STAR-ProBio

Sustainability Transition Assessment and Research of Bio-based Products

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Recommendations concerning current sustainability standards associated with bio-based products and amendments to current standards of bio-based products

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Authors (Organisation)	Janusz Gołaszewski (UWM) Francesco Razza (Novamont) in collaboration with STAR-ProBio partners from UWM, NOVAMONT, UNITELMA, TUB, DBFZ, AUA, ECOS, SQ Consult, agroVet, UNIBO, UoY, UoSC, QUANTIS, SEPA
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Abstract

This report describes the outcome of WP8.1-3 given the main results from WP1-7. It provides a review of the current sustainability standards associated with bio-based products as the output of T8.1 and amendments to current standards of bio-based products as output of T8.2 and T8.3. The identified gaps in sustainability schemes were the basis for a SWOT/PESTEL analysis and led to the identification of potential performance indicators grouped according to adequate sustainability domains. The results were discussed in the context of a general certification scheme organized into principles, criteria and indicators for the three pillars of sustainability; the elaboration of the results also comprised the operationalisation of the indicators, benchmarking and guidance to identify a reference product, feasibility of sustainability thresholds as well as communication of environmental aspects. The STAR-ProBio consortium agreed to prepare a blueprint of the Sustainability Assessment Tracking/Tool of bio-based products called SAT-ProBio. Such a blueprint capitalizes on current standards and with respect to these includes additional and revised principles, criteria and indicators. The sustainability scheme blueprint to be developed in the STAR-ProBio project, will be proceeded in the process of CEN Workshop Agreement (CWA). It will include a list of aspects and related technical requirements to provide sustainability of bio-based products. Therefore, this blueprint can be considered as an overarching umbrella, describing sustainability principles, criteria and indicators as well as the methodological background for their application. For the future STAR-ProBio activities two internal draft documents were elaborated: "The Scoping Paper" and CWA-related "The Project Plan". The scoping paper provides methodical background on combining the STAR-ProBio results into the sustainability assessment framework of SAT-ProBio with the three components: (1) Technical requirement for the assessment of bio-based products (CWA), 2) Guidelines for a certification scheme based on the proposed framework (Rules of game), and 3) Application of the proposed certification scheme to bio-based case studies (Product Category Rules). The Project Plan for the CEN or CENELEC Workshop on "Sustainability qualification framework for bio-based products" under the acronym: SAT-ProBio, provides detailed information on the assumed procedure. The CWA lays down sustainability principles, criteria and indicators for bio-based products and the standard describes a methodological framework for qualifying the sustainability of bio-based products. It will be based both on CEN/TC 411 work and the work of the STAR-ProBio consortium.

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Abbreviations

Abbreviation	Description
WP	Wok Package
Tx.y	Research Task of Work Package x followed by the number y of the task
Dx.y	Deliverable of Work Package x followed by the number y of the deliverable
4IR	The 4th Industrial Revolution
ASTM	ASTM International
BBE	Bio-Based Economy
CEN	European Committee for Standardization
CEN AC	Amending Corrigendum
CEN CWA	CEN Workshop Agreement
CEN EN	European Standard (EN)
CEN prEN	Draft Standard
CEN TR	Technical Report
CEN TS	Technical Specification
CEN/TC 411	CEN Technical Committee 411 on Bio-based products
CFF	Circular Footprint Formula
CoC	Chain of Custody
DPSIR	Drivers-Pressures-State-Impacts-Responses
EoL	End-of-Life
EPD	Environmental Product Declaration
F.U.	Functional Unit
GAP	Good Agricultural Practices
GHG	Greenhouse Gases
ILCD	The International Reference Life Cycle Data System
iLUC	Indirect Land Use Change
ISCC	International Sustainability & Carbon Certification
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NSB	National Standard Body
OEF	Organization Environmental Footprint
PB	Planetary Boundaries
PEF	Product Environmental Footprint
PEFCRs	Product Environmental Footprint Category Rules
PEST	Political-Economic-Socio-cultural-Technological
PESTEL	PEST plus Environmental-Legal
R&D	Research and Development
RED	Renewable Energy Directive
RP	Reference Product
RSB	Roundtable on Sustainable Biomaterials
SCP	Sustainable Consumption and Production
SDG	Sustainable Development Goal
SDO	Standards Developing Organisations
SWOT	Strength-Weakness-Opportunities-Threats
TEA	Techno-economic assessment
WFD	Waste Framework Directive

Executive Summary

The fusion of technologies linking physical, digital and biological spheres shapes modern economic activities that pave the way for the fourth industrial revolution (4IR) and associated regulations. The avant-garde of 4IR is allied with sustainable development of circular bio-based economy. Concurrently, the incorporation of new bio-based products in the market, especially the ones manufactured with process-advanced innovation technology, shall be associated with a reliable measure of the sustainability.

The standards and associated certification schemes related to the sustainability of biomass and bioenergy compose a specific indirect milieu for the development of standards for bio-based products. The only CEN standard which addresses directly sustainability of bio-based products is EN 16751:2016 Bio-based products – Sustainability criteria. The standard 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. The standard can be used for two purposes; 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. Besides, the standard sets a framework for providing information on the management of sustainability aspects, although it cannot be used to make claims that operations or products are sustainable since, it does not establish thresholds or limits. The important prerequisite for its implementation is that it can be used for business-to-business (B2B) communication and for developing product specific standards and certification schemes.

The STAR-ProBio indicates potential improvements to the standard EN 16751:2016. They include assessment methods and thresholds in suitable areas, investigating the suitability of adjusting the list of sustainability indicators and initiating a series of additional standardization activities.

This report describes the outcome of WP8 research tasks T8.1-3 given the main results from WP1-7. It provides a review and analysis of the current sustainability standards associated with bio-based products as the output of T8.1 and amendments to current standards of bio-based products as output of T8.2 and T8.3. The gaps in certification schemes identified in the STAR-ProBio were the basis for a SWOT/PESTEL analysis and led to the identification of potential performance criteria grouped into adequate sustainability domains. The results were discussed in the context of a general certification scheme organized finally into a STAR-ProBio proposal of principles, criteria and indicators for the three pillars of sustainability; the elaboration of the results also comprised the operationalisation of the indicators, benchmarking and guidance to identify a reference product, feasibility of sustainability thresholds as well as the way for communication of sustainability aspects.

The report was organized according to the three methodical blocks.

- The gaps identified by STAR-ProBio, i.e.: 1) Gaps and weaknesses in criteria and indicator sets. 2) Harmonization of the criteria assessment and operationalization; 3) Legislation and consensus for minimum criteria in all BBE sectors; 4) Leakage effects from EU bio-based economy policies; 5) New innovative, inter-sectoral products; 6) End-of-Life (EoL); and 7) Traceability of sustainability and certificates along the value chain; they were the basis for SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis and consequently enabled the identification of potential performance criteria for their closing grouped into sustainability domains together with indication for R&D needs. The §3.1 provides insights into SWOT factors and PESTEL (Political-Economic-Social-Technical-Environmental-Legal) categories attributed to the factors and potential criteria for their operationalization.
- The proposal for certification scheme and recommendation of environmental, social and economic principles, criteria and indicators and their operationalization are discussed assuming normative issues related to benchmarking and reference product characteristics on the basis of analysis of mulch film and packaging markets, feasibility of defined sustainability thresholds definition and communication of sustainability aspects. Those issues are developed in the following §3.2-7.
- The conceptual framework and indicators for horizontal integration of interdisciplinary links in the assessment of sustainability of bio-based products along the life cycle on the basis of the Drivers-Pressures-State-Impacts-Response (DPSIR) system approach is presented in §3.9.

<u>Gaps in criteria and indicators.</u> The STAR-ProBio indications and criteria assessment showed that some issues related to criteria and indicators are not significantly represented in regulations on sustainability. In order to overcome the weaknesses in the current set of criteria and indicators a supplementary set was proposed, composed of 9 criteria addressing efficiency of land and tertiary resource use, land change and SO_2 related emissions, PM10 pollution, and end-of-life management.

<u>Harmonization of criteria assessment and operationalization.</u> The main activities for harmonization of criteria assessment and operationalization address directly the horizontal aspect of standardization and are associated with integrability of multiple environmental claims and socio-economic indicators into a single sustainability claim for a given bio-based product; improving the interoperability between all stages of supply chain and actors engaged by collecting/combining information on available regulations for specific environmental claims, and socio-economic attributes related to bio-based products; and conceptualizing a composable system that provides components that can be selected and assembled in various combinations to satisfy specific sustainability requirements. These activities are in accordance with the postulates by certification bodies claiming that the improvements in sustainability assessment is to be achieved not by developing new criteria and indicators, but by adapting and communicating more precisely the existing ones, as well as by harmonizing the actual operationalization of the existing criteria by the certification schemes and certification bodies.

Consensus on minimum criteria. The criteria and indicators in the context of obtaining the consensus for minimum criteria across bio-based economy sectors are related to the development of methodology for processing a meta-standard that enables checking of cross-sectoral compatibility of different certification schemes applied along the stages of supply chain (material, manufacture, consumption) and waste management. In the context of circular bioeconomy, the reference normative on the consensus for minimum sustainability criteria is provided by the French voluntary standard XP X30-901: 2018 "Circular economy – Circular economy project management system – Requirements and guidelines" (AFNOR Standardisation 2018). The standard proposes 3x7 matrix with three pillars of sustainability and seven areas of actions: sustainable procurement, eco-design, industrial symbiosis, functional economy, responsible consumption, extension of service life, and the effective management of materials and products at the end of their life cycle. Besides, this standard advocates continual improvement.

Leakage effects mean that positive effects generated by bio-based sectors such as revenues, mitigation of GHG emissions or improvement of social well-being can be lost to other countries' economies, can involve land degradation, change in carbon stocks in the case of deforestation, the shift to other sectors or countries without requirements on sustainability, temporary increase in GHG emissions (carbon debt) or limiting social development in other areas. Development of bio-based sectors will intensify competition for biomass resource and land use in the macro-regional or global scale. Leakage effects include land grabbing. It means land acquisitions or concessions which are (i) in violation of human rights, particularly the equal rights of women; (ii) not based on free, prior and informed consent of the affected land-users; (iii) not based on a thorough assessment, or in disregard of social, economic and environmental impacts, including the way they are gendered; (iv) not based on transparent contracts that specify clear and binding commitments about activities, employment and benefits sharing; and (v) not based on effective democratic planning, independent oversight and meaningful participation (ILC 2011). STAR-ProBio develops methodology on "low iLUC risk biomass"

Inter-sectoral products are systemic products which satisfy specific needs and expectations of the market assuming network cooperation in creation of the product value. The model example is a product whose production involves different sectors of economy such as agriculture, industry, services. Designing the regulatory framework for inter-sectoral bio-based products requires merging cross-sectoral approaches, which can reveal conflicts of interests between conventional biomass-based sectors (e.g. iLUC) and in the conjunction with industry sectors (e.g. market pressure for a given feedstock). An innovative, inter-sectoral product satisfies the definition of product innovation understood as the introduction of a goods or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics (OECD/EUROSTAT 2005). The internationally-comparable set of indicators was developed by the OECD as the Product Market Regulation (PMR). The indicators measure to what degree policies impact competition in viable competition areas of the product market.

End-of-life. At its end-of-life, a bio-based product is disposed of and becomes postconsumer waste. During waste collection a distinction is made between postconsumer and postindustrial waste. Post-consumer waste is produced by the consumer and is often collected together with other municipal solid residual waste. The separated organic waste can undergo a specific treatment and close the loop in circularity. Postindustrial waste is produced by companies, and includes off-spec products and cutting waste. For bio-based products the key EoL activities include recycling, composting, energy recovery and landfilling. The latter option should be only theoretical in a situation of uncontrolled methane emissions. A potential non-specific indicator related to sustainability of the EoL stage and material circularity can be associated with life-cycle conversion of waste into useful products.

Traceability of sustainability and certificates along supply chains are crucial requirements in the assessment of sustainability of bio-based products. Traceability is the ability to identify and trace the history, distribution, location and application of products, parts and materials, to ensure the reliability of sustainability claims, in the areas of green economy, human rights, labour (including health and safety), the environment and anti-corruption (UN Global Compact 2014). The legal base for certification of sustainability of bio-based products along the value chain is Chain-of-Custody (CoC) which provides documentation of evidences for sustainability at any stage of a supply chain management. CoC is an integral part of traceability by trailing and monitoring certified material along a supply chain. Currently, the most advanced CoC tracing system is related to the food and forestry sectors e.g. standard ISO 22000 on implementation of food safety management system (FSMS) and Forest Stewardship Council (FSC) CoC certification. Of the four available CoC methods, in order of strictness and level of assurance, they are: identity preservation, product segregation, mass balance and book-and-claim. Mass balance and superior CoC methods are recommended for bio-based products. Traceability systems are closely interlinked with the implementation of progressive solutions of information technology and the basis for tracing sustainability should be through effective and measurable indicators.

Principles, criteria, indicators. The main challenge of the STAR-ProBio is to combine the existing elements of standards (e.g. sustainable criteria reported in EN 16751) with the learned lessons from the project's results produced so far into a smart and meaningful framework supporting the sustainability assessment of bio-based products. It will be based on a meaningful combination of the existing results of all other STAR-ProBio work packages, adding a set of guidelines and rules regarding the actual implementation of all sustainability principles, criteria and indicators developed (i.e. SAT-ProBio blueprint and tool). To close the identified gaps, STAR-ProBio proposes environmental principles (13), criteria (15) and indicators (19) reflecting the latest outcomes of the consortium discussion on these topics and the work done within WP2-4 (Table 22), and social and economic principles (12+1), criteria (12+1) and indicators (15+4) is seen as the output from WP4-6 (Table 32). The STAR-ProBio project is ongoing thus changes and/or improvements are possible.

Benchmarking and reference product. The final aim for the proposed SAT-ProBio sustainability framework is to promote the market uptake of bio-based products characterized by a lower environmental impact, social compliance and economic feasibility within a specific product or service category through the development of a new Type I-based label certification scheme. In order to determine if a given bio-based product is environmentally preferable, it is necessary to define a "benchmark" to which a comparison is to be made. Within the STAR-ProBio project, the virtual reference product was followed given the use of a real product cannot be achieved without a tight involvement and collaboration of the representative economic operators.

Thresholds. LCA analysis does not provide any information about environmental sustainability of a product, i.e. how far we have to go in reducing the burdens to be sustainable, rather it shows if a product more or less of a burden compared to an equivalent product. STAR-ProBio proposes the following approach to be applied in future policy making. Assuming we know the buffering capacity of the planet for GHG emissions, i.e. maximum amount of GHG per year that does not cause an increase of the average temperature of the planet, and divide an amount by the planet's population, as a result we obtain the "sustainable threshold" per capita for GHG emissions. This can be considered as an (annual) budget of each citizen on the planet, hence it is our "Sustainable budget". It is possible to evaluate it through infinite combinations of goods/behaviors depending of the lifestyle.

Communication of sustainability. One of the main gaps in the existing environmental labels, such as ISO 14025 Type III (e.g. EPD, Environmental Product Declaration), is the absence of the reference values to which the LCIA results of a certified product can be compared so as to obtain a more complete picture of its environmental performance. STAR-ProBio proposes a scheme of graphical communication covering information on absolute LCIA in relation to F.U., the percentage positioning in comparison with the reference product, the relevance of LCIA results with the magnitude of impact, and a possible single score result (Figure 15).

Certification scheme. The proposal of a certification scheme presents key elements that should be considered, i.e. Program Operator, Scientific Committee, Steering Committee, Open Consultation Process for defining reference product and LCA analysis, Economic Operator and Accredited Certification Body (Figure 16).

DPSIR. A broader insight into environmental and socio-economic implications in the context of regulations and policy on sustainability is presented in the ecosystem-based DPSIR analysis. The starting point of the DPSIR analysis on drivers of sustainability of bio-based products is the natural world of human life and human economic activities, i.e. ecosystems (natural capital) and ecosystem services (natural resources), followed by economic activities (beneficiaries) and socio-economic implications related to improvement of the quality of ecosystems (management, conservation). Ecosystem management links economic activities and associated impact to ecosystems with the Earth's system processes including the planet's natural cycles of carbon, water, nitrogen, and phosphorus flows.

Regarding the PBs, SDGs, the EU environmental legislation and the ecosystem-based DPSIR analysis, the principles and criteria for development of horizontal aspects of sustainability of bio-based products have been grouped into five categories. The first three, i.e.: sustainable material, manufacturing and consumption, ensure circularity and are framed in the SDG12 *Sustainable consumption and production* (SCP) (UNEP 2018). The other two – sustainable ecosystems and sustainable communities are addressed directly in SDG15 *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss* and SDG11 *Sustainable cities and communities*.

Sustainable consumption and production (SCP) cover the whole value chain beginning from resource acquisition, its conversion to materials and products, and consumption. The key policy related to SCP is to decouple economic growth from resource use. Another significant consideration is social responsibility and this relates SCP with ecosystems and communities by ethical obligation for any engaged stakeholders who impact ecosystems to act for the benefit of the general society.

Sustainable Materials. Materials are used to manufacture bio-based products or deliver services. Sustainable Materials present positive impact on ecosystems and communities. Such materials have low environmental impacts throughout life cycle and do not harm the health of workers and people. They are renewable and consume a low amount of other ecosystem renewable resources such as CO_2, water and nutrients. Depending on the product's functionality, materials can be manufactured to frail or durable products. The materials embodied in bio-based products can be extracted at the EoL for reuse, secondary use, or decomposition to simpler compounds and further treatment, while the ultimate EoL option is energy recovery. In the context of regulations, sustainable material should comply with the precautionary principle that it is safe to be processed and final products will be safe when released to the public use by not impacting quality of life (health, air and water quality, standard of living, communities, human rights, legal rights, privacy, etc.) or to the environment by not causing detrimental effects in ecosystems (air pollution, water pollution, soil pollution, global warming, resource depletion, land degradation and biodiversity loss, etc.).

