample, for platforms.

Table 6: Quantitative results of the review – number of articles split by LCIA methods and by level. In some cases, several methods have been used.

	Raw material	Platform	Product	All levels
Number of articles	27	21	35	**83**
Studies using a version of the CML LCIA method	11	0	12	**23**
Studies using a version of the ReCiPe LCIA method	7	3	4	**14**
Studies using a version of the ILCD LCIA method	4	0	1	**5**
Studies using another LCIA method or a custom set of indicators	7	18	19	**44**
Total	**29**	**21**	**36**	**86**

6.6 Reviewed environmental indicators

For the sake of the analysis required for this review, the 38 midpoint indicators[35] that have been identified have been grouped into thematic clusters, as shown in Table 7. This allows analysing the results on a more accessible basis.

Thematic clusters are defined for this review as groups of midpoint indicators sharing similar effects at a level below the area of protection (endpoint), on a specific ecological theme.

Table 7 also displays the number of articles that use the indicators and clusters, of the 83 reviewed articles. The ranking that can be drawn at this stage (Table 8) represents the frequency at which an indicator is used in bio-based products studies, but does not necessarily represent the relevance of this choice.

Table 7: Grouping of all environmental indicators into thematic clusters and number of articles using this indicator / indicator cluster.

Cluster	Environmental indicator	Number of articles using this indicator	
Acidification	Acidification	49	49
Air quality	Particulate matter/respiratory inorganics	19	72
	Photochemical ozone formation	44	
	Indoor air quality	2	
	Total emissions	7	
Climate change	Climate change, GWP100	75	76
	Climate regulation potential (CRP)	1	
	Climate change (endpoint)	0	
Ecosystem quality (biodiversity)	Biodiversity damage potential (BDP)	1	10
	Ecosystem quality (endpoint)	8	
	Habitat alteration	1	
Ecotox	Terrestrial ecotox	13	47
	Ecotoxicity for aquatic fresh water	19	
	Marine ecotox	9	
	Ecotox (unspecified)	6	
Eutrophication	Eutrophication – terrestrial	12	75
	Eutrophication – aquatic and freshwater	19	
	Eutrophication – aquatic-marine	14	
	Eutrophication (unspecified)	30	
Human health	Human health (endpoint)	8	45
	Human toxicity and cancer effects	10	
	Human toxicity - non-cancer effects	8	
	Human tox (unspecified)	19	
Ionising radiation	Ionising radiation	7	7
Land transformation	Land transformation	4	4
Land use	Biotic production potential (BPP)	1	18
	Erosion regulation potential (ERP)	1	
	Agro land occupation	16	
Mineral and fossil resources	Resource depletion – mineral, fossil	45	71
	Abiotic depletion	20	

[35] Several indicators actually exist in several versions. See section 3.3.3.

	Resources (endpoint)	6	
Ozone layer	Ozone depletion	34	34
Wastes	Wastes	1	1
Water availability	Freshwater regulation potential (FWRP)	1	21
	Water purification potential through physicochemical filtration (WPPPCF)	1	
	Water purification potential through mechanical filtration (WPP-MF)	1	
	Resource depletion – water	10	
	Water use	8	

Note that the clusters reflect the indicators found in the literature. Some of them are situated at the inventory level, such as wastes or land transformation: they do ne reflect an impact but only a quantity.

Table 8 shows that indicators related to climate change, eutrophication, air quality and mineral / fossil resources are almost systematically used.

Table 8: Illustration of the relative frequency of the indicator clusters found in the reviewed articles. The absolute values can be higher than the total number of articles, as several indicators of the same cluster can be cumulated in one study.

Cluster	Platform	Product	Raw material	All levels	Frequency
Climate change	18	31	27	76	**High, almost systematically used**
Eutrophication	14	25	36	75	
Air quality	12	32	28	72	
Mineral and fossil resources	17	31	23	71	
Acidification	6	25	18	49	**Medium, often used**
Ecotox	4	16	27	47	
Human health	3	17	25	45	
Ozone layer	4	15	15	34	**Low, not often used**
Water availability	3	7	11	21	
Land use	4	7	7	18	
Ecosystem quality (biodiv.)	1	5	4	10	**Seldom used**
Ionising radiation	0	1	6	7	
Land transformation	0	1	3	4	
Wastes	1	0	0	1	
Total articles	21	35	27	83	

6.7 Environmental indicators found in the key international standards and guidelines

6.7.1 ISO 14040 and ISO 14044

These ISO standards do not recommend specific indicators or impact assessment methods, but provide general principles for the selection of impact categories which are relevant to STAR-ProBio such as:

"The selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration; (…)

The impact categories, category indicators and characterization models should be internationally accepted, i.e. based on an international agreement or approved by a competent international body; (…)

The impact categories, category indicators and characterization models should avoid double counting unless required by the goal and scope definition, for example when the study includes both human health and carcinogenicity" (ISO 14044, section 4.4.2.2).

This requirement will be fulfilled in the task 2.3 of this work package, using the present report as a basis.

6.7.2 International Reference Life Cycle Data System (ILCD) Handbook

The ILCD Handbook[36] presents a list of recommended midpoint fully described indicators (i.e., specifying the LCIA methodology to be used) that are summarized below:

- Climate change
- Ozone depletion
- Human toxicity, cancer effects
- Human toxicity, non- cancer effects
- Particulate matter/Respiratory inorganics
- Ionising radiation, human health
- Ionising radiation, ecosystems
- Photochemical ozone formation
- Acidification
- Eutrophication, terrestrial
- Eutrophication, aquatic
- Ecotoxicity (freshwater, terrestrial and marine)
- Land use
- Resource depletion, water
- Resource depletion, mineral fossil and renewable

Interestingly enough, this document also provides a list of other impact categories that are only occasionally or never addressed:

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

- Noise
- Accidents
- Desiccation
- Erosion
- Salination

6.7.3 Product Environmental Footprint (PEF) Guide and Product Environmental Footprint Category Rules (PEFCR) Guidance

The PEFCR Guidance[37] 6.2 presents a clear choice of fully described indicators (i.e., specifying the LCIA methodology to be used) that are shown in Table 9. This choice is based on the ILCD list presented above, with slight modifications.

Table 9: Impact categories recommended in the PEF Guidance

Impact category	Indicator	Unit
Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg $CO_{2\ eq}$
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11eq
Human toxicity, cancer effects	Comparative Toxic Unit for humans (CTU_h)	CTUh
Human toxicity, non- cancer effects	Comparative Toxic Unit for humans (CTU_h)	CTUh
Particulate matter/Respiratory inorganics	Impact on human health	Deaths
Ionising radiation, human health	Human exposure efficiency relative to ^{235}U	kBq ^{235}U
Photochemical ozone formation	Tropospheric ozone concentration increase	kg NMVOCeq
Acidification	Accumulated Exceedance (AE)	mol H+ eq
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq
Eutrophication, aquatic freshwater	Fraction of nutrients reaching freshwater end compartment (P)	fresh water: kg P equivalent
Eutrophication, aquatic marine	Fraction of nutrients reaching marine end compartment (N)	marine water: kg N equivalent
Ecotoxicity (freshwater)	Comparative Toxic Unit for ecosystems (CTU_e)	CTUe

[37] European Commission, *Product Environmental Footprint Category Rules Guidance - Version 6.2*.

Land use	- Soil quality index - Biotic production - Erosion resistance - Mechanical filtration - Groundwater replenishment	- dimensionless - kg biotic production - kg soil - m^3 water - m^3 ground-water
Water scarcity	User deprivation potential (deprivation-weighted water consumption)	m^3 world eq. deprived
Resource use, mineral	Abiotic resource depletion (ADP ultimate reserves)	kg Sb-eq
Resource use, energy carriers	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ

The impact categories recommended in the PEFCR Guidance 6.2 do not aim to represent state-of-the-art impact assessment, e.g. the latest USEtox® 2.0 model[38] is not recommended for toxicity assessment categories. They are the result of a scientific and political consensus, constituted of a set of indicators taken from various impact assessment methods which, in some cases, are not fully consistent with each other.

The PEFCR Guidance 6.2 remains a draft document. However, given its wide stakeholders acceptance, it is likely to become the new methodological standard for any environmental LCA studies conducted in a European context from 2018 onwards.

6.7.4 EN 16751 Bio-based products – Sustainability criteria

This norm presents indicators on the three pillars of sustainability. The environmental ones are the following:

- GHG emissions and removals
- Air quality
- Water quality and quantity
- Soil quality, productivity and erosion
- Biodiversity within the area of operation
- Biodiversity protected areas
- Efficient use of energy and material resources
- Use of renewable energy and material resources
- Responsible waste management

[38] Fantke et al., 2017, *USEtox® 2.0 Documentation (Version 1)*

6.7.5 EN 16760 Bio-based products – Life Cycle Assessment

This norm gives guidelines for specific impact indicators:

- Treatment of biogenic and non-biogenic carbon in assessing climate change
- Land use impact on natural environment/ecosystem quality
- Land use impact on ecosystem services/natural resources
- Water use

6.7.6 Recapitulation of the key international standards and guidelines

The key international standards and guidelines and the reviewed articles are in their large majority aligned, at least at the level of the indicators clusters that have been identified as relevant by these standards.

Table 10 shows that the EN 16751 and 16760 norms cover some gaps of the ILCD / PEFCR guidance: ecosystem quality and renewable resources are more directly addressed. Waste management is also reintroduced. Conversely, noise is a type of impact suggested by ILCD but never retained by the other standards.

This table also shows the evaluated relevance of each cluster for bio-based products, based on the number of times the cluster is recommended and by which reference it is recommended.

Table 10: Recapitulation of the indicators clusters recommended by the key international standards and guidelines. Values are the number of indicators recommended by the reference.

Cluster	ISO 14040 /44	ILCD	PEFCR guidance	EN 16751	EN 16760	Evaluated relevance
Acidification		1	1			Medium
Air quality		2	2	1		Important
Climate change		1	1	1	1	Important
Ecosystem quality (biodiversity)				2	1	Important
Ecotox		1	1			Medium
Eutrophication		2	3			Important
Human health		2	2			Medium
Ionising radiation		2	1			Medium
Land use		2	3	1		Important
Mineral and fossil resources		1	2	1		Important
Noise		1				Low

Other		1				Low
Ozone layer		1	1			Medium
Renewable resources		1		1	1	Important
Wastes				1		Medium
Water availability		3	3	1	1	Important
Total		21	20	9	4	

7 Interpretation and final conclusions

7.1 Synthesis of all indicators clusters

Table 11 shows in parallel the results of the literature review and recommendations of the key literature, sorted by the evaluated relevance, as evaluated in section 6.7.6.

Table 11: Illustration of the relative frequency of the indicator clusters found in the reviewed articles and in the key literature, in order of relevance for bio-based products. The absolute values can be higher than the total number of references, as several indicators of the same cluster can be cumulated.