Sustainable Manufacturing. Manufacturing is the biological or chemical processing or formulation of products. Sustainable manufacturing is the production of products using non-polluting, energy and natural resource conserving, and economically sound and safe processes. Taking into account those parameters, the regulations should connect sustainable manufacturing indicators with a sustainable design and engaged actors, i.e. suppliers, consumers, and communities, through eco-efficient practices that minimize generation of waste and adopt pro-environmental technologies. Consequently, current and ongoing standardization processes and related policies like GAP, RED, WFD and the eco-design of products have to be harmonized with a resource efficiency policy.

The efficient resource use and mitigation of detrimental impacts on ecosystems can be affected and handled by the pattern of consumption. In theory, sustainable consumption of bio-based products shall contribute to minimization of environmental impacts so that natural capital and ecosystem services can satisfy human needs of the present and next generations. This can be achieved by practices that contribute to saving resources where waste disposal and environmental pollution are minimized. The regulations related to sustainable consumption of bio-based products should contribute to building public awareness and to promoting sustainable consumption, including active involvement in EoL activities so as to prolong a bio-based product's durability and to facilitate reusability, recyclability and recoverability.

Sustainable ecosystems. The main policy related to sustainable ecosystems is focused on decoupling economic growth from environmental pressures and impacts. Economic activities influence many of the Earth's physical and biological processes organised into ecosystems. Therefore, it is important to control the impacts so that ecosystems can operate in a sustainable way, without severe loss or change of function. Nutrient cycling is essential for the continuous supporting of ecosystems as well as prevention of toxic accumulation of substances. Therefore, the sustainable management of ecosystems is not to turn nutrients into pollutants. All regulations on resource productivity and EoL processes associated with decomposition (chemical or physical processes) and biodegradation (breakdown of materials by microorganisms) of bio-based products are crucial in the context of resource efficiency, releasing available nutrients, and closing nutrient cycles in the ecosystems.

Sustainable communities. The main policy on sustainable communities is associated with activities that support decoupling of resource use from well-being. It means that all the natural, human and financial capital of communities is adequate to available resources. Sustainable communities have healthy and safe living and working places, including access to nutritious, uncontaminated food, clean air and water. The regulations on sustainable communities related to bio-based products should support the approval of a lifestyle oriented towards protection and enhancement of local and regional ecosystems and biological diversity, conservation of water, land, energy, and non-renewable resources, including maximum feasible reduction, recovery, and reuse and recycling of waste, utilization of prevention strategies and appropriate technology to minimize pollution emissions, and use of renewable resources no faster than their rate of renewal (ISC 2019).-

The gaps in the current legislations on sustainability of bio-based products identified during the STAR-ProBio project can be augmented by dealing with the issues indicated by the DPSIR analysis, which can contribute to the improvement of the current policy on sustainability of bio-based products.

1. Current and ongoing standardization and related policies like GAP, RED, WFD and the eco-design of products have to be harmonized with a resource efficiency policy.
2. Implementation of new models for value chains, business, customer offerings, consumer EoL approach and pricing, e.g.:
    a. development of new business models that assume selling services instead of products (impact on environment, local economy and communities)
    b. shifting tax burden from labour to resource use and eco-system services
    c. integration of the environmental accounts into certification scheme
3. Levelized life-cycle costs that enable comparison between bio-based products made from different feedstock.
4. Internalization of externalities that can be negative, i.e., external costs that are associated with uncompensated social or environmental effects, or positive, i.e., external benefits that are associated with positive social and environmental effects.
5. R&D related development of new technologies for SCP.

Recapitulation

This report proposes a set of environmental, social and economic principles, criteria and indicators that are consistent with the current sustainability schemes, in addition to the way of their operationalisation, monitoring and communication to consumers. In order to have a complete view of the certification scheme Task 8.7 develops documentation (CoC) needed to trace sustainability of bio-based products according to the from cradle to cradle LCA model (circularity).

The key contributions to the development of STAR-ProBio blueprint for the sustainability of bio-based products compose the outputs from the work packages WP1-7. In the delivered reports it was suggested that a thorough analysis of the existing certification and standardization landscape should serve as the starting point for development of coherent principles, criteria and indicator and their implementation into certification practice. In the course of numerous meetings and internal discussions supported by suggestions of internal and external experts novel concepts were proposed concerning the sustainability assessment of a whole supply chain in association with EoL options and circularity of material. These ideas are in this report, but the main challenge of this project is to aggregate the results into a coherent certification scheme that will enhance the sustainability assessment of bio-based products and associated policies.

The STAR-ProBio consortium partners agree that implementation of the above recommendations and amendments into the current sustainability certification schemes will be associated with the assessment of policy impacts studied in WP9. It will be achieved through the three integrated instruments: SAT-ProBio blueprint for sustainability assessment of bio-based products; SAT-ProBio tool for demonstration of the sustainability assessment of the STAR-ProBio case studies, i.e. bio-based polymers and fine chemicals; and SyD-ProBio tool for the policy impact assessment. The concept of the SAT-ProBio has already been started early in the project. As a result, different versions of a master document aiming at the description of the SAT-ProBio blueprint and its several elements have been drafted. The concept of combing the assessment of sustainability of bio-based product with the policy impact assessment was proposed by external reviewers of the ongoing project. Currently, the foundation for the development of a blueprint of a certification scheme for sustainability of bio-based products and policy impact assessment is laid in the third version of the approach in the form of the internal STAR-ProBio working documents: the draft of WP8 "SAT-ProBio Blueprint scoping paper" and the draft of the Project Plan for launching the CEN Workshop Agreement. The above recommendations and amendments will support those activities.

1. Introduction / Outcomes from STAR-ProBio WPs

The fusion of technologies linking physical, digital and biological spheres shapes modern economic activities that pave the way for the fourth industrial revolution (4IR) and associated regulations. The avant-garde of 4IR is allied with sustainable development of circular bio-based economy. Concurrently, the incorporation of new bio-based products in the market, especially the ones manufactured with process-advanced innovation technology, shall be associated with a reliable measure of sustainability. The overall indications on sustainability-related potential impacts of bio-based products are set in Table 1.

Table 1 Potential environmental, economic and social implications of bio-based products

Sustainability component	Environmental implications	Economic implications	Social implications
Resources	Depletion of natural biotic and abiotic resources	Higher prices of bio-based feedstock. Potential conflict with food sector (higher prices).	Food insecurity and threats to standard of life and lifestyle.
Land use	Destruction of natural habitats as a result of land use changes and biodiversity loss	The focus on short-term profits at the cost of maintaining the long-term environmental sustainability. Land grabbing.	Underpinning human life support systems (threats to provisional ecosystem services)
Soil	Soil degradation due to inadequate rehabilitation after intensive uptake of nutrients	Lower profitability for farmers (decreased soil fertility)	Local communities bear off-site costs
Water	Changes in watersheds both due to water overexploitation and agricultural runoffs (eutrophication)	Growing demand for fresh water	Limited access to fresh water.
Air	Emissions related to the use of non-renewable	Generation of external costs	Threat to health

	materials, manufacturing, and waste management		

The environmental impacts have occurred since the starting of economic activity because of the associated depletion of resources, emissions and changes of the functionality of the ecosystems. The dominant material input in bio-based production is biomass of plant origin. Negative environmental implications can be associated with changes in land use that implying in turn diminished soil fertility, water availability and quality and on field air pollution. This causes also economic implications due to an increased demand for the feedstock and to a potential conflict with food production. Further, it can involve pressures associated with land use including decrease in soil and water productivity, lower incomes with unequitable value distribution and price of products without implementation of external costs. From the social point of view, the changes in market and ecosystems can carry risks to the standard of life and lifestyle.

The potential negative impacts of bio-based products can affect any stage of value chains[1]. Table 2 presents the key potential impacts of bio-based products on sustainability along the supply chain and EoL options.

Table 2 The key negative-impact factors across the supply chain of bio-based products

Negative-impact factor
to the environment
Resource depletion
Land use change
Biodiversity loss
Soil degradation
Freshwater depletion
Waste deposition
GHG emissions
Nutrients loading (eutrophication)
SO_2 emission (acidification)
Particle emission (PM10)
to the economy
High costs of inputs
Low economic revenue
High prices
Inequitable value distribution
to the society
Pollution/deposition of emissions
Threats to work conditions
Threats to human health
Food insecurity
Threats to land rights
Threats to water rights

[1] EN 16751:2016 defines a supply chain as the linked set of resources and processes that begins with the production of raw material and extends through the manufacturing, processing, handling and delivery of products to purchaser; ISO 13065: 2015 defines it as the linked set of resources and processes that begins with the sourcing of raw material (including biomass production where applicable) and extends through transport and storage of products to the end user.

The main environmental impacts across the value chain can be attributed to the cultivation/extraction of raw materials, manufacturing and end-of-life management. At the same time, the economic impacts assigned to the whole life cycle can be related to economic and social well-being. This implies that the key principles of environmental sustainability shall be addressed to the efficient use of resources, protection and conservation of soil quality, biodiversity and water, reduction of air emissions and pollution, and responsible waste management. The principles of economic sustainability are to produce and trade bio-based products in an economically and financially viable and equitable way. The social sustainability principles shall be related to respecting rights (labour, water, land) and to promoting local sustainable development.

1.1 Characterization of the current normative documents on bio-based products

1.1.1. Standards Organizations

The main international organizations working on sustainability standards related to bio-based products are the International Organization for Standardization (ISO), European Committee for Standardisation (CEN), and ASTM International (ASTM). Besides, standards on sustainability of bio-based products are developed by national standards bodies (NSB) acting also as members of international standards organisations representing the CEN in the EU countries. Besides, sustainability of bio-based products is developed by industry-based Standards Developing Organisations (SDO) like international organisations: the Roundtable on Sustainable Biomaterials (RSB) and International Sustainability & Carbon Certification (ISCC).

1.1.2. CEN Standards and associated documentation

Depending on the purpose and advancement of a standardisation process, it can lead to different forms of standards and related documentation. The CEN standards can be in the form of European Standard (EN), Technical Specification (TS), CEN Workshop Agreement (CWA), Technical Report (TR), and Draft Standard (prEN). The amended standards are in the form of Amending Corrigendum (AC).

1.1.3. CEN Working Groups of TC 411

CEN standards for bio-based products are developed by Technical Committee 411 under EC Mandates M/429 (2008), M/491 and M/492 (2011). The standards have been developed by five working groups (WG): WG1: Terminology – EN 16575:2014 Bio-based products – Vocabulary; WG2: Bio-solvents – CEN/TS 16766: 2015 Bio-based solvents – Requirements and test methods; WG3 Bio-based content – CEN/TC 16721: 2014 Bio-based products – Overview of methods to determine the bio-based content, EN 16640:2017 Bio-based products – Bio-based carbon content – Determination of the bio-based content using the radiocarbon method, EN 16640:2017/AC:2017 Bio-based products – Bio-based carbon content – Determination of the bio-based content using the radiocarbon method, EN 16785-1:2015 Bio-based products – Bio-based content – Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis; WG4: Sustainability criteria, life cycle analysis and related issue – CEN/TR 16957:2016 Bio-based products – Guidelines for Life Cycle Inventory (LCI) for the End-of-life phase, EN 16751:2016 Bio-based products- Sustainability criteria, EN 16760:2015 Bio-based products – Life Cycle Assessment; WG5: Certification and declaration tools – EN 16848:2016 Bio-based products – Requirements for Business to Business communication of characteristics using a Data Sheet; EN 16935:2017 Bio-based products – Requirements for Business-to-Consumer communication and claims.

1.1.4. Overarching priorities of sustainability and relevant normative documents

SDGs.

The importance of sustainable development in the next decade (by 2030) is expressed in the 17 Sustainable Development Goals and 169 associated targets which are measured with indicators. All of the goals are relevant to bio-based products although in the context of regulations some of them need to be directly addressed SDG12 *Responsible consumption and production (SCP)*, SDG6 *Clean Water and Sanitation*, SDG13 *Climate action*, SDG15 *Life on Land* and SDG11 *Responsible Cities and Communities*.

Planetary boundaries

"Planetary boundaries" is a concept associated with the Earth's system processes that drive the global environmental change (Rockström et al. 2009, Steffen et al. 2015). There are nine Earth processes described by a set of control variable thresholds. They are 1) climate change: atmospheric CO_2 concentration, increase in radiative forcing; 2) biodiversity loss: extinction rate; 3) biogeochemical cycling of nitrogen and phosphorus: anthropogenic nitrogen removed from the atmosphere, anthropogenic phosphorus going into the oceans; 4) ocean acidification: global mean saturation state of aragonite in surface seawater; 5) land use: land surface converted to cropland; 6) freshwater: global human consumption of water; 7) ozone depletion: stratospheric ozone concentration; 8) atmospheric aerosols and overall particulate concentration in the atmosphere on a regional basis; and 9) chemical pollution: concentration of toxic substances, plastics, endocrine disruptors, heavy metals, and radioactive contamination in the environment. The former four crossed boundaries and require a special regulatory approach. The results provided by Rockström et al. (2009) and Steffen et al. (2015) confirm the importance of the processes in maintaining the existing system of the Earth. The authors point to a greater risk of problems associated with renewable resources (mainly water and food resources, but also biodiversity) rather than non-renewable ones (energy resources, and even rare earth elements). As a result, it can be assumed that the current degradation of natural processes and excessive use of resources are likely to lead to the risk of a catastrophe on a global scale. Due to the typical time lag between cause and effect of a given phenomenon, one can expect that environmental issues will have increasing importance for the global community in the longer term. The authors assume the turning point will occur around 2030. Rockström et al. (2017) claim that in global governance, climate stabilization must be placed on par with economic development, human rights, democracy, and peace. It is worth mentioning that the tenth boundary, namely – terrestrial net primary production (NPP) that could indicate the health of ecosystems was proposed by Running (2012).

ILCD

The International Reference Life Cycle Data System (ILCD) is a common basis for quality life cycle data and studies into the environmental implications of an entire supply chain of products. The data and studies support legislation activities related to the sustainable consumption and production in the private (eco-labeling, eco-design, Carbon footprint) and public sectors (Green Public Procurement) (ILCD 2010).

Product Environmental Footprint & Organization Environmental Footprint

The Product Environmental Footprint (PEF) and the Organization Environmental Footprint (OEF) provide a life-cycle approach to quantify the environmental performance, i.e. "environmental footprint", of goods or services and organizational activities as a whole, respectively. The product- or organization-addressed measures are in accordance with the EU "Roadmap to a Resource Efficient Europe"[2] seen as a process of increasing resource productivity and decoupling economic growth from resource use and environmental impacts.[3] The PEFs are based on Product Environmental Footprint Category Rules (PEFCRs)[4] and other assessments focus on specific sites and thresholds. The PEFCRs assure that all the PEFs of a given product category undergo the assessment in a harmonized way. Besides, PEFCRs provide a basis for comparability analysis between different PEFs.

The life-cycle approach for PEF and OEF refers to all stages of a supply chain from raw material production or acquisition through manufacturing of a bio-based product to distribution and consumption and EoL options together with assessments of relevant environmental impacts and socio-economic consequences. The regulations that are relevant to PEF and OEF are presented in Table 3. The environmental assessment methods for PEF are regulated in the series of standards ISO 140xx and GHG Protocol, the specification for the assessment of the life cycle GHG emissions in PAS 2050: 2011 (BSI), and the environmental communication in BPX 30-323 (ADEME).

The methods and guidance of environmental assessment for organization are provided by standard ISO 14046: 2006 and other organisations Global Reporting Initiative (GRI), Carbon Disclose Project (CDP) ILCD, DEFRA and Bilan Carbone (ADEME)

Table 3 Regulations relevant to Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF).

Documents	Title	Source
Environmental assessment methods for PEF		
ISO 14020: 2000	Environmental labels and declarations -- General principles	http://www.iso.org/
ISO 14025: 2006	Environmental labels and declarations -- Type III environmental declarations – Principles and procedures	
ISO14044: 2006	Environmental Management: Life Cycle Assessment	
ISO 14067: 2012	Carbon Footprint of Product	
ILCD	International Reference Life Cycle Data System Handbook	http://lct.jrc.ec.europa.eu/
EFS 2009	Ecological Footprint Standard 2009	http://www.footprintnetwork.org/
GHG Protocol	Greenhouse Gas Protocol (WRI/ WBCSD). The World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD) started to develop its corporate standard in 1998 and its Product and Value Chain	WRI and WBCSD (2011). Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting

2 European Commission 2011: COM(2011) 571 final: 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.

3 Product Environmental Footprint (PEF) Guide. 2012. European Commission, Joint Research Centre, Institute for Environment and Sustainability, H08 Sustainability Assessment Unit.