Cluster	Occurrences in the reviewed articles	Occurrences in the key literature	Evaluated relevance
Water availability	21	8	High
Land use	18	6	High
Ecosystem quality (biodiv.)	10		High
Ionising radiation	7	3	Medium
Wastes	1	1	Medium
Climate change	76	4	High
Eutrophication	75	5	High
Air quality	72	5	High
Mineral and fossil resources	71	4	High
Acidification	49	2	Medium
Ecotox	47	2	Medium
Human health	45	4	Medium
Ozone layer	34	2	Medium
Land transformation	4		Low
Noise	0	1	Low
Total references	83	4	

For the indicators judged as highly relevant, the following observations can be made:

- There is a strong convergence between the reviewed articles and the key literature for **climate change, eutrophication, air quality and mineral and fossil resources**. These important indicators are systematically used in the scientific studies.
- **Water availability and land use** are very important topics in the key literature, with the highest numbers of indicators suggested, while it is only used by a small fraction (25% or lower) of the reviewed articles.

- **Ecosystem quality (biodiversity)** is an important topic, but as an endpoint it is also included in other indicators, hence does not appear in its full importance in this table. Only a few reviewed articles used endpoints. The direct effects on biodiversity of land use and land use change are not captured by the indirect indicators such as the ecotoxicity and heavily rely on the LCIA methodology applied to land use.

For the indicators judged of medium relevance, the following observations can be made:

- There is a strong convergence between the reviewed articles and the key literature for **acidification, ecotox, human health and ozone layer**. These moderately important (for bio-based products) indicators are often used in the scientific studies.
- **Ionising radiation** is a relatively important topic in the key literature, but it is only used by a very small fraction (less than 10%) of the reviewed articles.
- **Wastes** are not strongly recommended by the key literature, due to the lack of methodology addressing their impact outside those that are captured by other indicators (such as toxicity). It is almost never used in the reviewed articles.

Finally, for the indicators judged of low relevance, the following observations can be made:

- **Land transformation** as an inventory flow is not recommended by the key literature, which focuses on the impacts related to land transformation (or land use change). These impacts are captured by the other indicators recommended. However, this indicator is used by a few of the reviewed articles.
- **Noise** is mentioned as a difficult environmental topic to address in the key literature. It is not particularly relevant for bio-based products and never used in the reviewed literature.

7.2 Interpretation

Most of the indicators used in the reviewed articles are in line with the indicators recommended by the key literature. However, some important discrepancies can be identified and described by Table 12:, notably the fact that some indicators are not used in the literature as they should.

Table 12: Summary assessment of the indicators clusters, comparing their use in the literature with their use as recommended by the key literature.

Evaluated relevance	Convergence between practice and recommendation	Not as used as recommended	Not appropriately addressed
High	Climate change	Water availability	
	Eutrophication	Land use	
	Air quality	Ecosystem quality (biodiv.)	
	Mineral and fossil resources		
Medium	Acidification	Ionising radiation	Wastes
	Ecotox		
	Human health		

Low	Ozone layer		
	Land transformation (inventory)		
	Noise		

It is also interesting to notice that wastes are not really addressed outside their toxicity effect or the impacts of their treatment. The problem of littering and the ubiquitous presence of plastic particles in soil or in water bodies is not addressed. The fact that a part of bio-based products might be biodegradable and, in some cases, rapidly biodegradable in marine environment, cannot be directly captured with the recommended indicators. An assessment of the risk that the presence of plastic in the environment represents is something that could be of interest to the public opinion, if not its final impacts on the ecosystem quality or on human health.

7.3 Conclusion

The environmental indicators found in the literature covering bio-based products can be grouped into thematic clusters covering similar types of effects. These clusters are in large part in line with those recommended by the key literature sources, such as the PEFCR guidance[39] or the EN 16751 norm[40].

However, the indicators belonging to the following clusters are considered highly relevant by the key literature and are not used in the reviewed articles as frequently as they should:

- Water availability
- Land use
- Ecosystem quality (biodiversity)

Ionising radiation is also a cluster "under-used" compared to the recommended indicators. This could be explained by the fact that this indicator is often dominated by nuclear electricity, masking any other potential impacts.

Finally, the impacts of **wastes** are not really addressed by the reviewed articles neither by the key literature sources, mostly because of the lack of methodology for the assessment of the risk that the presence of plastic in the environment represents.

[39] European Commission, *Product Environmental Footprint Category Rules Guidance - Version 6.2*.
[40] CEN, "EN 16751:2016 Bio-Based Products - Sustainability Criteria".

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- Tsiropoulos, I., A. P C Faaij, L. Lundquist, U. Schenker, J. F. Briois, and M. K. Patel, "Life Cycle Impact Assessment of Bio-Based Plastics from Sugarcane Ethanol", *Journal of Cleaner Production*, Vol. 90, 2015, pp. 114–127. http://dx.doi.org/10.1016/j.jclepro.2014.11.071.
- UNEP, *Guidelines for Social Life Cycle Assessment of Products*, United Nations Environment Programme, 2009.

9 ANNEXES

9.1 List of reviewed articles

Table 13: Full list of reviewed articles, by level of realisation

Level	Reviewed article	Defined family
Platform	Adom, Felix K., and Jennifer B. Dunn, "Life Cycle Analysis of Corn-Stover-Derived Polymer-Grade l-Lactic Acid and Ethyl Lactate: Greenhouse Gas Emissions and Fossil Energy Consumption", Biofuels, Bioproducts and Biorefining, Vol. 11, 2017, pp. 258–268	Platforms obtained by fermentation route
Platform	Cok, Benjamin, Ioannis Tsiropoulos, Alexander L. Roes, and Martin K. Patel, "Succinic Acid Production Derived from Carbohydrates: An Energy and Greenhouse Gas Assessment of a Platform Chemical toward a Bio-Based Economy", Biofuels, Bioproducts and Biorefining, Vol. 8, No. 1, 2014, pp. 16–29	Platforms obtained by fermentation route
Platform	Dros, A. B., O. Larue, A. Reimond, F. De Campo, and M. Pera-Titus, "Hexamethylenediamine (HMDA) from Fossil- vs. Bio-Based Routes: An Economic and Life Cycle Assessment Comparative Study", Green Chemistry, Vol. 17, No. 10, October 2, 2015, pp. 4760–4772	Platforms obtained by other routes
Platform	Ekman, Anna, and Pal Börjesson, "Environmental Assessment of Propionic Acid Produced in an Agricultural Biomass-Based Biorefinery System", Journal of Cleaner Production, Vol. 19, No. 11, 2011, pp. 1257–1265	Platforms obtained by fermentation route
Platform	Forte, Annachiara, Amalia Zucaro, Riccardo Basosi, and Angelo Fierro, "LCA of 1,4-Butanediol Produced via Direct Fermentation of Sugars from Wheat Straw Feedstock within a Territorial Biorefinery", Materials, Vol. 9, No. 7, 2016, pp. 1–22.	Platforms obtained by fermentation route
Platform	Gezae Daful, Asfaw, and Johann F. G??rgens, "Techno-Economic Analysis and Environmental Impact Assessment of Lignocellulosic Lactic Acid Production", Chemical Engineering Science, Vol. 162, 2017, pp. 53–65. http://dx.doi.org/10.1016/j.ces.2016.12.054	Platforms obtained by fermentation route
Platform	Groot, Wim J., and Tobias Boren, "Life Cycle Assessment of the Manufacture of Lactide and PLA Biopolymers from Sugarcane in Thailand", International Journal of Life Cycle Assessment, Vol. 15, No. 9, 2010, pp. 970–984.	Platforms obtained by fermentation route
Platform	Khoo, Hsien Hui, Reginald B H Tan, and Kevin W L Chng, "Environmental Impacts of Conventional Plastic and Bio-Based Carrier Bags", International Journal of Life Cycle Assessment, Vol. 15, No. 3, 2010, pp. 284–293.	Platforms obtained by fermentation route
Platform	Koller, Martin, Daniel Sandholzer, Anna Salerno, Gerhart Braunegg, and Michael Narodoslawsky, "Biopolymer from Industrial Residues: Life Cycle Assessment of Poly(hydroxyalkanoates) from Whey", Resources, Conservation and Recycling, Vol. 73, 2013, pp. 64–71. http://dx.doi.org/10.1016/j.resconrec.2013.01.017	Platforms obtained by fermentation route
Platform	Lokesh, K., C. West, J. Kuylenstierna, J. Fan, V. Budarin, P. Priecel, J. A. Lopez-Sanchez, and J. Clark, "Environmental Impact Assessment of Wheat Straw Based Alkyl Polyglucosides Produced Using Novel Chemical Approaches", Green Chemistry, Vol. 19, No. 18, September 19, 2017, pp. 4380–4395	Platforms obtained by other routes
Platform	Madival, Santosh, Rafael Auras, Sher Paul Singh, and Ramani Narayan, "Assessment of the Environmental Profile of PLA, PET and PS Clamshell	Platforms obtained by

	Containers Using LCA Methodology", Journal of Cleaner Production, Vol. 17, No. 13, 2009, pp. 1183–1194. http://dx.doi.org/10.1016/j.jclepro.2009.03.015.	fermentation route
Platform	Morales, Merten, Pierre Y Dapsens, Isabella Giovinazzo, Julia Witte, Cecilia Mondelli, Stavros Papadokonstantakis, Konrad Hungerbuhler, and Javier Perez-Ramirez, "Environmental and Economic Assessment of Lactic Acid Production from Glycerol Using Cascade Bio- and Chemocatalysis", Energy & Environmental Science, Vol. 8, No. 2, 2015, pp. 558–567. http://http//pubs.rsc.org/en/Content/ArticleLanding/2015/EE/c4ee03352c	Platforms obtained by fermentation route
Platform	Morgan-Sagastume, Fernando, Sara Heimersson, Giuseppe Laera, Alan Werker, and Magdalena Svanström, "Techno-Environmental Assessment of Integrating Polyhydroxyalkanoate (PHA) Production with Services of Municipal Wastewater Treatment", Journal of Cleaner Production, Vol. 137, 2016, pp. 1368–1381	Platforms obtained by fermentation route
Platform	Moussa, Hassan I., Ali Elkamel, and Steven B. Young, "Assessing Energy Performance of Bio-Based Succinic Acid Production Using LCA", Journal of Cleaner Production, Vol. 139, 2016, pp. 761–769	Platforms obtained by fermentation route
Platform	Mu, Dongyan, Thomas Seager, P. Suresh Rao, and Fu Zhao, "Comparative Life Cycle Assessment of Lignocellulosic Ethanol Production: Biochemical versus Thermochemical Conversion", Environmental Management, Vol. 46, No. 4, 2010, pp. 565–578.	Platforms obtained by fermentation route
Platform	Parajuli, Ranjan, Marie Trydeman Knudsen, Morten Birkved, Sylvestre Njakou Djomo, Andrea Corona, and Tommy Dalgaard, "Environmental Impacts of Producing Bioethanol and Biobased Lactic Acid from Standalone and Integrated Biorefineries Using a Consequential and an Attributional Life Cycle Assessment Approach", Science of the Total Environment, Vol. 598, 2017, pp. 497–512. http://dx.doi.org/10.1016/j.scitotenv.2017.04.087.$	Platforms obtained by fermentation route
Platform	Ponder, Celia, and Michael Overcash, "Cradle-to-Gate Life Cycle Inventory of Vancomycin Hydrochloride", Science of the Total Environment, Vol. 408, No. 6, 2010, pp. 1331–1337	Platforms obtained by fermentation route
Platform	Sheldon, Roger A., "Utilisation of Biomass for Sustainable Fuels and Chemicals: Molecules, Methods and Metrics", Catalysis Today, Vol. 167, No. 1, Utilisation of Biomass for Fuels and Chemicals:The Road to Sustainability, June 10, 2011, pp. 3–13.	Platforms obtained by other routes
Platform	Singh, Anoop, Deepak Pant, Nicholas E. Korres, Abdul-Sattar Nizami, Shiv Prasad, and Jerry D. Murphy, "Key Issues in Life Cycle Assessment of Ethanol Production from Lignocellulosic Biomass: Challenges and Perspectives", Bioresource Technology, Vol. 101, No. 13, 2010, pp. 5003–5012. http://linkinghub.elsevier.com/retrieve/pii/S0960852409015673	Platforms obtained by fermentation route
Platform	Sun, Xiao-Zheng, Tomoaki Minowa, Katsunobu Yamaguchi, and Yutaka Genchi, "Evaluation of Energy Consumption and Greenhouse Gas Emissions from Poly(phenyllactic Acid) Production Using Sweet Sorghum", Journal of Cleaner Production, Vol. 87, 2015, pp. 208–215. http://www.sciencedirect.com/science/article/pii/S0959652614009718	Platforms obtained by fermentation route
Platform	Tufvesson Par, Anna Ekman, Roya R R Sardari, Kristina Engdahl, and Linda Tufvesson, "Economic and Environmental Assessment of Propionic Acid Production by Fermentation Using Different Renewable Raw Materials", Bioresource Technology, Vol. 149, 2013, pp. 556–564	Platforms obtained by fermentation route
Product	Adom, Felix, Jennifer B. Dunn, Jeongwoo Han, and Norm Sather, "Life-Cycle Fossil Energy Consumption and Greenhouse Gas Emissions of Bioderived	Fine and bulk chemicals