4 European Commission, PEFCR Guidance document, - Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3, December 2017.

	GHG Accounting and Reporting Standard in September 2008	Standard, 2011.
PAS 2050: 2011	The specification for the assessment of the life cycle greenhouse gas emissions of goods and services	http://www.bsigroup.com
BPX 30-323 (ADEME)	The general principles for an environmental communication on mass market products.	http://www2.ademe.fr/
Environmental assessment methods developed for organisations[5]		
ISO 14046: 2006	Principles and requirements at the organization level for quantification and reporting of greenhouse gas (GHG) emissions and removals.	
Global Reporting Initiative (GRI)	Multi-stakeholder network of experts worldwide.	
CDP Water Disclosure Project	The Carbon Disclosure Project is an independent not-for-profit organization.	
GHG Protocol (WRI/WBCSD)	Greenhouse Gas Protocol (WRI/ WBCSD).	
ILCD	In response to commitments in the IPP Communication of the European Commission, the International Reference Life Cycle Data System (ILCD) has been established for ensuring consistent and reproducible life cycle data and robust impact assessments.	
Defra	Guidance on how to measure and report your greenhouse gas emissions.	
Defra	Guidance on Environmental Key performance Indicators – Reporting Guidelines for UK Business	
Bilan Carbone (ADEME)	Bilan Carbone is an organizational GHG accounting guidance document and tool	

1.2 Overview of current standards related to sustainability of bio-based products

The regulations on sustainability of bio-based products involve standards, certification schemes and labelling.

Current standards covering horizontal aspects of sustainability of bio-based products

The horizontal standards provide requirements, specifications and guidelines that ensure that materials, manufacturing, products and services comply with sustainability.

The standards and associated certification schemes related to sustainability of biomass and bioenergy compose a specific indirect milieu for development of standards for bio-based products. The only CEN standard which addresses directly sustainability of bio-based products is EN 16751:2016 Bio-based products – Sustainability criteria. The other relevant standard EN 16760:2015 Bio-based products – Life Cycle Assessment addresses environmental sustainability.

A general overview of the current regulations related to biomass and bioenergy market and bio-based product is presented in Figure 1.

[5] Analysis of Existing Environmental Footprint Methodologies for Products and Organizations: Recommendations, Rationale, and Alignment . 2011. European Commission, Joint Research Centre, Institute for Environment and Sustainability, H08 Sustainability Assessment Unit.

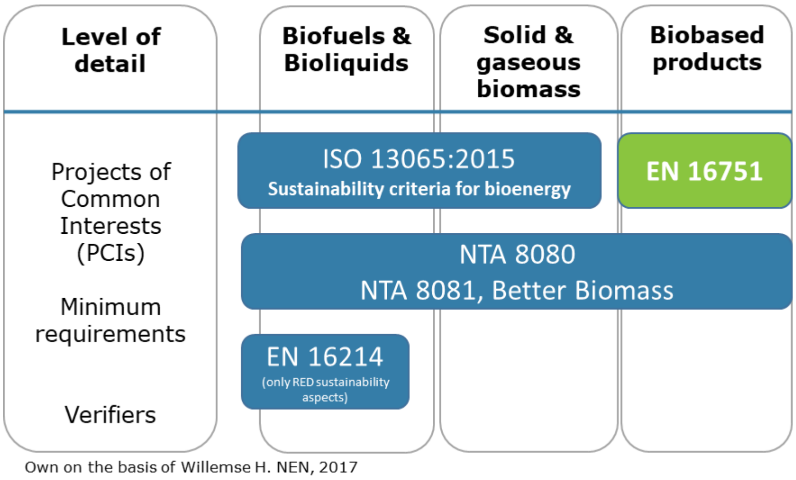


Figure 1 Overview of regulations relevant to sustainability of bio-based products.

- ISO 13065:2015 Sustainability criteria for bioenergy. This ISO standard specifies principles, criteria and indicators for a bioenergy supply chain to facilitate assessment of environmental, social and economic aspects of sustainability. It is applicable to a whole supply chain, parts of a supply chain or a single process in the supply chain, but it does not establish thresholds, does not determine the sustainability of processes or products and it is intended to facilitate comparability of various bioenergy processes or products.
- EN 16214: EN 16214-1:2012 (08-2012) Sustainability criteria for the production of biofuels and bioliquids for energy applications – Principles, criteria, indicators and verifiers.
- CEN/TS 16214-2:2014 (01-2014) Part 1: Terminology;
- EN 16214-3:2012 (08-2012) Part 2: Conformity assessment including chain of custody and mass balance;
- EN 16214-4:2013 (01-2013) Part 3: Biodiversity and environmental aspects related to nature protection purposes;
- Part 4: Calculation methods of the greenhouse gas emission balance using a LCA approach.
- NTA 8080:2015 (NEN) – Sustainably produced biomass for bioenergy and bio-based products. Part 1 Sustainability requirement. It provides the basis for the development of a certification system that offers organizations an instrument to demonstrate that they comply with the sustainability requirements of NTA 8080.
- NTA 8081:2012-04 Better Biomass. It is an international certification scheme for NTA 8080. It addresses solid, liquid and gaseous biomass. It consists of sustainability requirements, chain-of-custody requirements and rules for certification.

The scope of the standard EN 16751:2016

The standard EN 16751:2016 Bio-based products – Sustainability criteria 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.

The 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. Besides, the standard sets a framework to provide information on management of sustainability aspects, although it cannot be used to make claims that operations or products are sustainable since, it does not establish thresholds or limits.

An important prerequisite for its implementation is that it can be used for business-to-business (B2B) communication and for developing product specific standards and certification schemes.

The issues beyond the scope of EN 16751:2016

The report STAR-ProBio D1.1 indicates potential improvements to the standard EN 16751:2016. Such improvements include assessment methods and thresholds in suitable areas, investigating the suitability of adjusting the list of economic indicators, initiating a series of additional standardization activities, and collaborating with TCs working groups on specific product standards for bio-based products such as bio-solvents.

The identified issues beyond the scope of EN 16751 can be addressed through the following activities:

- providing additional assessment methods and thresholds;
- providing assessment methods and thresholds for ISO 13065: 2015 criteria;
- facilitating cradle-to-grave or cradle-to-cradle analyses of bio-based products;
- providing a standard, to facilitate comparisons of bio-based and fossil-derived products;
- considering iLUC and related issues appropriately by standardization;
- developing standards, which provide guidance on social and economic LCA;
- creating standards for the circular economy;
- recognizing sustainability criteria for bio-based polymers and lubricants.

Finally, the report STAR-ProBio identifies seven gaps for consideration in the context of recommendation and amendments to the current sustainability standards associated with bio-based products (D1.1).

1. Gaps and weaknesses in criteria and indicator sets.
2. Harmonization in criteria assessment and operationalization.
3. Legislation and consensus for minimum criteria in all BBE (Bio-Based Economy) sectors.
4. Leakage effects from EU BBE policies.
5. New innovative, inter-sectoral products.
6. End-of-Life (EoL).
7. Traceability of sustainability and certificates along the value chain.

1.2.1 Sustainability certification schemes of bio-based products

A sustainability certification scheme of bio-based products should involve legal, contractual or specific requirements in the field of environmental, economic and social sustainability. A certification scheme should be composed of i) certification standards that provides requirements to be met, ii) accreditation requirements ensuring that the accreditation is made on the competency basis of an accreditation body, and iii) certification process requirements which determine whether the standard requirements have been met.

1.2.2 Chain of Custody for bio-based products and standard-related reliable traceability systems (and potential databases)

A full life cycle of a bio-based product was elaborated in WP3 to discuss LCA system boundaries (D3.1). It assumes six consecutive stages (Figure 2):

- from biomass production (stage 1);
- through manufacturing of bio-based product (2,3,4);
- distribution and use (5);
- and EoL options (6).

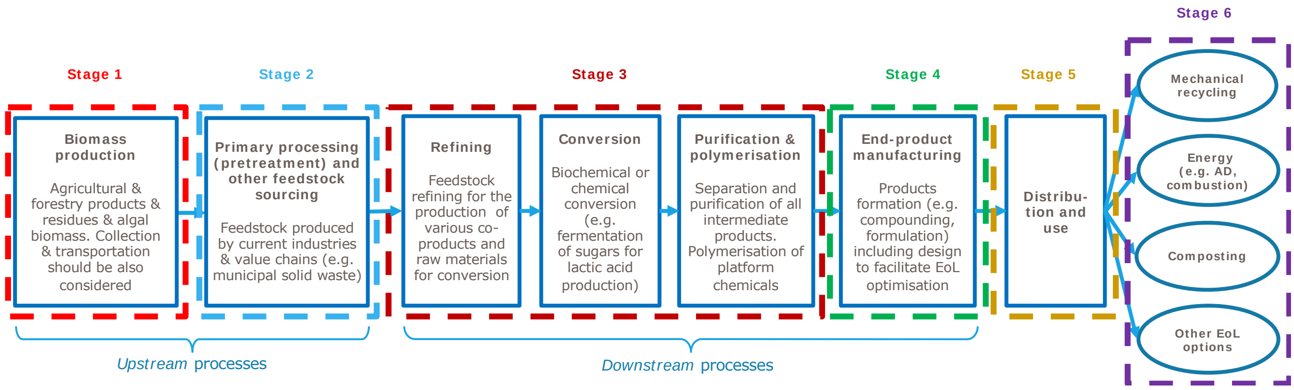


Figure 2 Life cycle stages for bio-based products using renewable feedstocks (D3.1).

The sustainability scheme of bio-based products entails description of traceability system (see §3.1) with three components: a mechanism for identifying traceable resource units (TRU), a mechanism for documenting transformation, and a mechanism for recording the attributes of traceable resource units (Olsen and Borit, 2018). The standardisation programme on sustainability criteria for biomass for bioenergy applications initiated in 2008 by the European Commission contained the request to the CEN to work on standards of the mass balance method of custody chain management; the provisions of evidence that the production of raw material has not interfered with nature protection purpose, and the auditing by member states and by voluntary schemes using the information submitted by economic operators. As a result the CEN/TC 383[6,7] provided a series of four standards EN 16214 on sustainability criteria for the production of biofuels and bioliquids for energy applications. One of them, the technical specification CEN/TS 16214-2: 2014, provides requirements to economic operator to fulfil the sustainability criteria of RED in relation to primary production of biomass and every stage within the supply chain. Requirements were also defined concerning conformity assessment bodies for verification compliance with given requirements. The regulations on conformity assessment are provided by standards:

- EN ISO/IEC 17000:2004, Conformity assessment – Vocabulary and general principles (ISO/IEC 17000:2004)
- EN ISO/IEC 17050-1, Conformity assessment – Supplier's declaration of conformity – Part 1: General requirements (ISO/IEC 17050-1)
- EN ISO/IEC 17050-2, Conformity assessment – Supplier's declaration of conformity – Part 2: Supporting documentation (ISO/IEC 17050-2)

[6] CEN/TC 383 Sustainably produced biomass for energy applications

[7] No mandate from the EC, include only sustainability of liquid biofuels (Thrän D., Fritsche U.R. 2015. Standards for bio-based fuels and resources – status and needs. IEA Bioenergy Conference, Berlin.)

Analogously, the supply chain of a bio-based product composes the basis for development of the Chain of Custody (CoC) with relevant documentation. An exemplar supply chain of bio-based products is sketched in Figure 3 (on the basis of CEN/TS 16214-2: 2014).

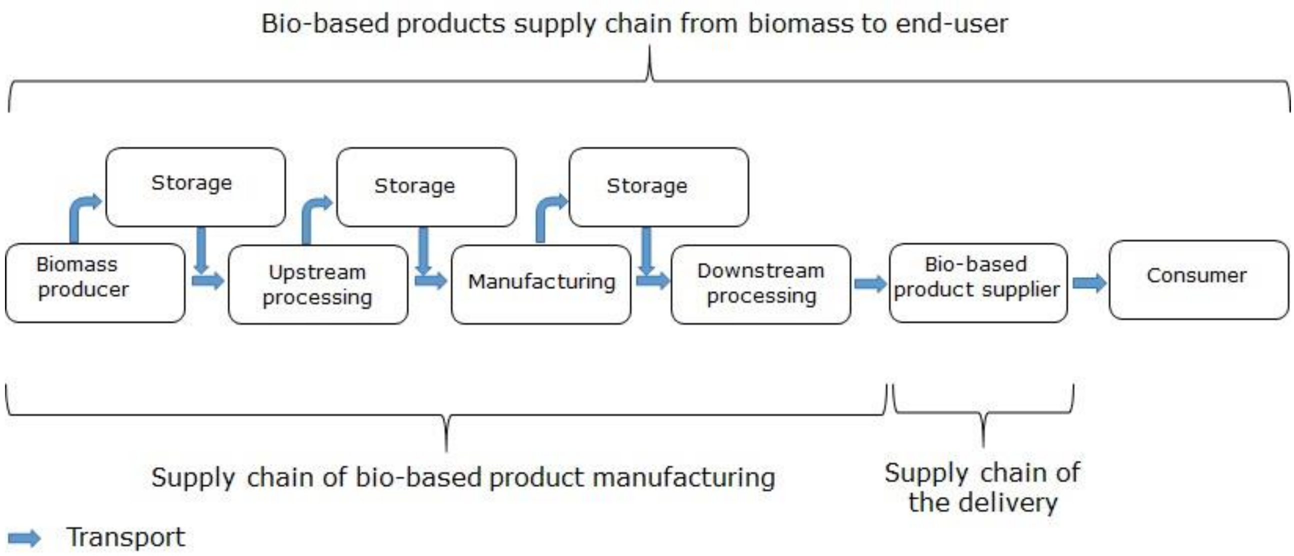


Figure 3 Example of a supply chain of bio-based products

Figure 3 represents the main steps of documentation of supplying materials from one actor to another, while Figure 2 focuses on the processes rather than actors.

In practice, the CoC is about implementing and verifying a control mechanism for each relevant actor in the supply chain. The CoC is lost, if an actor does not comply with the rules of the control mechanism.

1.2.3 Environmental sustainability

The WP2 of STAR-ProBio aimed at developing an LCA approach for strategic and supporting policy decision that is compliant with the European Commission's ILCD and PEF frameworks; and to perform upstream LCA for the three case studies of the project.

In the context of the environmental sustainability assessment this work provides a selection of the life cycle impact assessment (LCIA), standardized environmental indicators and impact categories that are relevant for the environmental life cycle assessment (E-LCA) of bio-based products (D2.2). Eleven environmental indicators were selected that will be applied in the STAR-ProBio case studies, looking at a wide array of possible feedstocks, which should demonstrate their applicability in all situations. They are: acidification; particulate matter; global warming potential BIO; affected biodiversity; terrestrial eutrophication; freshwater eutrophication; human toxicity, cancer; land use, soil quality index; soil erosion; fossil resources depletion; water scarcity. The list is open to new metrics or methodologies. This particularly applies to the risk of plastics leakage into the environment, for which several initiatives have attempted to define sound metrics usable with an LCA framework.

WP3 developed a framework to create a coherent and LCA-based system for the sustainability assessment of bio-based products and feedstocks, including downstream and end-of-life stages.

The research reported in D3.1 contributed to the identification and development of efficiency / circular metrics that could contribute to the evaluation of the environmental performance of bio-based products, independently or in comparison with that of fossil-based counterparts. A set of LCA indicators were identified. Having set this evaluation in the context of circular economy, the need for methods to capture resource efficiency characteristics was satisfied and this led to the development/ identification of novel/ existing indicators that highlight the material circularity and waste reduction capability introduced to the process design by the economic operators.

A set of guidance criteria was established to aid the development of these novel indicators which are a combination (hybridization) of industrially-used resource efficiency indicators, green chemistry and material circularity principles. The robustness of the selected LCA and hybridized (an efficiency metric scaled to the functional unit) indicators were evaluated through a comparative LCA of bio-based case studies and their fossil-derived commercial equivalents, from "manufacturing to distribution to consumer" stages.

It was also determined that the accuracy of the quantification drawn from these hybridized indicators (similar to LCA) are a function of the transparency in documentation among the economic operators, aiding the appropriate reporting of the flow of resources (material and energy) along the supply chain.

Thresholds have been proposed. They were successfully applied to the indicators used in the case studies and gave interpretable results. However, setting instrumental thresholds for environmental LCA indicators proved to be very difficult. The relative pathway explored for environmental LCA indicators, using the planetary boundaries, is interesting but suffers from too many weaknesses. The recommendation regarding these thresholds is to abandon the relative pathway and re-join the subjective pathway used for the efficiency / circular metrics.

However, the subjective pathway requires a consensus that should be achieved through wide consultation, which was not possible in the scope of the present deliverable. A recommendation is to follow the work done by the JRC for developing an evidence-based weighting set for the environmental footprint[8], in the context of the Environmental Footprint Pilots.

Through the WP7 - ILUC risk assessment for bio-based products - STAR-ProBio is developing a risk-based approach to assess the ILUC risk of the bio-based products and to define low indirect impact of biomass (LIIB) for certification schemes. Risk factors include the evaluation of (i) additional biomass ("additionality"), (ii) adopted agricultural practices, (iii) use of abandoned land and (iv) use of co-products at intermediate production level (v) use of co-products at raw material and (vi) biomass origin area.

[8] Development of a weighting approach for the Environmental Footprint, Sala et al. 2018.

1.2.4 Techno-economic sustainability

Techno-economic assessment (TEA) developed in WP4 provides evaluation of the technical performance and economic feasibility of bio-based product processing in a way which reflects uncertainties in techno-technologic parameters and economic risk. TEA is especially useful in evaluation of new technologies that are designed for environmental purposes, such as those associated with advanced processes of biomass conversion selected by STAR-ProBio as case studies, i.e. a thermoplastic polymer resin, packaging film, and mulching film (D1.3). The sustainability of TEA results from combined assessment of technological feasibility, economical profitability using life cycle costing (LCC) alongside with conventional economic indicators such as net present value and internal rate of return, environmental (LCA) and social assessment (s-LCA).

The crucial economic sustainability aspect is addressed to the potential dishonest consumer or commercial practices. The economic research conducted in the work package market assessment (D5.1) was focused on the following topics:

- the awareness of bio-based products and willingness to purchase them;
- the importance of sustainability information and certification in buying decisions;
- relevant sustainability preferences of consumers (both end-consumers and procurers) and product characteristics, in particular in the three sustainability pillars, addressing environmental, social and economic issues;
- relevant characteristics of sustainability assessment schemes; and
- additional factors to support decisions to buy bio-based products.