	Chemicals and Their Conventional Counterparts”, Environmental Science & Technology, Vol. 48, No. 24, December 16, 2014, pp. 14624–14631	
Product	Akiyama, Minoru, Takeharu Tsuge, and Yoshiharu Doi, “Environmental life cycle comparison of polyhydroxyalkanoates produced from renewable carbon resources by bacterial fermentation”, Polymer Degradation and Stability, Vol. 80, No. 1, 2003, pp. 183–194.	Plastic polymers (non-fibre)
Product	Batouli, Seyed Mostafa, Yimin Zhu, Mangesh Nar, and Nandika Anne D'Souza, "Environmental Performance Of Kenaf-Fiber Reinforced Polyurethane: A Life Cycle Assessment Approach", Journal Of Cleaner Production, Vol. 66, 2014, pp. 164-173.	Others
Product	Belboom, Sandra, and Angélique Léonard, “Does biobased polymer achieve better environmental impacts than fossil polymer? Comparison of fossil HDPE and biobased HDPE produced from sugar beet and wheat”, Biomass and Bioenergy, Vol. 85, 2016, pp. 159–167.	Plastic polymers (non-fibre)
Product	Chen, Luyi, Rylie E.o. Pelton, and Timothy M. Smith, “Comparative life cycle assessment of fossil and bio-based polyethylene terephthalate (PET) bottles”, Journal of Cleaner Production, Vol. 137, 2016, pp. 667–676.	Plastic polymers (non-fibre)
Product	Feijoo, S., S. González-García, J.M. Lema, and M.T. Moreira, "Life Cycle Assessment Of B-Galactosidase Enzyme Production", Journal Of Cleaner Production, Vol. 165, 2017, pp. 204-212.	Proteins
Product	Fernández-Dacosta, Cora, John A. Posada, Robbert Kleerebezem, Maria C. Cuellar, and Andrea Ramirez, “Microbial community-based polyhydroxyalkanoates (PHAs) production from wastewater: Techno-Economic analysis and ex-ante environmental assessment,” Bioresource TechnologyVol. 185, 2015, pp. 368–377.	Plastic polymers (non-fibre)
Product	Fiorentino, G., M. Ripa, S. Mellino, S. Fahd, and S. Ulgiati, “Life Cycle Assessment of Brassica Carinata Biomass Conversion to Bioenergy and Platform Chemicals”, Journal of Cleaner Production, Vol. 66, No. Supplement C, March 1, 2014, pp. 174–187.	Fine and bulk chemicals
Product	Gilpin, Geoffrey S., and Anders S. G. Andrae, "Comparative Attributional Life Cycle Assessment Of European Cellulase Enzyme Production For Use In Second-Generation Lignocellulosic Bioethanol Production", The International Journal Of Life Cycle Assessment, Vol. 22, No. 7, 2016, pp. 1034-1053	Proteins
Product	González-García, Sara, Gumersindo Feijoo, Carol Heathcote, Andreas Kandelbauer, and M. Teresa Moreira, "Environmental Assessment Of Green Hardboard Production Coupled With A Laccase Activated System", Journal Of Cleaner Production, Vol. 19, No. 5, 2011, p	Others
Product	H. Khoo, H., W. L. Ee, and Valerio Isoni, “Bio-Chemicals from Lignocellulose Feedstock: Sustainability, LCA and the Green Conundrum”, Green Chemistry, Vol. 18, No. 7, 2016, pp. 1912–1922	Fine and bulk chemicals
Product	Harding, K, J Dennis, H Vonblottnitz, and S Harrison, “Environmental analysis of plastic production processes: Comparing petroleum-Based polypropylene and polyethylene with biologically-based poly-β-Hydroxybutyric acid using life cycle analysis,” Journal of BiotechnologyVol. 130, No. 1, 2007, pp. 57–66.	Plastic polymers (non-fibre)
Product	Jeswani, Harish K., Temitope Falano, and Adisa Azapagic, “Life Cycle Environmental Sustainability of Lignocellulosic Ethanol Produced in Integrated Thermo-Chemical Biorefineries”, Biofuels, Bioproducts and Biorefining, Vol. 9, No. 6, November 1, 2015, pp. 661–67	Fine and bulk chemicals
Product	Kim, Seungdo, Concepción Jiménez-González, and Bruce E. Dale, "Enzymes For Pharmaceutical Applications—A Cradle-To-Gate Life Cycle Assessment", The International Journal Of Life Cycle Assessment, Vol. 14, No. 5, 2009, pp. 392-400.	Proteins

Product	Kit, Yoong, Leong Pau, and Loke Show, "Economic and Environmental Analysis of PHAs Production Process", Clean Technologies and Environmental Policy, Vol. 19, No. 7, 2017, pp. 1941–1953.	Plastic polymers (non-fibre)
Product	La Rosa, A.D., G. Cozzo, A. Latteri, A. Recca, A. Björklund, E. Parrinello, and G. Cicala, "Life Cycle Assessment Of A Novel Hybrid Glass-Hemp/Thermoset Composite", Journal Of Cleaner Production, Vol. 44, 2013, pp. 69-76.	Others
Product	Leceta, I., A. Etxabide, S. Cabezudo, K. De La Caba, and P. Guerrero, "Bio-based films prepared with by-products and wastes: environmental assessment", Journal of Cleaner ProductionVol. 64, 2014, pp. 218–227.	Plastic polymers (non-fibre)
Product	Madival, Santosh, Rafael Auras, Sher Paul Singh, and Ramani Narayan, "Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology", Journal of Cleaner Production, Vol. 17, No. 13, 2009, pp. 1183–1194.	Plastic polymers (non-fibre)
Product	Marinussen and Kool. "Environmental impacts of synthetic amino acid production", report from Blonk Milieu Advies BV, 2010 Netherlands	Proteins
Product	Ministry of environment and food of Denmark. Danish Environmental Protection Agency "Novo Nordisk's Environmental Profit and Loss account". 2014 http://mst.dk/service/publikationer/publikationsarkiv/2014/apr/assessment-of-potentials-and-limitations-in-valuation-of-externalities	Proteins
Product	Nielsen, Per H., Karen M. Oxenbøll, and Henrik Wenzel, "Cradle-To-Gate Environmental Assessment Of Enzyme Products Produced Industrially In Denmark By Novozymes A/S", The International Journal Of Life Cycle Assessment, Vol. 12, No. 6, 2006, pp. 432-438.	Proteins
Product	Oxenboll, K.M., K. Pontoppida, and F. Fru-Nji, "Use Of A Protease In Poultry Feed Offers Promising Environmental Benefits", International Journal Of Poultry Science, Vol. 10, No. 11, 2011, pp. 842-848.	Proteins
Product	Papong, Seksan, Pomthong Malakul, Ruethai Trungkavashirakun, Pechda Wenunun, Tassaneewan Chom-In, Manit Nithitanakul, and Ed Sarobol, "Comparative assessment of the environmental profile of PLA and PET drinking water bottles from a life cycle perspective", Journal of Cleaner Production, Vol. 65, 2014, pp. 539–550.	Plastic polymers (non-fibre)
Product	Pargana, Nuno, Manuel Duarte Pinheiro, José Dinis Silvestre, and Jorge de Brito, "Comparative Environmental Life Cycle Assessment Of Thermal Insulation Materials Of Buildings", Energy And Buildings, Vol. 82, 2014, pp. 466-481.	Others
Product	Pérez-López, P., S. González-García, C. Jeffryes, S.N. Agathos, E. McHugh, D. Walsh, P. Murray, S. Moane, G. Feijoo, and M.T. Moreira, "Life Cycle Assessment Of The Production Of The Red Antioxidant Carotenoid Astaxanthin By Microalgae: From Lab To Pilot Scale", Journal Of Cleaner Production, Vol. 64, 2014, pp. 332-344.	Proteins
Product	Pérez-López, Paula, Sara González-García, R. Gabriela Ulloa, Jorge Sineiro, Gumersindo Feijoo, and Mª Teresa Moreira, "Life Cycle Assessment Of The Production Of Bioactive Compounds From Tetraselmis Suecica At Pilot Scale", Journal Of Cleaner Production, Vol. 64, 2014, pp. 323-331.	Proteins
Product	Pursula, Tiina, and Minna Päällysaho, Report: LCA Of Enzyme Production And Calculation Of Key Performance Indicators For Metgen, Gaia Consulting Oy, 2016. http://www.metgen.com/wp-content/uploads/2017/01/Final-report-LCA-and-KPIs-for-enzyme-production-18.11.2016.pdf.	Proteins
Product	Qiang, Tao, Demei Yu, Anjiang Zhang, Honghong Gao, Zhao Li, Zengchao Liu, Weixing Chen, and Zhen Han, "Life Cycle Assessment On Polylactide-Based	Others