The research results contributes to understanding the needs, preferences and views of different stakeholder groups, for identifying and confirming the sustainability and communication issues that need to be addressed to ensure fluent market uptake and displacement of fossil-based products.

The development and implementation of robust methodologies, criteria, standards and certification schemes for assessing the sustainability impact of bio-based products can support the further development of the bio-based products sector but currently many gaps still exist. Major measurement gaps on the criteria level include in particular an inappropriate consideration of environmental issues such as GHG emissions, land use efficiency and change, risks related to food prices, thresholds for bio-based content and various end of life aspects.

The in-depth analysis of the consumer perspective showed the importance of seven aspects influencing the adoption of bio-based products: 1. product information and trust, 2. functionality, performance and quality, 3. price and life cycle cost, 4. environmental factors, 5. social and socio-economic factors, 6. individual market drivers and 7. specific issues in B2B markets and public procurement.

1.2.5 Social sustainability

Social aspects of sustainability assessment of end-of-life options were researched in WP6. For development of the tailored EoL options several suggestions (D6.1) were provided, including: methodological features (specificity of a product, ranking of alternatives), selection of EoL options (most desirable: mechanical and chemical recycling options), policy strategies (importance of mechanical recycling), EoL responsibility (points of view of manufacturer, customer, policy), data collecting (creating a database reporting the quantitative impacts of different EoL options), waste disposal cost (polluters pay principle), bio-based product comparison (to choose the most sustainable EoL route), stakeholders cooperation (to improve the product sustainability).

It was recommended that designing products in a smarter way, extending their useful lives, and providing complete and clear information for consumers regarding the most sustainable end-of-life options represent necessary changes for going well beyond the traditional waste disposal. In this perspective and looking at the investigated bio-based product (i.e. packaging and mulching film), policy makers should aim at developing mechanical recycling streams and recycling industry. This can be attained by increasing the economic viability of the required investments and promoting the market uptake for recycled bio-based raw materials.

From the stakeholders point of view, the social LCA (SLCA) of bio-based products has been developed in the form of a social impact tree for bio-based products (D6.2). The tree identifies 8 impact categories (i.e. labour rights and decent work, human rights, health and safety, social benefits/social security, social acceptability, contribution to economy, food security, fair competition in the market, and migration) and encompasses groups of stakeholder (i.e. workers, consumers, local community, general society and value chain actors), 15 subcategories and 15 social indicators that are worth to be considered for an effective SLCA of bio-based products.

1.3 The STAR-ProBio context for the objectives of this report

The STAR-ProBio project aims at supporting the transition of the economy towards more sustainable production system through the development and implementation of sustainability schemes to bio-based products.

The past standards and certification schemes related to sustainability of bio-based products (EN 16751:2016), bioenergy (ISO 13065:2015), biofuels (EN 16214:2012) and biomass for bioenergy (NTA 8080:2015) were studied in WP1 to provide indications for improvements.

The baseline of the improvements in standards and certification schemes is the LCA framework (ISO 14040:2006, EN 16760:2015) applied in WP2-4 and estimation of ILUC effects (WP7) (RED Directive, Project of REDII Directive) are coherent with indications of the Life Cycle Data System (ILCD) Handbook and Product Environmental Footprint (PEF) Guide developed by the Institute for Environment and Sustainability in the European Commission Joint Research Centre (JRC). The WP4-6 contribute to social and economic sustainability.

The structure of WP8 entails 7 consecutive tasks which are assumed to provide recommendations to the current sustainability schemes for bio-based products, elaboration of the blueprint and fast-track documentation for certification schemes. The objectives of Work Package 8 are as follows:

- Definition of recommendations to be applied to current standards addressing sustainability of bio-based products (T8.1)
- Amplification of the principles, criteria and tools addressing environmental, economic and social aspects of sustainability standards for bio-based products (T8.2-3)
- Proposition of a blueprint for a sustainability certification scheme including the requirements for bio-based products and the rules for management (T8.4-6)
- Development of fast-track documentation eventually leading to European standards (T8.7)

The three tasks that contributed to the report were as follows:

- T8.1. Defining recommendations on the current sustainability standards for bio-based products.
- T8.2. Amplification of the criteria, indicators and tools addressing environmental aspects of sustainability standards for bio-based products.
- T8.3. Amplification of the criteria, indicators and tools addressing socio-economic aspects of sustainability standard for bio-based products.

The aim of this report is to compile indications for improvements of sustainability schemes for bio-based products through recommendations, and amendments concerning current sustainability standards of bio-based products.

2. Methods

2.1. SWOT/PESTEL analysis

The gaps identified in the report STAR-ProBio (see §1.1) were the basis for a SWOT analysis followed by a PESTEL analysis and consequent identification of criteria; these were grouped into domains associated with gaps in the sustainability schemes and resulting in environmental, economic and social domains together with indication for R&D needs.

A SWOT analysis was applied to facilitate the enumeration of factors influencing bio-based product regulations from internal and external environments points of view. For the sake of sustainability assessment of bio-based products, the method (Table 4) visualizes the factors of internal strengths (S) and weaknesses (W) while responding at the same time to the external environment of opportunities (O) and threats (T) (e.g. Quansah et al. 2010).

Table 4 Generic scheme for SWOT analysis

	Internal factors	External factors
Favorable factors	Strengths a resource that can be effectively used to achieve its objectives	Opportunities any favorable situation in the external environment
Unfavorable factors	Weaknesses a limitation, fault or defect that makes achieving objectives difficult	Threats any unfavorable situation in the external environment that is potentially damaging to the strategy

The PEST analysis enables classification of factors that affect sustainability assessment of the bio-based product under consideration from political (P), economic (€), social (S), and technological (T) perspectives. When the analysis is broadened to PESTEL, it includes environmental (E) and legal (L) factors

- Political factors – interventions of a government in the economy (the policy of government, foreign trade, tax, labour law, environmental law, political stability/instability, etc.)
- Economic factors – organization of business and profits (economic growth, interest rates, inflation, disposable income of consumers, micro- and macro-economic factors, etc.)
- Social factors – belief and attitudes of the population (population growth, age distribution, health consciousness, career attitudes, etc.)
- Technological factors – technological changes, the way products are marketed (new technology to produce/distribute bio-based goods and services, communication with target market, etc.)
- Environmental factors – involves such elements as resources, pollution, carbon footprint, etc.
- Legal factors – health and safety, equal opportunities, advertising standards, consumer rights and laws, product labelling and product safety, etc.

The factors of the SWOT analysis were denoted according to the PESTEL classification of factors.

In the course of the analysis, from gaps in sustainability schemes to recommendations the approach assumes two steps in the sequence:

- For a given gap in the sustainability schemes setting up factors in the SWOT table with denotation resulting from the PESTEL analysis.
- Identification and description of potential performance criteria addressing SWOT factors under consideration of STAR-ProBio case studies for bio-based products.

It was assumed that the potential performance criteria/indicators would meet the following requirements:

- to be quantifiable;
- to provide valuable information concerning the performance or status of the particular gap or/and environmental, social and economic domains;
- to be adopted by policy regulations;
- to be available and allow benchmarking over time and international comparisons;
- to point out clearly better or worse performance or status when changing.

2.2. Amplification of the criteria, indicators and tools addressing environmental and socio-economic aspects of sustainability standards for bio-based products

The methodical approach to sustainability assessment of bio-based products corresponds to the ten Bellagio Principles (1997) and their upgraded version BellagioSTAMP (The Bellagio Sustainability Assessment and Measurement Principles) with eight principles as follows (Pintér 2012):

1. Guiding vision (aimed at well-being within the capacity of the biosphere to sustain it for future generations);
2. Essential considerations (to consider social, economic and environmental systems and interactions, synergies, trade-offs among them);
3. Adequate scope (to adopt an appropriate time horizon and geographical scope);
4. Framework and indicators (to be based on a conceptual framework and core indicators addressed to targets);
5. Transparency (to ensure that sustainability assessment are accessible to the public);
6. Effective communications (to attract the broadest possible audience);
7. Broad participation (to engage early on with users of the assessment so that it best fits their needs);
8. Continuity and capacity (continuous learning and improvement).

Taking into account the above principles and other approaches proposed in literature, Waas et al. (2014) provide a generic scheme of sustainability assessment in the context of supporting decision making by grouping the items of sustainability assessment into four categories: fostering sustainability objectives, adopting a holistic perspective, incorporating sustainability in the assessment process, and supporting decisions (Table 5).

Table 5 Generic scheme of sustainability assessment.

Categories	Items
Fostering sustainability objectives	• Intergenerational equity • Intragenerational equity • Geographical equity • Interspecies equity • Procedural equity
Adopting a holistic perspective	• Assess the system as a whole, including its parts and their interactions • Assess the system considering the different sustainability objectives together (integration) • Assess dynamics and interactions between trends and drivers of change • Adopt appropriate time horizon (short, medium, and long term) and (geographical) scope
Incorporating sustainability in the assessment process	• Consider the normative nature of sustainability • Broad participation of stakeholders, including experts, while providing active leadership to the process • Transparency regarding data (sources, methods), indicators, results, choices, assumptions, uncertainties, funding bodies and potential conflicts of interest • Avoid irreversible risks and favor a precautionary approach • Be responsive to change, including uncertainties and risks (dynamism)
Supporting decisions	• Assessment of sustainability impacts and alternatives for decision-making, including synergies and trade-offs • Establish formal and transparent synergy/trade-off rules • Assessment is based on a conceptual sustainability framework and its indicators • Ensure effective communications (clear language, fair and objective, visualization tools and graphics, make data appropriately available) • Adapted to and integrated into the institutional context • Iterative assessment process, starting at the onset of the decision-making process • Develop and maintain adequate capacity • Continuous learning and improvement

2.3. Amplification of the criteria, indicators and tools addressing socio-economic aspects of sustainability standard for bio-based products

The conceptual framework and its indicators for horizontal integration of interdisciplinary links in the assessment of sustainability of bio-based products (goods and services) along the life cycle has been based on the DPSIR system approach. The DPSIR model relates human activities in the function of time to the sustainability of bio-based products through sequential analysis of causalities between Drivers/driving forces (D), Pressures (P), States (S), Impacts (I) and Responses (R) as the activities related to D,P,S,I (Figure 4).

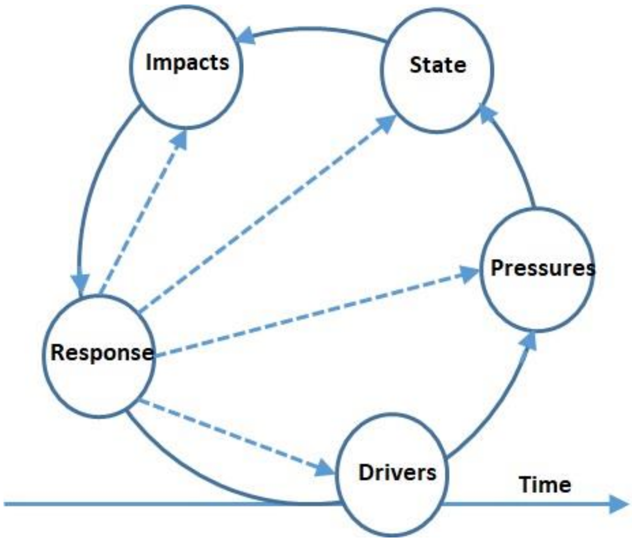


Figure 4 DPSIR model in application to sustainable development of bio-based products.

In the context of bio-based products the DPSIR analysis through the policy life cycle[9] can be generalized as follow:

- Drivers/Driving forces (human needs).

There are global, regional or local drivers such as demography, socio-economic and socio-cultural development of societies, the corresponding changes in life styles, and patterns of production and consumption. Drivers can be associated with human needs: physiological (air, food, water, energy, health), security (safety, shelter, stability) and cultural expectations.

- Pressures (by human activities).

[9] Bassi, S., Mazza, L., ten Brink, P., Medarova, K., Gantioler, S., Polakova, J., Lutchman, I., Fedrigo-Fazio, D., Hjerp, P., Baroni, L. and Portale, E. (2011) Opportunities for a better use of indicators in policy-making: emerging needs and policy recommendations. Deliverable D7.2 of the IN-STREAM project.

These are intentional or unintentional pressures generated from human activities impacting the environment and related socio-economic system on a spatial scale. The bio-based product-related pressures refer to resource use, land use changes (e.g. forest clearings) air/water emissions, production of wastes, employment rate, local businesses, and others.

- State (of ecosystems).

There are intentional or unintentional changes exerted by society in ecosystems. A problem arises when the changes negatively impact the state of ecosystems in a direct or indirect way. For a certain area, physical (temperature, light availability), chemical (CO_2 concentration, N, P levels) and biological (biodiversity) properties of biotic and abiotic components of ecosystems are considered. The state presents the social and economic functions of the environment (ecosystem services).

- Impacts (on degradation of ecosystem services).

The changes in ecosystems have an impact on ecosystem services that determine well-being of humans. There are supporting services (e.g. primary production, nutrient cycling, soil formation), provisioning services (e.g. raw materials, freshwater), regulatory services (e.g. climate regulation – CO_2 stored/released, waste decomposition, water purification) and cultural services (e.g. aesthetic, spiritual, recreational, therapeutic, educational) (MEA 2003). The value of ecosystem services depends on human needs and use (e.g. market/social value).

- Response (decisions taken).

There are actions by individuals, local management or governments to prevent, compensate, ameliorate or adapt to changes in the state of the environment by implementation of control drivers or pressures through regulation, prevention, or mitigation; directly maintain or restore the state of the environment.

The application of the DPSIR framework can address many aspects of sustainability in numerous ways through adequate descriptive, performance, efficiency and total welfare indicators, summarizing and categorizing information from different resources and providing framework for developing decision support tools to evaluate of potential outcomes (Bassi et al. 2011, Waas et al 2014).

The DPSIR framework was structured into four consecutive stages:

1. Description of drivers of sustainability assessment of bio-based products and their pressures to the environment.
2. The life cycle perspective analysis of the environmental impacts.
3. The outlook to policy and societal actions to drive the sustainability of bio-based products.
4. The recommendations to policymakers, bio-based sectors and society to promote sustainable production bio-based products, their consumption and EoL management.

The Regulatory Cycle model was used for discussion on regulating the impact to the environment and to develop policy and legislation (Figure 5) (on the basis of IMPEL 2018).

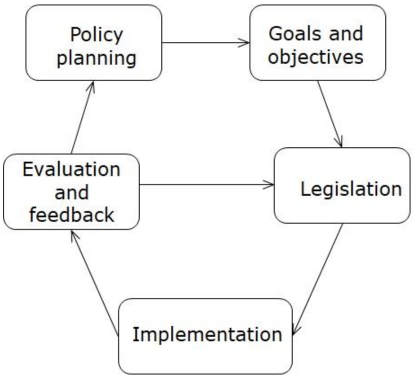


Figure 5 The Regulatory Cycle in application to sustainable development of bio-based products

The regulatory cycle involves 5 interrelated sequential steps and begins with the definition of goals and objectives. Then, specific measures related to drivers, pressures and state are developed. On the basis of these measures, the policy can be reviewed and further improvement of goals and objectives can be made. In this way, the regulatory cycle can be repeated.

3. Results

3.1. SWOT/PESTEL analysis

3.1.1. SWOT/PESTEL summary results

Table 6 presents the number of SWOT factors and PESTEL categories attributed to the factors in relation to gaps in regulations on sustainability of bio-based products in Europe.

In the framework of the SWOT analysis 125 factors were assigned for 7 gaps, including 29 for strength, 39 for weakness, 33 for opportunities and 24 for threats. The most represented factors in PESTEL analysis were associated with legal status (32), economy (23) and technicalities (22).

- Political factors. There was no indication for gaps 1, 2 and 5 while the most represented were categories of weaknesses (7 of 19) and opportunities (8 of 19).
- Economic factors. In total there were 23 factors identified while not one was assigned to leakage effects, and the most represented gaps are new innovative inter-sectoral products (9), traceability (5), and legislation in the BBE sectors (4). 35% of the factors were associated with opportunities.
- Social factors. The most represented were factors related to gaps and weaknesses in criteria and indicator sets (4 of 10) and legislation and consensus for minimum criteria in all BBE sectors (3 of 10)
- Technical factors. In total, there were 22 technical factors related mostly to R&D on development of new methods for assessment of indicators. 6 of 22 factors were assigned to gaps and weaknesses in criteria and indicator sets.
- Environmental factors. The most represented gap was EoL (5 of 19); 16 of 19 factors were attributed to the SWOT internal factors.
- Legal factors. As it could be expected the highest number of factors (8 of 32) were assigned to legislation and consensus for minimum criteria in all BBE sectors.