	Wood Plastic Composites Toughened With Polyhydroxyalkanoates", Journal Of Cleaner Production, Vol. 66, 2014, pp. 139-145	
Product	Razza, Francesco, Francesco Degli Innocenti, Antonio Dobon, Cesar Aliaga, Carmen Sanchez, and Mercedes Hortal, "Environmental profile of a bio-based and biodegradable foamed packaging prototype in comparison with the current benchmark", Journal of Cleaner Production, Vol. 102, 2015, pp. 493–500.	Plastic polymers (non-fibre)
Product	Sierra-Pérez, Jorge, Jesús Boschmonart-Rives, Ana C. Dias, and Xavier Gabarrell, "Environmental Implications Of The Use Of Agglomerated Cork As Thermal Insulation In Buildings", Journal Of Cleaner Production, Vol. 126, 2016, pp. 97-107.	Others
Product	Slater, C. Stewart, Mariano J. Savelski, David Hitchcock, and Eduardo J. Cavanagh, "Environmental Analysis of the Life Cycle Emissions of 2-Methyl Tetrahydrofuran Solvent Manufactured from Renewable Resources", Journal of Environmental Science and Health, Part A, Vol. 51, No. 6, May 11, 2016, pp. 487–494.	Fine and bulk chemicals
Product	Tsiropoulos, I., A.p.c. Faaij, L. Lundquist, U. Schenker, J.f. Briois, and M.k. Patel, "Life cycle impact assessment of bio-based plastics from sugarcane ethanol", Journal of Cleaner Production, Vol. 90, 2015, pp. 114–127.	Plastic polymers (non-fibre)
Product	Vink, Erwin T H, Steve Davies, and Jeffrey J Kolstad, "The Eco-Profile for Current Ingeo Polylactide Production", Industrial Biotechnology, Vol. 6, No. 4, 2010, pp. 212–224	Plastic polymers (non-fibre)
Product	Wilson, James B., Eric T. Sakimoto, "Gate-to-gate life-cycle inventory of softwood plywood production" Wood and Fiber Science, Society of Wood Science and Technology, 37 Corrim Special Issue, 2005, pp. 58 – 73	Others
Product	Zhang, Yanan, Guiping Hu, and Robert C. Brown, "Life Cycle Assessment of Commodity Chemical Production from Forest Residue via Fast Pyrolysis", The International Journal of Life Cycle Assessment, Vol. 19, No. 7, July 1, 2014, pp. 1371–1381	Fine and bulk chemicals
Raw material	Agyekum, Eric Ofori, K.p.j. (Karen) Fortuin, and Eugenie Van Der Harst, "Environmental and social life cycle assessment of bamboo bicycle frames made in Ghana," Journal of Cleaner ProductionVol. 143, 2017, pp. 1069–1080	Fibres
Raw material	Arrigoni, Alessandro, Renato Pelosato, Paco Melià, Gianluca Ruggieri, Sergio Sabbadini, and Giovanni Dotelli, "Life cycle assessment of natural building materials: the role of carbonation, mixture components and transport in the environmental impacts of hempcrete blocks," Journal of Cleaner Production Vol. 149, 2017, pp. 1051–1061	Fibres
Raw material	Benedikt Buchspies, Martin Kaltschmitt, "Life cycle assessment of bioethanol from wheat and sugar beet discussing environmental impacts of multiple concepts of co-product processing in the context of the European Renewable Energy Directive", Biofuels, Vol 7, No 2, 2016, pp. 141-153, DOI: 10.1080/17597269.2015.1122472	Sugars and starch (non-polymerized)
Raw material	Carmen Galan-Marin, Carlos Rivera-Gomez and Antonio Garcia-Martinez, (2016) "Use of Natural-Fiber Bio-Composites in Construction versus Traditional Solutions: Operational and Embodied Energy Assessment," Materials.9. 465. 10	Fibres
Raw material	Chan et al., 2015 (palm oil, bio-oil with undefined use, LCA)	Oils (non-polymerized)
Raw material	Cherubini, Francesco and Ulgiati, Sergio, "Crop residues as raw materials for biorefinery systems - A LCA case study", Applied Energy, Vol. 87, 2017, pp. 47-57.	Oils (non-polymerized)

Raw material	Cosate de Andrade, Marina F., Souza, Patricia M.F., Cavalett, Otavio, and Morales, Ana R. "Life Cycle Assessment of Poly(Lactic Acid) (PLA): Comparison Between Chemical Recycling, Mechanical Recycling and Composting", Journal of Polymers and the Environment, Vol. 24, No. 4, 2016, pp. 372-384	Sugars and starch (non-polymerized)
Raw material	Diego Magalhães do Nascimento, Amanda Ferreira Dias, Celso Pires de Araújo Junior, Morsyleide de Freitas Rosa, João Paulo Saraiva Morais,Maria Cléa Brito de Figueirêdo; 'A comprehensive approach for obtaining cellulose nanocrystal from coconut fiber. Part II: Environmental assessment of technological pathways'; Industrial Crops and Products Volume 93, 25 December 2016, pp. 58-65	Fibres
Raw material	Gilani, Banafsheh, Stuart, Paul R., Life cycle assessment of an integrated forest biorefinery: hot water extraction process case study, Biofuels, Bioproducts and Biorefining, Vol. 9, No. 6, 2015, pp. 677-695. doi: 10.1002/bbb.1570	Sugars and starch (non-polymerized)
Raw material	González-García, Sara., Hospido, Almudena., Agnemo, Roland., Svensson, Patrik., Selling, Eva., Moreira, Ma Teresa., and Feijoo, Gumersindo, « Environmental Life Cycle Assessment of a Swedish Dissolving Pulp Mill Integrated Biorefinery », Journal of Industrial Ecology, Vol.15, No. 4, pp. 568-583.	Sugars and starch (non-polymerized)
Raw material	Günther, Jasmin, Niels Thevs, Hans-Jörg Gusovius, Ina Sigmund, Torsten Brückner, Volker Beckmann, and Nurbay Abdusalik, "Carbon and phosphorus footprint of the cotton production in Xinjiang, China, in comparison to an alternative fibre (Apocynum) from Central Asia," Journal of Cleaner Production Vol. 148, 2017, pp. 490–497	Fibres
Raw material	Jorge Cristobal, Cristina T. Matos, Jean-Philippe Aurambout, Simone Manfredi, and Boyan Kavalov, "Environmental sustainability assessment of bioeconomy value chains". Biomass and Bioenergy, Vol. 89, 2016, pp 159-171.https://doi.org/10.1016/j.biombioe.2016.02.002	Sugars and starch (non-polymerized)
Raw material	Krzyżaniak, Michal, Stolarski, Mariusz Jerzy., Szczukowski, Stefan, and Tworkowski, Józef, "Life Cycle Assessment of New Willow Cultivars Grown as Feedstock for Integrated Biorefineries", Bioenergy Research, Vol. 9, No. 1, pp. 224-238. doi: 10.1007/s12155-015-9681-3	Sugars and starch (non-polymerized)
Raw material	Mandegari, Mohsen Ali, Farzad, Somayeh., von Rensburg, Eugene, and Görgens, Johann. F, «Multi-criteria analysis of a biorefinery for co-production of lactic acid and ethanol from sugarcane lignocellulose, Biofuels, Bioproducts and Biorefining, doi: 10.1002/bbb.1801 (in press)	Sugars and starch (non-polymerized)
Raw material	Martijn L.M. Broeren, Stijn N.C. Dellaert, Benjamin Cok, Martin K. Patel, Ernst Worrell, Li Shen; "Life cycle assessment of sisal fibre e Exploring how local practices can influence environmental performance" Journal of Cleaner Production 149 (2017) 818-827	Fibres
Raw material	Martinez, S., Bessou, C., Hure, L., Guilbot, J. and Helias, A., "The impact of palm oil feedstock within the LCA of a bio-sourced cosmetic cream", Journal of Cleaner Production, Vol. 145, 2017, pp. 348-360.	Oils (non-polymerized)
Raw material	Murphy, Richard J, and Andrew Norton, "Life Cycle Assessments of Natural Fibre Insulation Materials" Published by National Non-Food Crops Centre, February 2008. http://nova-institut.de/news-images/20080306-05/lca_fibre.pdf	Fibres
Raw material	Poopak, Sotoodehnia, and Amiri Roodan, "Environmental Benefit of Using Bagasse in Paper Production - A Case Study of LCA in Iran," Global Warming - Impacts and Future Perspectives, 2012	Fibres

Raw material	Saraiva, Anna Bernstad, Elen B.a.v. Pacheco, Gabriel M. Gomes, Leila L.y. Visconte, C.a. Bernardo, Carla L. Simões, and Antonio G. Soares, "Comparative lifecycle assessment of mango packaging made from a polyethylene/Natural fiber-Composite and from cardboard material," Journal of Cleaner ProductionVol. 139, 2016, pp. 1168–1180	Fibres
Raw material	Secchi, Michela, Castellani, Valentina, Collina, Elena, Mirabella, Nadia, and Sala, Serenella, "Assessing eco-innovations in green chemistry: Life Cycle Assessment (LCA) of a cosmetic product with a bio-based ingredient", Journal of Cleaner Production, Vol. 129, 2016, pp. 269-281.	Oils (non-polymerized)
Raw material	Souza, Alexandre., Watanabe, Marcos Djun Barbosa, Cavalett, Otavio, Ugaya, Cassia Maria Lie, and Bonomi, Antonio, « Social life cycle assessment of first and second-generation ethanol production technologies in Brazil », The International Journal of Life Cycle Assessment, (in press), doi: 10.1007/s11367-016-1112-y	Sugars and starch (non-polymerized)
Raw material	Spyros Foteinis, Victor Kouloumpis, and Theocharis Tsoutsos, "Life cycle analysis for bioethanol production from sugar beet crops in Greece". Energy Policy, 39, 2011, 4834–4841.	Sugars and starch (non-polymerized)
Raw material	Suwanmanee, Unchalee, Varabuntoonvit, Viganda, Chaiwutthinan, Phasawat, Tajan, Monchai, Mungcharoen Thumrongrut, and Thanawadee Leejarkpai, "Life cycle assessment of single use thermoform boxes made from polystyrene (PS), polylactic acid, (PLA), and PLA/starch: cradle to consumer gate", The International Journal of Life Cycle Assessment, Vol. 18, No. 2, 2013, pp. 401-417	Sugars and starch (non-polymerized)
Raw material	Vercalsteren An, Boonen Katrien, "Life Cycle Assessment study of starch products for the European starch industry association (Starch Europe): sector study", Report no. 2015/SMAT/R/0083, Flemish Institute for Technological Research NV"VITO", pp. 30	Sugars and starch (non-polymerized)
Raw material	Yelin Deng, Yajun Tian, Assessing the Environmental Impact of Flax Fibre Reinforced Polymer Composite from a Consequential Life Cycle Assessment Perspective; Sustainability, 2015, Vol. 7, pp. 11462-11483	Fibres
Raw material	Zhang, Yanan, Hu, Guiping and Brown, Robert C., "Life cycle assessment of a commodity chemical production from forest residue via fast pyrolysis", International Journal of Life Cycle Assessment, Vol. 19, 2014, pp. 1371-1381.	Oils (non-polymerized)
Raw material	Zucaro, Amalia, Forte, Annachiara, Fagnano, Massimo, Bastianoni, Simone., Basosi, Riccardo, Fierro, Angelo, « Comparative attributional life cycle assessment of annual and perennial lignocellulosic feedstocks production under Mediterranean climate for biorefinery framework », Integrated Environmental Assessment and Management, vol. 11, no. 3,2015, pp. 397-403. doi: 10.1002/ieam.1604	Sugars and starch (non-polymerized)

9.2 Short bibliographic reports

Every reviewed article has been summarized in a short bibliographic report. These reports are available in the annexed file "D2.1 Reviewed articles short reports annex 2.pdf".

9.3 Synthesis of reviewed articles

The table collecting all the key information from the reviewed articles is available in the annexed file "D2.1 Synthesis of reviewed articles annex 3.xlsx".