Table 6 Number of PESTEL factors in the frame of SWOT categories for gaps in regulations[10]

Gaps in regulations	PESTEL						Total
	P	€	S	T	E	L	
1. Gaps and weaknesses in criteria and indicator sets		1	4	6	3	3	17
S					2	1	3
W				4	1	1	6
O		1	3				4
T			1	2		1	4
2 Harmonisation in criteria assessment and operationalisation		2		3	4	4	13
S					1	1	2
W		1		1	3		5
O		1				2	3
T				2		1	3
3 Legislation and consensus for minimum criteria in all BBE sectors	7	4	3	3	1	8	26
S						5	5
W	4	1	2	1	1	1	10
O	3	1	1			2	7
T		2		2			4
4 Leakage effects from EU BBE policies	2	3		15	2	8	15
S	2				1	1	4
W	2				1	1	4
O	3				1		4
T	1		2				3
5 New innovative, inter-sectoral products		9		4	1	2	16
S		4			1	1	6
W				1		1	2
O		3		2			5
T		2		1			3
6 End-of-Life (EoL)	1	2		2	5	6	16
S				1	3	1	5
W				1	1	3	5
O	1	1				1	3
T		1			1	1	3
7 Traceability of sustainability and certificates along the value chain	3	5	1	4	2	7	22
S		1		1		2	4
W	1	2	1	1	1	1	7
O	1	1		1	1	3	7
T	1	1		1		1	4
Total	19	23	10	22	19	32	125

[10] (SWOT symbols: S – strength, W – weakness, O – opportunities, T – Threats; PESTEL symbols P – political, € - economic, S – social, T – technological, E – environmental, L – legal)

3.1.2. SWOT analysis – characterization of gaps in the current standards on sustainability of bio-based products

The factors of the SWOT analysis with PESTEL denotations were attributed for seven gaps identified in STAR-ProBio D1.1 report.

Gaps & weaknesses in criteria & indicator sets

A thorough analysis and comparison obtained from STAR-ProBio experts' indications and criteria assessment showed that some issues related to criteria and indicators are not significantly represented in regulations on sustainability. The SWOT analysis for this gap is presented in Table 7.

Table 7 SWOT analysis for Gap 1: Gaps & weaknesses in criteria & indicator sets

	Internal factors	External factors
Favorable factors	Strengths L Some BBE sectors already have well established and recognized certification schemes, whose implementation is proved and accepted (e.g. RED compliant schemes) E Many criteria and indicators are already available ('list of sustainability criteria and indicators included in current sustainability certification of the EU BBE') E Existing criteria already cover a broad range of issues ('The criteria and indicators available cover a wide range of sustainability aspects.')	Opportunities S Choosing the right indicators enable to show if the product is truly sustainable S Having a comprehensive set of criteria also ensures that nothing was overlooked and that the product is again, truly sustainable S A good set of sustainability criteria and indicators – meaning robust scheme – enables one to create trust in the products € and hence, drive market uptake
Unfavorable factors	Weaknesses E No consensus as to what additional criteria/indicators are needed ('for some experts, it is not about developing more criteria and indicators but about improving systematic use of existing criteria and indicators, for others, there are still some gaps as to principles, criteria and indicators') T Hard to find one size fit all indicators and criteria ('the certification frameworks are developed under specific regulations, for specific markets, specific products, with specific stakeholders') T The uptake of new indicators and criteria is difficult ('depend on a number of elements: the legal framework, requirements regarding sustainability certification within a specific BBE sector or country; availability of appropriate standards and tools to support the	Threats T If the right indicators are not chosen, there is a risk that the certification scheme may fail to show sustainability L Risk of being 'too comprehensive' and hence too hard to fulfil S Risk of being too complex for the consumers and therefore unable to provide a clear message on sustainability T Certain indicators may not be operationalized (see gap No 3)

	implementation') T The development of new criteria almost automatically raises the question of access to data L Indicators / criteria may not have the same purpose for all certification instruments ('some frameworks set minimum criteria (e.g. sustainability criteria in the RED), others tend to frequently update and expand their criteria and indicator sets') T Numerous criteria and indicators have already been identified as generally not well covered, most of which are key ones for any sustainability (the list below)	

Strengths. The conventional biomass-based food and forestry sectors as well as bioenergy have well established and recognized certification schemes. Many existing criteria and indicators cover a broad range of issues which can be considered for transfer to the horizontal standard of bio-based product.

Weaknesses. It is difficult to reach a consensus on the criteria and indicators in the context of horizontal regulations regarding the uptake of additional indicators, availability of databases and different sectoral requirements on sustainability. At the same time, the STAR-ProBio project indicates few key indicators that are not completely represented in the current standards

Opportunities. A comprehensive set of appropriate criteria and indicators will prove sustainability and increase public confidence and market uptake of bio-based products.

Threats. The lack of comprehensive and fair criteria and indicators generates the risk that a certification scheme will not be able to show sustainability. Other negative aspects can be associated with difficulties to fulfill requirements, to be operationalized, and to be complex enough yet understood by consumers.

In order to overcome the weaknesses in the current criteria set, a supplementary set of 9 criteria was proposed, addressing the efficiency of land and tertiary resource use, land change and SO2 related emissions, PM10 pollution, and end-of-life management. The other recommendations are related to the comparability of bio-based products by assessment of the functionality and levelized life-cycle cost as well as to potential negative implication to the food market (Table 8).

Table 8 Potential key performance criteria for closing Gap1: Gaps and weaknesses in criteria sets

Criteria	Comment	Reference (regulations, relevant documents, approach to assessment)
Domain: Environmental		
Reduce ILUC related GHG emissions	Resulting from carbon stock changes as a direct or indirect effect of feedstock production	STAR-ProBio ILUC risk approach
Reduce SO_2 equivalents	Life cycle emissions of SO_2, NO_x, NH_3 and HCl/HF from bio-based product life cycle	LCA
Reduce PM10	Life cycle emissions of PM10 from bio-based product life cycle, calculated in accordance to the life cycle emission methodology for GHG	LCA
Reach targeted bio-based content and recyclability/ biodegradation	The share of a product originating from biomass/Percentage or share of the bio-based products that is biodegradable.	Waste Management
Domain: Economic		
Promote land use efficiency	No of bio-based products per hectare	TEA
Promote tertiary resource use efficiency	Value of the bio-based output divided by the value of the secondary resource	Waste Management
Improve functionality	Value of the outputs, compared to the economic value of the heat which could be produced from burning the primary inputs	TEA, LCC
Reduce levelized life-cycle cost	Excluding subsidies, including CAPEX, OPEX.	TEA, LCC
Domain: Social		
Reduce risks for negative impacts on food prices and supply	Securing a sufficient supply of food and biomass for bio-based products	Bioenergy and Food Security (BEFS)

Harmonization in criteria assessment and operationalization

The main activities for harmonization in criteria assessment and operationalization address directly the horizontal aspect of standardization and are associated with:

- Integrability of multiple environmental claims[11] and socio-economic indicators into a single sustainability claim for a given bio-based product. In general, such sustainability claim should comply with all relevant environmental regulations, promote long-term economic feasibility including promotion of fair competition and allowing consumers to make informed choice of a product, and build social responsibility including community outreach and fair labor practices.

[11] Environmental claims that can appear on products "refer to the practice of suggesting or otherwise creating the impression (in the context of a commercial communication, marketing or advertising) that a product or a service, is environmentally friendly (i.e. it has a positive impact on the environment) or is less damaging to the environment than competing goods or services. This may be due to, for example, its composition, the way it has been manufactured or produced, the way it can be disposed of and the reduction in energy or pollution which can be expected from its use. When such claims are not true or cannot be verified this practice can be described as 'greenwashing'. EC 2014. Consumer market study on environmental claims for non-food products. DG for Justice and Consumers.

- Improving the interoperability between all stages of supply chain and actors engaged by collecting/combining information on available regulations for specific environmental claims, and socio-economic attributes related to bio-based products.
- Conceptualizing a composable system that provides components that can be selected and assembled in various combinations to satisfy specific sustainability requirements

Those activities are in accordance with the postulates by certification bodies claiming that the improvements in sustainability assessment is not to develop new criteria and indicators, but to adapt and more precisely communicate the existing ones, as well as to harmonize the actual operationalization of the existing criteria by the certification schemes and certification bodies. The SWOT analysis for the gap is presented in Table 9.

Table 9 SWOT analysis for Gap 2: Harmonisation in criteria assessment and operationalization

	Internal factors	**External factors**
Favorable factors	Strengths L Existence of bio-based oriented sustainability regulations and operationalization E Clearly defined the general methodology for GHG emission calculation as well as comparator values for a determination of mitigation values are clearly defined	Opportunities L Development of the guidance regarding the technical application of different sustainability criteria in auditing practice L Possibility to unify different certification schemes in order to facilitate the assessment € Better development of B2B markets with a high degree of regulations
Unfavorable factors	Weaknesses E An overwhelming number of sustainability criteria and indicators available T Most of available indicators and methods for sustainability assessment have been developed for scientific purposes not necessary for practice € Time/resource consuming auditing can result in higher price of product E There are differences regarding the overall comprehensiveness of the criteria and indicator sets, but also with regards to the point how the same criteria are being operationalized and implemented between the different certification frameworks E Differences in upstream emission factors or definitions of by-products or waste materials can lead to significant differences in results	Threats T Optimization of production from the point of view mitigation of GHG emission can result in calculation methodology itself than from an actual optimisation of the value chain L Difficulties in transferring existing methodologies into certification practice T Complicated assessment and operationalisation

Strengths. In the context of harmonization in criteria assessment there are numerous certification schemes and their operationalization present in the market and different frameworks for audits exist in practice. The methodology for the key environmental impact associated with assessment of GHG emissions as well as and mitigation values are clearly specified in global and European regulations (LCA and LCA-related standards).

Weaknesses. Even if there is abundance of available sustainability criteria and indicators ,most of them were developed by scientists and usually for scientific purposes, and they require time for adaptation in practice. Often this can cause difficulties in public comprehension while the advanced analytics can generate a higher price of a certification process that cannot be commonly accepted.

Opportunities. The collection and compilation of different practices of auditing frameworks provide an opportunity to develop the guidance on technicalities of the application of sustainability criteria in practice. Another opportunity is related to the potential unification of sustainability schemes to be more universal in the context of B2B market development.

Threats. The risks can be related to focusing not on optimization of production but on mitigation of environmental impact. There is also a risk that a horizontal standard will be not considered in the certification scheme due to difficulties in methodologies and complicated assessment and operationalization of the criteria and indicators in practice.

Assuming differences regarding the overall comprehensiveness of the sets of criteria and on how the same criteria are being operationalized and implemented between the different certification frameworks, there are proposed five supporting criteria for closing the gap (Table 10).

Table 10 Potential key performance criteria for closing Gap 2: Harmonisation in criteria assessment and operationalisation

Criteria	**Comment**	**Reference (regulations, relevant documents, approach to assessment)**
Domain: Environmental		
Reduce GHG mitigation thresholds or GHG emissions calculation	It should be integrated with other regulations (GAP, RED, WFD, eco-design) over the whole value chain	LCA
Eliminate annual deforestation rate	To guarantee no deforestation after a certain cut-off date.	FAO, 1995
Domain: Social		
Respect labour rights	To promote opportunities for women and men to obtain decent and productive work, in conditions of freedom, equity, security and dignity.	ILO, 2019
Observe legality of sourcing	Supply base evaluation on the legality and sustainability of sources for biomass based materials.	FSC/PEFC/SBP certification schemes (wood)
Respect land use rights	Percentage of women, men, indigenous peoples, and local communities (IPLCs) with secure rights to land, property, and natural	Land related targets and indicators under SDGs 1,2,5,11,15

	resources, measured by a. percentage with legally documented or recognized evidence of tenure, and b. percentage who perceive their rights are recognized and protected	

Legislation & consensus for minimum criteria in all BBE sectors

The gap is related to the previous one in that it also addresses horizontal aspects of sustainability requirements for bio-based products. So far there has been no normative approach to a level playing field in order to elaborate universal requirements for various sectors of the bio-based products in the EU. This is the reason why some unexpected effects of policies and legislation cannot be anticipated. The most important ones can be associated with leakage effects related to the risks of indirect land use change and food security and the lack of compatibility between current frameworks of certification schemes on sustainability (harmonization). The consensus on minimum criteria of sustainability would contribute to reduction of leakage effects and administrative implications on markets and policy. The SWOT analysis of the gap is presented in Table 11.

Table 11 SWOT analysis for Gap 3: "Legislation and consensus for minimum criteria in all BBE sectors"

	Internal factors	**External factors**
Favorable factors	**Strengths** L Existence of basal standards (EN 16575:2014; EN 16751:2016; ISO 13065:2015) and numerous certification schemes L Existing eco-labelling standards for bio-based products such as EU Ecolabel, NORDIC ECOLABEL, DER BLAUE ENGEL L Existing public procurement system (GPP, SPP, CPP) can be developed for bio-based products L Direct subvention for bio-based products on the national level – tax incentives, reduced VAT for bio-based products L Existence of legal basis for biofuels support can be a reference to bio-based products	**Opportunities** P Including bio-based products in a quota system regulated in RED P Integration of the support for bio-based products with ETS system (RED II) P Eco-labelling as an indirect instrument of supporting and promoting bio-based products S Public procurement may increase awareness of bio–based products in the society € Tax incentives as an instrument for increasing the usage of bio–based products L Possibility to use the legal basis regulating biofuels for other bio-based products L Harmonization the existing criteria and requirements for sustainability certification across the various sectors of the BBE
Unfavorable factors	**Weaknesses** P Possibly high cost of integrating bio-based products general program on sustainability with existing systems P Complicated system for completing information. P No integrated policy related to bio-based products	**Threats** T Limited development of bio-based industry € Higher costs of circular economy based on bio-based products T Low progress in implementation of circular economy € Lack of level playing field related to sustainability requirement across various sectors of bioeconomy

	S No direct influence of certification schemes and eco-labelling's on redirecting biomass flow to bio-based products E Limited implementation of requirements on environmental effects in public procurement S Limited awareness and interest of public procurement in society € High costs of tax incentives L Tax incentives are problematic from the UE provisions related to State Aid P Lack of support system for bio-based products in the future T Required R&D on methodology of combining data from different schemes and proving mitigation of environmental impacts	

Strengths. The legislative background for the formulation of general requirements for sustainability of bio-based product exists. There are standards (e.g. EN 16575:2014; EN 16751:2016; ISO 13065:2015), certification schemes (e.g. FSC, ISCC, NTA 8080,REDcert, RSB) and ecolabels (e.g. EU Ecolabel, NORDIC ECOLABEL, DER BLAUE ENGEL), public procurement systems (e.g. GPP, SPP, CPP) and national policies that indicate different economic subventions via tax incentives or reduced VAT for bio-based products. Besides, the legal basis for biofuels support can be a reference for supporting of bio-based products.

Weaknesses. The integration of different programs related to sustainability of bio-based products and the process for combining requirements can turn out to be complicated. As a consequence it can involve difficulties in creation of integrated policy, limited implementation of sustainability requirements for bio-based products in public procurements and tax incentives in accordance with the EU provisions related to state aid. Another weakness is related to the lack of an agreed methodological approach for the creation of such general requirements and proving sustainability.

Opportunities. The opportunities associated with the designation of minimum requirements for sustainability of bio-based products provide a direct answer to the weaknesses. First of all, there are advanced regulations for sustainability of biofuel and bioenergy sectors so the bio-based products can be considered in the context of the quota system currently available for renewable energy in some EU countries and this can facilitate greatly the integration of bio-based products with the ETS system. The harmonization of regulations on sustainability of bio-based products can stimulate the development of a general eco-labelling scheme, social awareness on their use in public procurements, and policy-related incentives.

Threats. Even if the development of the bio-based industry in the context of circular economy progresses the expansion can be limited due to the low competitiveness of bio-based products substituting the fossil ones and the lack of a level playing field related to sustainability requirement across various bio-based sectors.

In the context of circular bioeconomy, the reference normative on the consensus for minimum sustainability criteria is provided by the French voluntary standard XP X30-901: 2018 "Circular economy - Circular economy project management system - Requirements and guidelines" (AFNOR Standardisation 2018). The standard proposes a 3x7 matrix with three pillars of sustainability and seven areas of actions: sustainable procurement, eco-design, industrial symbiosis, functional economy, responsible consumption, extension of service life, and the effective management of materials and products at the end of their life cycle. Besides, the principle of this standard is continual improvement.

The criteria and indicators in the context of reaching a consensus about minimum criteria across bio-based economy sectors are related to the development of methodology for processing a meta-standard that will enable checking cross-sectoral compatibility of different certification schemes applied along the stages of supply chain (material, manufacture, consumption) and waste management. Potential criteria and indicators for operationalization of this gap is shown in Table 12.

The meta-standard is a "standard of standards" that describes quality and technical rules which allow one to check the compliance and conformity of different regulation schemes on sustainability of bio-based products. It should enable making an assessment of sustainability criteria and auditing procedures of a given standard or a certification scheme against the meta-standard. The methodological approach can be based on the two-dimensional sustainability assessment, e.g.: a set of minimum requirements (principles, criteria, indicators as one dimension) and sustainability of material, manufacturing, consumption, ecosystems and communities (second dimension).

Table 12 Potential key performance criteria for closing Gap 3: Legislation & consensus for minimum criteria in all BBE sectors

Criteria	Comment	Reference (regulations, relevant documents, approach to assessment)
Domain: Legislation & consensus for minimum criteria in all BBE sectors		
Compliance with meta-standard on sustainability	It describes quality and technical rules that allow assessment of compliance and conformity of different regulation schemes on sustainability of bio-based products.	STAR-ProBio
Domain: Environmental, Economic, Social		
Source sustainable materials	The material-related sustainability principles, criteria and indicators associated with the efficiency of material use	STAR-ProBio
Practice sustainable manufacturing	The manufacturing-related sustainability principles, criteria and indicators associated with production process e.g. economic efficiency, levelized life-cycle costs, external costs	STAR-ProBio
Promote sustainable consumption	The consumption-related sustainability principles, criteria and indicators associated with the lifestyle such as consumption, waste management, etc.	STAR-ProBio

Maintain sustainable ecosystems	The ecosystem-related sustainability principles, criteria and indicators associated with land area, resources, water, air, biodiversity, etc.	STAR-ProBio
Promote sustainable communities	The society-related sustainability principles, criteria and indicators associated with health and safety, food security, land use rights, etc.	STAR-ProBio

Leakage effects from EU BBE policies

Leakage effects create a situation where positive effects generated by bio-based sectors such as revenues, mitigation of GHG emissions or improvement of social well-being can be lost to other countries' economies, can involve land degradation, change in carbon stocks in the case of deforestation, a shift to other sectors or countries without requirements on sustainability, temporarily increase in GHG emissions (carbon debt) or limit social development in other areas.

Development of bio-based sectors will intensify competition on biomass resource and land use on a macro-regional or global scale. One aspect of leakage effects can be related to land grabbing, that is land acquisitions or concessions which are (i) in violation of human rights, particularly the equal rights of women; (ii) not based on free, prior and informed consent of the affected land-users; (iii) not based on a thorough assessment, or are in disregard of social, economic and environmental impacts, including the way they are gendered; (iv) not based on transparent contracts that specify clear and binding commitments about activities, employment and benefits sharing; and (v) not based on effective democratic planning, independent oversight and meaningful participation (ILC 2011).

The SWOT analysis related to the gap is presented in Table 13.

Table 13. SWOT analysis for Gap 4: Leakage effects from EU BBE policies

	Internal factors	**External factors**
Favorable factors	Strengths P Experience from the bioenergy policies that we can build on to better grasp (and avoid these leakage effects). That experience indeed showed that: iLUC, food security and carbon debt were three major gaps that needed to be addressed. E There are already existing methods assessing these parameters (iLUC) L There are even some pieces of legislation assessing some of these parameters (e.g. iLUC) P On the certification side too, there are initiatives aiming to cope with such leakage effects (e.g. the "low iLUC risk biomass" when produced from degraded or abandoned land or from yield increases)	Opportunities P Accounting for and fighting against leakage effect would automatically lead to building better governance; P The best way to fight against leakage effect would be to develop a global model, which would have two advantages: 1. Adoption of the model globally (more people using the model) 2. No leakage effect as the rules are the same for everyone (minimizing unwanted effects of certain policies); P Such a model should also apply to all sectors of bioeconomy to make sure that adverse effects arising from the competition between the different uses of biomass is encompassed; E Accounting for leakage effects would ensure correct measurement of the impacts.

Unfavorable factors	Weaknesses P Leakage effects are very hard to predict, since there are generally indirect consequences of policies or decisions; E Most of the time leakage effects are also very hard to quantify (e.g. iLUC); P Since these effects are so hard to grasp and quantify, there is also a lot of political opposition to tackle them; L Leakage effects, as any loophole, are hard to fight against as they are usually not illegal	Threats P If not accounted for properly/not fought against, leakage effects undermine sustainability policies S As seen from the bioenergy example, the fact that leakage effects such as iLUC arose, shed light on potential problems linked with an environmental policy and tarnished the perception of the public on the BBE S International or national land grabbing

Strengths. Development of normative definitions on sustainability of bio-based products can benefit from positive and negative experiences associated with policies and legislation on biofuels and bioenergy (RED, ISO 13065: 2015). The identified key leakage effects are indirect land use change, food security and carbon debt. The effects are well recognized and the methodology of their assessment is consequently developed, including the approach suggested by STAR-ProBio (WP7) as "low-iLUC risk biomass".

Weaknesses. The problem with leakage effects is that they are hard to predict because the future consequences of the present policies or decisions cannot be anticipated. The weight of leakage effect is relevant as they can account from negligible up to more the 100% of a specific indicator, such as greenhouse gas emissions. This involves problems requiring a quantified assessment difficult to accept unanimously or by the majority of stakeholders. It is a well-known fact that politicians rarely make decisions on uncertain subjects implying high stakes. Besides, counteracting or precautionary actions are difficult because very often they are generated by unintentional or illegal activities.

Opportunities. Reliable assessment and anticipation of leakage effects can lead to better governance on sustainability by avoiding unwanted effects. A solution can be a global model that allows an analysis of different scenarios and provides the public with a comprehensive output. Owing to a better assessment of potential leakage effects, the measurements of sustainability of bio-based products would be more comprehensive.

Threats. The main risk associated with the lack of a precise assessment of leakage effects can undermine the overall policy on sustainability and tarnish the public perception and approvals. As a result, land grabbing oriented toward short-term economic profits can evolve.

The potential criteria associated with operationalization of the gap are presented in Table 14.

Table 14. Potential key performance criteria for closing Gap 4: Leakage effects from EU BBE policies

Criteria	Comment	Reference (regulations, relevant documents, approach to assessment)
Domain: Environmental		
Reduce iLUC	There is a significant change of the production of bio-based products, either market or policy driven, that results in an indirect land use change, thus external to the system where market forces and policies operate.	STAR-ProBio developed methodology on "low-iLUC risk biomass" (WP7)
Avoid carbon leakage	It is an emission reduction policy not taking into account the emissions due to products manufactured outside the system's boundaries generating a spill-over effect	STAR-ProBio
Domain: Social		
Preserve food security with four pillars: availability, access, utilization and stability	All people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO 2000).	FAO 1999-2017

New innovative, inter-sectoral products

Inter-sectoral products are systemic products which satisfy specific needs and expectations of the market assuming network cooperation in the creation of the product value. A model example is a product which combines different sectors of economy, such as agriculture, industry, services.

Designing the regulatory framework for inter-sectoral bio-based products requires merging cross-sectoral approaches that can reveal conflicts of interests between conventional biomass-based sectors (e.g. iLUC) and in the conjunction with industry sectors (e.g. market pressure for a given feedstock).

Fritsche and Iriarte (2014) point to the lack of coherence in inter-sectoral approaches in considerations of sustainability criteria and indicators for the bio-based economy in Europe. The authors suggest more comprehensive intra-sectoral (for various types of biomass regardless of final use) and inter-sectoral (biomass use and bio-based product perspective) approaches.

Inter-sectoral products which engage cooperation of different subsectors can involve the same or various stages of a given supply chain. Sometimes the use of different resources is involved, e.g. bioplastic's functionality can result from the combination of renewable and non-renewable feedstock, it can combine the product of one sector with the material originated in another one, e.g. the use of waste CO2 from conventional power plant for algae cultivation (waste-to-product, W2X). The surplus power from renewable energy (wind turbines) can be used to synthetize chemicals or for carbon sequestration (power-to-product, P2X).

In another other case the value of products can be enhanced through specific extra functionality, e.g. integrated IT information on the service life of the product with the time of product usage (service-to-product, S2X). Selected examples for inter-sectoral cooperation at different stages of supply chain are given in Table 15.

Table 15 Selected examples of inter-sectoral cooperation and inter-sectoral products

Stage of value chain	Sector I	Sector II	Bio-based inter-sectoral product
Material	Agriculture: renewable (biomass)	Industry: non-renewable (fossils, minerals)	M2X: Bioplastic (partly bio)
Upstream-downstream	Energy: waste product CO_2	Aquaculture: algae cultivation	W2X: Raw material
Manufacturing	Energy industry: excess renewable energy from wind/hydro turbine	Chemical industry: electrolysis	P2X: Bio-hydrogen
Consumption	IT: tool for predicting the product longevity	Bio-based industry: integration of IT with the product	S2X: Bioplastic with info on the stage of wear
EoL	Biotechnology: specificity of microbes	Waste management: anaerobic/aerobic process	W2X: Biogas/ compost

The SWOT analysis factors for the gap are presented in Table 16.

Table 16 SWOT analysis for Gap 5: New innovative, inter-sectoral products

	Internal factors	External factors
Favorable factors	Strengths L Some sectors have regulations (e.g. biofuels) € Common inter-sectoral product value € Establishment of a long-term inter-sectoral cooperation € Synergy effect and value increase E Mitigation of environmental impact in the sector with higher environmental burden € Risk sharing	Opportunities € Easier access to resources T Development of innovative technologies for combining the potential of different sectors T Development of R&D sector oriented to model for market of inter-sectoral products € Increasing the efficiency of production by lowering and sharing costs € Limiting uncertainty
Unfavorable factors	Weaknesses T Lack of knowledge and low advancement of techno-technological approach to manufacturing of multi-sectoral products L Lack of sustainability blueprints for inter-sectoral products, including interpretation of such aspects as system boundaries, sustainability criteria and allocation.	Threats T Description of requirements for innovative technologies will take long time € Increase in the competition between sectors can lead to negative cooperation (conflict) € The term "inter-sectoral product" can be only a theoretical category because bio-based products are manufactured by a single company with established cooperation with others in the frame of a supply chain

Strengths. There are regulations on sustainability in some sectors, thus presuming that the value of a product is contributed by sectors and the value chain integrates the sectors, the sustainability assessment should be also common. The strength of inter-sectoral products results from the synergistic outcome, mitigation of environmental burden caused by one sector by a positive impact of another one, and sharing the risks by involved sectors.

Weaknesses. There are technological and legislative constraints including the lack of knowledge on techno-technological aspects of advanced manufacturing and the lack of unified legislation on allocation of contributions from different sectors into a common inter-sectoral sustainability aspect.

Opportunities. They are associated with a potential of a more efficient resource use and manufacturing by lowering and sharing costs as a result of the development of new technologies with a strong involvement of R&D sector. Another opportunity is lowered market uncertainty.

Threats. Achieving the mature stage of a new technology is a long-term process. In the face of market competition cooperation between sectors can evolve into negative cooperation. It is also suggested that inter-sectoral product does not exist because a final marketable product is already an output of established cooperation along the whole value chain. Although it can be true from the economic point of view the integration of the activities is not fully reflected in a sustainability assessment along the whole value chain.

An innovative, inter-sectoral product corresponds to the definition of product innovation as the introduction of goods or services that are new or significantly improved with respect to characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics (OECD/EUROSTAT 2005). The internationally-comparable set of indicators was developed by OECD as the Product Market Regulation (PMR). The criteria measure to what degree policies impact competition in viable competition areas of the product market. The potential key performance criteria for operationalization of the gap is presented in Table 17.

Table 17 Potential key performance criteria for closing Gap 5: New innovative, inter-sectoral products

Criteria	**Comment**	**Reference (regulations, relevant documents, approach to assessment)**
Domain: New innovative, inter-sectoral products		
Achieve maturity levels of new inter-sectoral product	A matrix of maturity levels of cooperation with stakeholders across value chain and product innovation maturity levels. There are six output categories: default, initiating, enabling, integrating, optimizing, pioneering.	SEI 2011
Domain: Environmental		
Contribute to system expansion (consequential LCA)	To capture change in environmental impact as a consequence of contributions from different sectors	LCA

End-of-Life (EoL)

At its end-of-life, a bio-based product is disposed of and becomes postconsumer waste. During collection a distinction is made between postconsumer and postindustrial waste. Post-consumer waste is produced by the consumer and is often collected together with other municipal solid residual waste. The separated organic waste can undergo a specific treatment and close the loop in circularity. Postindustrial waste is produced by companies, and includes off-spec products and cutting waste. For bio-based products, the key EoL activities include recycling, composting, energy recovery and landfilling. The last option should be only theoretical in a situation of uncontrolled methane emissions. The SWOT analysis for EoL of bio-based products in the context of gaps in regulations is presented in Table 18.

Table 18. SWOT analysis for Gap 6: End-of-Life (EoL)

	Internal factors	External factors
Favorable factors	Strengths L The waste hierarchy prioritizes methods of dealing with bio products at their end-of-life. E Use and disposal routes of bio-based products are strategized in order to ensure appropriate service conditions and adequate valorization and/or elimination after their service-life. E Material valorization is a benefit from more specialized sorting technologies for bio based waste. E Biological valorization to reintegrate sources into the C cycle is a way for bio-based polymers T Energy/feedstock valorization is prioritized after material valorization.	Opportunities P The new way of looking at the hierarchy should support the way we think about using solid waste as a resource. L In an attempt to fill identified gaps in the WFD (2008) and bring clarity to the key measures of waste prevention, reduction and recovery, alternatives are being developed for the definitions and the hierarchy of resource use. € Government policies favor such end-of-life options as a mechanical recycling, industrial composting , anaerobic digestion, direct fuel substitution in industrial facilities, incineration with heat recovery in municipal solid waste incinerators.
Unfavorable factors	Weaknesses E EoL criteria are sporadically used, e.g. minimum recycled content in product, implemented waste management, intended cascade use L Lack of cross compatibility and recognition between the certification systems in EoL scenarios (especially cascading, recycling, etc.) L WFD (2008) waste hierarchy still suffers from a lack of clarity L The WFD (2008) does not indicate how to measure recovery and reuse. T The knowledge in the area of	Threats E Improper materials management options increase the total impact of waste production and waste processing on the environment € Lack of research and investment in the implementation of combined valorization techniques for bio based products especially on a pilot scale and industrial-scale can result in improper performance of each methodology, and decrease the profit of bio-based products. L Lack of clear law about the waste/ material management hierarchy can result in an improper selection in end-of-life options

	EoL of biobased products has been built on results from experiments conducted mainly on model materials at labs.	

Strengths. The WFD (2008) and CEN/TR 16957: 2017 are examples of regulations that present the waste hierarchy in the context of prioritizing methods for treatment of bio products at their end-of-life or disposal of waste after their service life. Specialized sorting technologies enable valorization of material use and biological reintegration of waste into the C cycle. There are advanced technologies for energy use although, it is prioritized after material use and biological conversions.

Weaknesses. There are no sustainability criteria or thresholds for EoL options, such as minimum recycled content in product, implemented waste management and intended cascade use. The waste-related normative documents are not compatible, including the implicated lack of clarity and measurements of recovery and reuse in the waste hierarchy (WFD 2008). Currently, the new knowledge on EoL treatment of bio-based products is acquired in labs on the basis of model materials.

Opportunities. The regulations on the waste hierarchy and other matters related to the packaging sector can built awareness of the treatment of solid waste as a resource for further manufacturing. Besides, they are a good basis for the elaboration of key measures to assess waste prevention, reduction and recovery. A clear indication of the waste hierarchy facilitate policy decisions and legislation.

Threats. The improper waste management will contribute to the high impact of the EoL stage on the life-cycle product sustainability assessment. There is the lack of R&D investment and new knowledge on how to implement combined valorization techniques for EoL of bio based products, especially in the pilot scale and industrial-scale management. Such a situation affects the proper assessment of each method and decreases the overall revenue of bio-based products. The lack of clear legislation on waste in material management can result in a wrong selection from the hierarchy of end-of-life options.

The potential sustainability environmental criteria for the EOL of the bio based waste are shown in Table 19.

Table 19 Potential key performance criteria for closing Gap 6: End-of-Life (EoL)

Criteria	**Comment**	**Reference (regulations, relevant documents, approach to assessment)**
Domain: End-of-Life (EoL)		
Maximize percentage of waste converted to useful products	Life cycle conversion of waste into useful products	LCI (JRC 2012)
Domain: Environmental		
Enforce organic recycling	The aerobic treatment in composting or anaerobic treatment in biogasification of organic waste	2005/20/EC EN 14995: 2006 EN 13432:2000
Enforce mechanical recycling	Obtaining secondary material without changing the basic structure of the material (e.g. back to bio-based plastic	EN 13437: 2003 EN 13430: 2004 (ISO/TC 61)

	recycling)	
Enforce chemical recycling	Breaking down the polymers into monomers and converting them into useful products	ISO 15270:2008 (ISO/TC 61)
Promote biodegradability	Breakdown of organic matter by microbes	EN 17033: 2018
Maximize energy recovery	Waste conversion to energy to minimize the input of energy (NCV, net calorific value)	EN 13431: 2004
Reduce ecotoxicity	Impact of chemical, biological and physical factors to ecosystems	LCA
Reduce percent of traceable withdrawn or disposed product that undergo EoL options to End-of Waste	End-of-waste: stage at the end of the waste treatment process when materials are no longer considered waste, provided they meet certain conditions known as 'end-of-waste criteria'.	WFD 2008 JRC 2014

Traceability of sustainability and certificates along the supply chain

Traceability of sustainability and having certificates along supply chains are crucial requirements in the assessment of sustainability of bio-based products. Traceability is the ability to identify and trace the history, distribution, location and application of products, parts and materials, to ensure the reliability of sustainability claims, in the areas of green economy, human rights, labour (including health and safety), the environment and anti-corruption (UN Global Compact 2014).

The legal basis for certification of the sustainability of bio-based products along the value chain is Chain-of-Custody (CoC), which provides documentation of evidence for sustainability at any stage in supply chain management. CoC is an integral part of traceability by trailing and monitoring the certified material along the supply chain. Currently, the most advanced CoC tracing system is in the food and forestry sectors e.g. standard ISO 22000 on implementation of food safety management system (FSMS) and Forest Stewardship Council (FSC) CoC certification.

Following earlier work of food traceability, Karlsen et al. (2013) identified legislation, sustainability and certification as the three out of ten key drivers, including in addition food safety, quality, welfare, competitive advantages, chain communication, bioterrorist threat and production optimization. Traceability can be viewed from different perspectives. For a company, it is important for quality and safety purposes and to be the basis for improvement in value chains by selecting best suppliers and minimizing risks (Karlsen et al. 2013).

Mol and Oosterveer (2015) suggest four ideal types of value chain traceability, including management traceability, regulatory traceability, consumer traceability, and public traceability. In the context of sustainability, the first two types are focused on product quality and the other two – on product/process quality and sustainability, respectively. In consumer traceability, information is traced from economic actors in chains to consumers and certification bodies, while in the public traceability the tracing information is going from economic actors in chains and certification bodies to the public sector (citizen-consumers, NGOs, media).

The traceability schemes can trace sustainability claims according to the following methods, listed from highest to lowest level of assurance:

- Identity preservation. It tracks and records a commodity's characteristics from extraction of a resource to the consumer.
- Product segregation model. It assumes that certified materials are physically separated from non-certified ones. The certification procedure can follow two alternative ways: "bulk commodity" (it approves for mixing certified materials provided by different companies) and "identity preservation" for materials from the primary resource to the final users (does not allow mixing of certified materials).
- Mass balance model. It allows mixing certified and non-certified materials. At the same time, the exact volume of certified material entering and leaving the value chain must be controlled in order to be sold as a certified product.
- Book-and-claim model. The amount of certified material produced at the beginning of the value chain is connected with the certified product purchased at the end of the value chain.

In the context of bio-based feedstock/product, the voluntary labels and traceability methods exist for vegetable oil: palm oil (RSPO), soy oil (RTRS, ProTerra), sugar (Fair Trade, Bonsucro), cotton (Fair Trade, Better Cotton Initiative), timber (FSC, PEFC), biofuel EU market (15 different schemes), nonGMO crops (EU), biofuels (RSB), agricultural products (IFOAM, Rainforest Alliance, Organic label US and EU), and other (Mol and Oosterveer 2015).

In Table 20 there are set up SWOT factors and related PESTEL domains.

Table 20 SWOT analysis for Gap 7: Traceability of sustainability and certificates along the supply chain

	Internal factors	**External factors**
Favorable factors	**Strengths** L Credible and robust chain-of-custody standard/ certification schemes for some of bio-based products (food, forestry, bioenergy). L Proving claims and attributes for sustainability of biomass and bio-based products. € Integration of actors (companies and stakeholders) over the value chain in a multi-stakeholder initiative in order to create collaborative responsibility. T There are proofs of good practices at any stage of supply chain.	**Opportunities** L The assurance of sustainability in the entire supply chain • reduce the potential for misuse of certificates; • limit incorrect claims; L Establishment of overall integrity of sustainability certification schemes T Due to numerous tiers in the production process and numerous suppliers engaged at each tier, keeping registers and databases can make easier management/monitoring of sustainability traces. € The costs of monitoring sustainability can be shared by engaged stakeholders. E Sustainable practices implemented at any stage of a

		supply chain can progress traceability of sustainability. L Combined approach to tracing sustainability by meta-standard • approval of different certification schemes from different stages of a supply chain. P Increasing the availability of consistent and complete chains of information • due to pressing sustainability risks such as deforestation or misuse because of false claims (e.g., waste declarations, etc. • EU commission recognizes the importance of registries and databases as tools to trace sustainability characteristics in reliably
Unfavorable factors	**Weaknesses** E For bio-based product, certified material is traced and usually ends before the use phase, the responsibility for EoL and nutrients recovery is separately regulated (e.g. WFD). L Full responsibility for traceability of sustainability is attributed to single steps of a supply chain, but it should cover the entire supply chain. P Implementation of traceability of sustainability into CoC can be a long-term process. € Establishing global cooperation along supply chains can be difficult. S "Land grabbing" may exclude small-scale farmers from monitoring traces of sustainability. T Difficulties in establishing an unique method for tracking and recording (databases) sustainability along value chain • economic, environmental and social indicators should be addressed directly to a given bio-based product; • different frameworks require to be more compatible and easier to implement in a meta-standard.	**Threats** L Traceability of sustainability does not address security of natural resources and critical points in supply chains. € For many of the partly bio-based products, monitoring traceability can be impossible due to numerous tiers in the supply chain and numerous suppliers engaged at each tier (tier one company supplies components directly to the manufacture; tier two companies supply tier one companies with products needed). P Inability to monitor the whole market supply of a given bio-based product. T Lack of quantitative and qualitative rules for elaboration of the standard of standards (meta-standard) or to combine certification schemes applicable to the different stages of supply chain.

	€ The recognition of sustainability traced in a multi-stakeholder value chain may be difficult, thus it needs to involve collaboration of all actors and technology development.	

Strengths. In some sectors of bio-based products such as food, forestry and bioenergy there are credible and robust CoC regulations and the market confirms that the proved claims contribute to sustainability of biomass and bio-based products. Such circumstances facilitate integration of involved actors and implementation of good practices at any stage of a supply chain.

Weaknesses. Traceability is fragmented by the stages of a supply chain and covers the supply chain from resources to final products without tracing the fate of bio-based products after use. Establishing life-cycle traceability can take a long time and encounter difficulties considering the integration of stakeholders in the case of global interlinks, potential land grabbing effects, the lack of a commonly accepted methods for tracking and recording sustainability and the level of technological development.

Opportunities. First of all, traceability is a guarantee of the sustainability of bio-based products across the entire supply chain. Indirectly, it limits potential misuse of certificates, incorrect sustainability claims and it enhances the overall integrity of sustainability certification. Certain potential exists in regulations associated with a meta-standard that can integrate numerous registers and databases into a uniform approach, which can contribute to a more equitable share and lower costs of certification.

Threats. Traceability and certification schemes of sustainability do not address critical points related to the whole supply chain, such as the security of natural resources. Covering all tiers of a value chain as well as life-cycle monitoring of the whole market of a given bio-based product can be difficult to manage. The meta-standard is still only a concept, hence the methods for monitoring traceability of certification schemes across value chains require elaboration of quantitative and qualitative rules.

Traceability systems are closely interlinked with the implementation of progressive solutions of information technology and the basis for tracing sustainability should be through effective measurable indicators. Traceability indicators build a link between place of origin and bio-based product. They can be divided into (i) primary/direct indicators related to elemental composition of both – the geographical area the feedstock is from and to bio-based product and (ii) secondary/indirect indicators related to bio-based product's elemental composition/making procedure (bio-based product fingerprint). The primary indicators which can link the place of origin with the composition of bio-based products can be calculated according to the three approaches[12]:

- based on representative bio-based product samples and a relationship with the place of origin estimated by a multivariate method (need for existence of a calibration set);
- direct measurements on the samples of bio-based product and the place of origin (soil);
- soil samples are combined with climate, geographical and geological features and extended to macro-areas (100-200 km^2).

[12] Chemometrics in Food Chemistry. Chapter 10. Ed. 2013. Marini F. Data handling in science and technology 28. Elsevier B.V.

The traceability indicators can be referred to internal traceability with the record-keeping of a product within a particular operation/company/production facility, and external (or chain traceability), which refers to the recordkeeping outside a business entity, along the entire supply chain.

Outside the mentioned schemes of sustainability claims, the traceability of the overall sustainability characteristics and certificate information along the supply chain of a bio-based product is an open issue for bio-based product regulations. The traceability of sustainability and certification (ToS&C) of a bio-based product can be defined as the ability to identify and simultaneously to trace and document of external sustainability indicators associated with environmental, social, and economic domains across the entire value chain.

The regulations associated with ToS&C shall cover such principles as

- unique identification of lots and operators;
- data capture and management;
- to trace a stage before and after own operations;
- IT for tracing compliance with requirements;
- data communication;
- exchange information across the entire supply chain;
- to link the information with identification label.

The potential criteria for operationalization of the gap in traceability is presented in Table 21.

Table 21 Potential key performance criteria for closing of Gap 7: Traceability

Criteria	Comment	Reference (regulations, relevant documents, approach to assessment)
Domain: Traceability		
Maintain index of traceability records	The tests shall be carried out for randomly selected products in a given bio-based sector.	Dzwolak 2015
Optimize time of traceability	Total time necessary to trace the history of bio-based product from suppliers to consumers and from consumer to suppliers.	Dzwolak 2015
Enforce mass balance in the supply chain	In calculation quantities of the following main components' shall to be used: final product, product stock, product delivered to customer, product withdrawn, product disposed.	Felder, Rousseau 2005; Dzwolak 2015
Domain: Environmental		
Monitor GWP_{100}+GWP_{bio}	IPCC GWP_{100} model complemented with GWP_{bio} model for biogenic carbon	IPCC 2013 Guest et al. 2013 STAR-ProBio D2.1
Increase percentage of traceable bio-component in a bio-based product	The tracing of the amount of a bio-based component in bio-based products along the value chain	EN 16785-1:2015 EN 16640:2017
Domain: Economic		
Reduce cost of tracing sustainability and certification	Investment decisions for an enterprise with a tracking and tracing system in place	Fritz & Schiefer, 2009

Maximize value added affected by tracing sustainability and certification along the supply chain	The benefits from tracing sustainability should be higher than the costs of participating in the traceability process	Asioli et al. 2011
Improve consumer perception of bio-based products	Quality and safety assurance system.	Gellynck et al. 2005 Rijswijk et al. 2008
Domain: Social		
Increase percent of certified companies in the supply chain	Certification process from resource to disposal is in compliance with the sustainability criteria	STAR-ProBio
Reduce health complains per product	Large number of complaints related to health per product can show negative social impact of the product and inability of the company to providea healthy and safe product to consumers. Target value: *HC*=0	Mehralian et al., 2013 Popovic et al. 2017

3.2. Certification schemes: environmental principles, criteria and indicators and their operationalization

Since the kick-off of STAR-ProBio, the consortium has put a great deal of effort into the analysis of the existing certification and standardisation landscape and the development of coherent criteria and indicator sets aiming at improving existing sustainability certification and assessment approaches. This external attention as well as the self-concept of the consortium are constantly increasing the expectations to create project outcomes which will support a sustainable transition and development of bioeconomy in Europe. In this sense, the main challenge is to combine the existing elements (e.g. sustainable criteria reported in EN 16751) with the learned lessons from project results produced so far into a smart and meaningful framework supporting the sustainability assessment of bio-based products. It will be based on a meaningful combination of the existing results of all other STAR-ProBio work packages and key performance criteria closing the gaps (§3.1), adding a set of guidelines and rules regarding the actual implementation of all sustainability principles, criteria and indicators developed (i.e. SAT-ProBio blueprint and tool see ahead). Table 22 summarizes the proposed environmental principles, criteria and indicators that should complement current principles, criteria and indicators already considered in EU sustainability legislation, namely the EU Renewable Energy Directive. Table 22 reflects the latest consortium's discussion on these topics and the work done within WPs 2 and 3 (i.e. D2.2 and D3.1). Proposed indicators could still be subject to change in the light of new developments and methodology improvement.

Table 22 Principles, criteria and indicators, before establishing thresholds, proposed for the environmental pillar of sustainability

ENVIRONMENTAL PILLAR (from D2.2 and D3.1)	PRINCIPLE	CRITERIA	N°	INDICATOR
	Mitigate climate change and promote good air quality	The economic operator provides information on how greenhouse gas (GHG) emissions related to their operation are managed	1	Describe procedures taken to identify and minimize GHG emission and/or potential impacts on climate change related to their operations. Provide the "Cradle to grave" Global Warming Potential (GWP) of the bio-based product determined through LCA analysis (i.e. GWP bio)
		The economic operator provides information on how air pollutants related to their operations are managed	2	Describe procedures taken to identify and minimize air pollutants and/or potential impacts related to their operations. Provide the "Cradle to grave" particulate matter emissions (PM) of the bio-based product determined through LCA analysis (i.e. particulate matter)

	Conserve and protect water resources	The economic operator provides information on how quality and quantity of water drawn and released are addressed	3	Describe procedures to identify potential impacts and provide water consumption related to their operations. Provide the "Cradle to grave" water use of the bio-based product determined through LCA analysis (i.e. water deprivation)
	Protect soil quality and productivity	The economic operator provides information on how soil quality, productivity and erosion are addressed	4	Describe procedures taken to identify and address potential impacts on soil quality, productivity and soil erosion forces. Provide the "Cradle to grave" land occupation for bio-based product determined through LCA analysis (i.e. land use, soil quality index)
			5	Provide Land occupation associated with their operation and the erosion risk associated with the crop and region. Provide the amount of soil loss for bio-based product determined through LCA analysis (i.e. soil erosion)
	Promote efficient use of energy resources and the prevention of non renewable resource depletion.	The economic operator provides information on how energy efficiency related to their operations are addressed.	6	Describe measures taken to address energy efficiency. Provide the "Cradle to grave" Non-renewable energy resources consumption for bio-based product determined through LCA analysis (Resource use fossil)
	Promote the positive and reduce the negative impacts on ecosystems	The economic operator provides information on how ecosystem values are addressed within the area of operation and the environment directly influenced by the economic operator	7	Describe measures taken to promote positive and reduce negative impact on the ecosystem within the area of operation. Provide the "Cradle to grave" potential impacts on freshwater and terrestrial ecosystems for bio-based product determined through LCA analysis (i.e. acidification terrestrial and Freshwater)
			8	Provide the "Cradle to grave" potential impacts on freshwater and terrestrial ecosystems for bio-based product determined through LCA analysis (i.e. eutrophication freshwater)
			9	Provide the "Cradle to grave" potential impacts on freshwater and terrestrial ecosystems for bio-based product determined through LCA analysis (i.e. eutrophication terrestrial)
			10	Provide Land occupation associated with their operation and the species richness of the climatic region where it occurs. Provide the number of potentially affected species for bio-based product (i.e. LCA analysis -> potentially affected biodiversity)
	Minimize the impacts on Human Health	The economic operator provides information on how Human Health values are addressed within the area of operation	11	Describe measures taken to promote positive and reduce negative impact on the Human Healt within the area of operation. Provide the "Cradle to grave" potential impacts on Human healts for bio-based product determined through LCA analysis (i.e. cancer Human health effects)
	Promote responsible use of high concern materials	The economic operator provides information on how hazardous chemical is addressed	12	Describe measures taken to avoid, reduce or find greener alternatives to the use of substances of very high concern (SVHC) through a thorough screening of the product's "cradle to gate. Provide approaches to identify and REACH-register any previously unidentified, unregistered hazardous chemicals that are inherently present in the post-consumer recyclates (i.e. non-LCA indicative metric -> Presence of Hazardous Chemicals)
	Minimize the use of raw materials	The economic operator provides information on how the feedstock intensity is addressed	13	Describe measures taken to address material efficiency encompassing the maximum capacity of an optimized process to transform raw starting materials into intermediate products and useful co-products (i.e. Resource efficiency and circularity analysis: Feedstock intensity)
	Promote responsible waste management	The economic operator provides information on how waste is managed and reduced	14	Describe procedures related to waste management, for the manufacturing from "Cradle to gate" boundaries (i.e. Resource efficiency metric -> Waste factor)
		The economic operator provides guidance to the consumer on how the	15	The bio-based final product must contain clear indications on how it has to be disposed

		bio-based product has to be disposed after use		
	Promote use of renewable materials and prevent resource depletion	The economic operator provides information on use of renewable and non-renewable resources	16	Describe measures taken to promote the use of renewable material resources (i.e. Non-LCA indicator -> Product renewability)
	Promote process material circularity	Describe measures taken to address material efficiency	17	Describe measures taken to address material efficiency where the term "materials" refers to process consumables (such as solvents, process water and catalysts) (i.e. Resource efficiency and circularity analysis: Process material circularity)
	Promote efficient use of energy (fossil derived, renewable and internally derived energy)	Describe measures taken to address energy efficiency for manufacturing	18	Describe a procedure to measure the overall energy consumption for a given process or processes under consideration (i.e. Energy intensity)
	Minimize Indirect Land-Use Change (ILUC) risk	The economic operator provides information on how Indirect Land-Use Change (ILUC) risk of bio-based products is addressed	19	Describe measures to obtain additional biomass ("additionality") minimizing the ILUC risk. The economic operator provide ILUC risk value calculated according to ILUC Risk Tool.

All the proposed indicators represent quantitative metrics for addressing the environmental principles and criteria identified within STAR-ProBio project. Specifically indicators from 1 to 11 derive from the LCA methodology and they cover all life cycle stages of the bio-based product under study (i.e. Cradle to grave) with the exception of indicators 5 and 10 which address the biomass growth phase, thus the impacts associated with the soil erosion and biodiversity linked to the agricultural land occupation. To calculate indicators 5 and 10 and 18, it is necessary to know the country where biomass (crops) is cultivated. Indicators from 12 to 17 address the most important principles of circularity, like the promotion of the use of safe chemical substances, renewable raw materials, material and energy efficiency and reduction of waste. To conclude, the indicators reported in Table 20 represent the most updated, complete list of parameters that characterize the environmental profile of bio-based products, and they will be operationalized within the proposed certification scheme (i.e. SAT-ProBio blueprint framework) described in §3.7.

3.3. Benchmarking and Reference Product (RP) characteristics

The final aim for the proposed SAT-ProBio sustainability framework is to promote the market uptake of bio-based products characterized by a lower environmental impact, social compliance and economic feasibility within a specific product or service category through the development of a new Type I-based label certification scheme[13] (see also §3.8). However in order to determine if a given bio-based product is environmentally preferable it is necessary to define a "benchmark" against which a comparison will be performed.

[13] Type I labelling is a voluntary, multiple-criteria based, third party program that awards a license that authorises the use of environmental labels on products indicating overall environmental preferability of a product within a particular product category based on life cycle considerations

According to the PEF methodology[14], a "benchmark" is defined as follows: "*A standard or point of reference against which any comparison can be made. In the context of PEF, the term 'benchmark' refers to the average environmental performance of the representative product (RP) sold in the EU market. A benchmark may eventually be used, if appropriate, in the context of communicating environmental performance of a product belonging to the same category*". There are two options for defining a representative product:

1) It could be a virtual (non-existing) product (based on secondary data, low-medium representativeness)
2) It could be a real product (based on primary industry data, high representativeness)

The development of a reliable RP is a complex, task which needs to be properly managed as suggested in the proposed certification scheme (§3.7). Within the STAR-ProBio project option 1) was followed, and a series of important consequences were derived (see §3.5). Option 2), instead, cannot be achieved without a tight involvement and collaboration of the representative economic operators.

3.4. Determination of the RP and LCA analysis for mulch film in Europe and packaging in Europe

Within STAR-Probio project, two reference products (RPs) were drafted using secondary, literature data and making some assumptions. For these reasons, their (expected) representativeness is low/medium making them suitable for informative purposes rather than for evaluative considerations/uses..

This section summarizes how the LCIA results for the (informative) RP for mulch film and packaging case studies have been worked out.

3.4.1. Mulch film

Plastic mulch films represent an important agronomical technique, well established in the production of many vegetables[15] owing to agronomical advantages:

- increased yield and higher quality of productions;
- weed control and reduced use of pesticides;
- early crop production;
- reduced consumption of irrigation water.

In Europe, about 85.000 ton/y[16] (11% of the plastic used in agriculture) of mulch films for agriculture are used, covering 460.000 ha[11] (about 90% is represented by polyethylene). In reference to the end of life, plastic mulches should be removed and disposed of properly and the recovered mulch film is generally heavily contaminated with soil and organic residues making mechanical recycling difficult and economically expensive. The contamination of mulch films can reach 3 to 4 times the initial weight of plastic (representative 2,8 → every 100 kg of plastic film about 280 kg of film waste are generated).

[14] http://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf
[15] Source of data: Plasticulture, 2016 and 2018 (http://plasticulture.qualif.e-catalogues.info/)
[16] Plasticulture, 2016 and 2018 http://plasticulture.qualif.e-catalogues.info

Since January 2018, China has prohibited the import of 24 types of waste categories, including agricultural films. For this reason, and most common end of life in the EU the is still landfilling (ca. 50 %), followed by incineration and finally mechanical recycling (data, 2014[15]).

A screening LCA study aiming at defining the reference product (RP) for mulch film, a case study has been performed. In Table 23 the main characteristics of the "average" plastic mulch film are reported.

Table 23 Main characteristics of plastic mulch film

Parameter	Unit	Value	Remark
Material	na	Polyethylene (LD)	Representing 90% of the EU market
Recycled material in input	%	Unknown	Max 20% (personal communication) → sensitivity analysis
Thickness	µm	35	Range: 25-45 (in the past 50-70 µm)
Density	g/cm3	0.9	
Weight	g/m2	31.5	

- The functionality of mulch film is the covering of agricultural soil. Generally 1 ha of mulched soil correspond to 6000 m^2 of mulch film, thus 189 kg of plastic mulch film would be needed.
- The functional unit (F.U.) in the STAR-ProBio LCA model is defined as 1 ha of mulched soil (i.e. 6.000 m^2 of mulch film → 189 kg of plastic film).

The main assumptions of LCA model are listed below:

- Attributional LCA
- LCA impact categories: those reported in the D2.2 (Selection of environmental indicators and impact categories for the life cycle assessment of bio-based products)
- Boundaries: "Cradle to grave"
- F.U. = 1 ha of mulched soil (i.e. 6.000 m2 of mulch film → 189 kg of plastic film)
- Polyethylene granule production: avg. industry data (Ecoinvent database based on Plastics Europe Eco-profile) - Ethylene production: mass allocation
- Mulch film production: energy and process yield → assumption based on personal communication
- Transports: material distribution to converters 250 km, mulch film distribution 250 km and mulch film disposal 100 km (assumption)
- Electricity and heat: avg. EU technology (Ecoinvent and ILCD databases)
- Mulch film laying: representative data from "Prontuario ENAMA"
- Disposal scenario: average EU (2013) residual waste disposal: 55% landfill and 45% incineration with energy recovery. Soil contamination excluded
- Inventory data for end of life treatments: Ecoinvent tools based on chemical composition of (disposed) materials and average technology

A sensitivity analysis has been carried out taking in consideration the follow data:

- material in input: 20% of recycled LDPE
- Inventory data for recycling process: Ecoinvent 3.4 database.

The LCA impact categories considered were those reported in D2.2 (Selection of environmental indicators and impact categories for the life cycle assessment of bio-based products). Impacts and benefits of end of life in the context of entire life cycle developed by T3.3 have been modelled applying the Circular Footprint Formula (CFF)[17] reported below. The integrated formula holds the physical reality of using recycled materials in a product and clarifies the impacts due to EoL processes (e.g. recycling, landfilling) and the benefits on material and energy system level as well (i.e. produced recyclate and recovered energy that avoid primary production). This covers the true downcycling effects on recyclate quantity and quality - including the changes in the inherent properties of material – as well as energy recovery. The directly related burdens and benefits are kept in the same life cycle.

It employ all the principles and elements that a suitable EoL formula should possess. Moreover, the Integrated formula can cover upcycling processes as well. In a formalized way, environmental impacts ($\boldsymbol{E}$) can be calculated as the sum of four components of the Integrated formula:

E = Primary material input + secondary material input + Material recycling + Energy recovery + Disposal.

The Integrated formula is the following :

$$CFF = Material + Energy + Disposal$$

where:

$$\boldsymbol{Material} = (1-R_1)E_V + R_1 \times \left(AE_{recycled} + (1-A)E_V \times \frac{Q_{Sin}}{Q_p}\right) + (1-A)R_2 \times (E_{recyclingEoL} - {E^*}_V \times \frac{Q_{Sout}}{Q_P})$$

$$\boldsymbol{Energy} = (1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

$$\boldsymbol{Disposal} = (1-R_2-R_3) \times E_D$$

In STAR-ProBio the formula has been applied only for those applicable components: energy recovery (refers to impacts and benefits of incineration) and disposal (refers to landfill impact)

The formula is reduced to:

$$\boldsymbol{E} = R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}) + (1-R_3) \times E_D$$

where:

- R_3 = The proportion of material in the analysed product that is used for energy recovery (e.g. incineration with energy recovery) at EoL.
- E_{ER} = Resources consumed/emissions to operate the energy recovery process, including transporting, conditioning, storage etc. of the material or product. (Gate-to-gate)

[17] Product Environmental Footprint Category Rules Guidance – Ver. 6.3 May 2018

- E_D = Resources consumed/emissions for disposal of the various waste materials from the EoL product that are obtained due to direct landfilling, reject, wastes generate during recycling or energy recovery processes (e.g. ashes, unusable slags), including transporting, conditioning, storage etc. of the material or product. (Gate-to-gate)
- LHV = Lower Heating Value of the material in the EoL product that is processed for energy recovery
- X_{ER} = The efficiency of the energy recovery process (electricity and thermal energy).

In Table 23 the values of parameters for CFF are reported.

Table 23 Parameters of Circular Footprint Formula (CFF)

Parameter	Value
R_3	45%
LHV	42.47 MJ/kg
$X_{ER,heat}$	25%
$X_{ER,elec}$	13%

In Figure 6 the system boundaries for RP (mulch film) are shown.

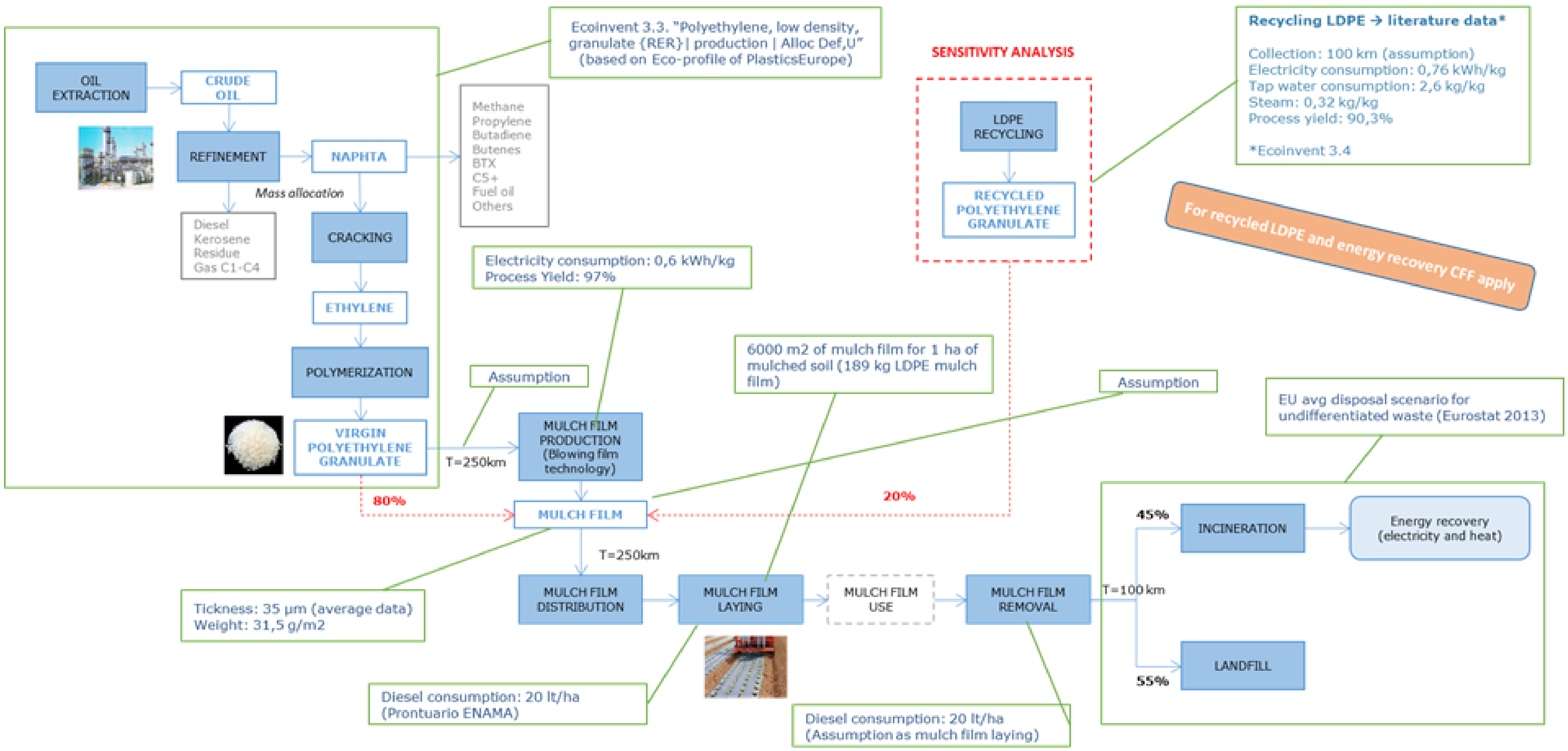


Figure 6 System boundaries of the RP (mulch film)

The data refer to F.U. 1 ha of mulched soil (i.e. 6.000 m^2 of mulch film → 189 kg of plastic film) (Table 24)

Table 24 The data referring to F.U. 1 ha of mulched soil

Life cycle stage	Process/material	Inventory Amount	Source/Dataset
Upstream	Polyethylene low density production	189 kg	Polyethylene, low density, granulate {RER}| production | APOS, U (Database Ecoinvent 3.4)
Core	Granule Transport	250 km	Assumption
	Mulch Film production	Kwh 117 kWh	Assumption based on personal communication
	Mulch film distribution	250 km	Assumption
	Mulch ilm laying	Diesel consumption: 20 l/ha	Prontuario ENAMA
Downstream	Mulch film removal	Diesel consumption: 20 l/ha	Assumption based on mulch film laying
	Mulch film to incineration with energy recovery	85 kg	Database Ecoinvent 3.4
	Mulch film to landfill	104	Database Ecoinvent 3.4
Sensitivity analysis	Recycled PE granule	39 kg	20% in input
	Recycling LDPE process (process yield: 97%)*	Electricity=0.76 kWh/kg Tap water=2.6 kg/kg Steam=0.32 kg/kg Diesel=0.00047 kg/kg	Database Ecoinvent 3.4

*Sensitivity analysis

The LCA analysis has been performed with the software SimaPro 8.0.5

The preliminary LCIA absolute results and contribution analysis for the RP (mulch film) are shown in Figure 7. It is worth pointing out that LCA impact categories 5 and 10 (Table 22) were not determined due to the lack of data about the country where land occupation occurs. Also the circular indicators from 12 to 17 were not calculated since the scope of application is under discussion/development.

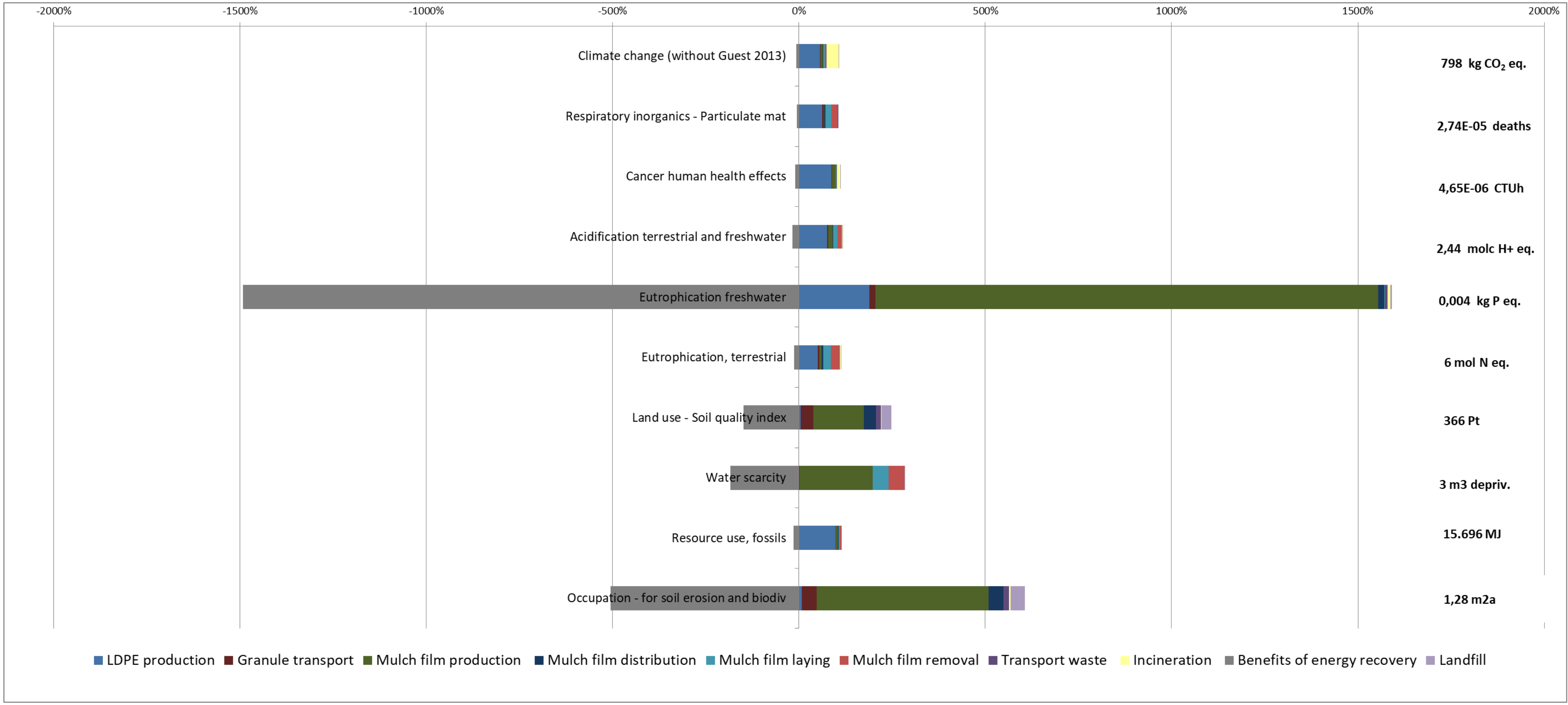


Figure 7 Absolute LCIA results for the reference product (preliminary results subject to change)

An important point to be considered is that the contamination of mulch film by soil and vegetable residues was not included in the preliminary LCA study, however, assuming an average *contamination factor* of 2.8, for 1 ha of mulched soil about 529 kg of contaminated mulch film waste are generated (further improvements of the LCA model on these issue will be performed in the next weeks/months). Soil represents the main contaminant (Soil organic matter depletion).

Furthermore, during the mulch film removal operations some pieces of plastic film remain in the soil. The lower the film's thickness, the higher the contamination rate (e.g. 25 µm PE film → 10% remain in soil, with 10 µm PE film → 68% remain in soil)[18]. Such a phenomenon (known as "white pollution") has taken impressive dimensions over the last ten years, especially in Xinjiang, China where residual plastic film mulch has become a serious issue that needs to be addressed in policy, regulation and technology in an all-round manner. In the future, the covered cropped area in China is expected to reach above 30 millions of hectares, and residual plastic film mulch levels in the (current) contaminated areas are in the order of 200 kg/ha in the top soil (0–20 cm)[19].

Unfortunately, this "big issue" is not properly addressed or, in other terms quantitatively accounted in LCA due to methodology constrains. Nevertheless, there are important international initiatives/projects aiming at overcoming this methodological limitation (i.e. Medellin Declaration[20] and Quantis[21])

This aspect will be further investigated, especially the initiative led by Quantis.

Table 25 Sensitivity analysis regarding the use of recycled PE in input

Impact category	Unit	Base scenario (A)	Scenario with PE recycled in input (B)	B vs A
Climate change	kg CO2 eq	798	756	-5%
Respiratory inorganics - Particulate mat	Deaths	2.74E-05	2.54E-05	-7%
Cancer human health effects	CTUh	4.65E-06	4.2E-06	-10%
Acidification terrestrial and freshwater	molc H+ eq	2.44	2.27	-7%
Eutrophication Freshwater	kg P eq	0.004	0.0096	+159%
Eutrophication terrestrial	mol N eq	6.29	6.01	-4%
Land use - solid quality index	Pt	366	427	+17%
Water scarcity	m3 depriv.	3	3.68	+23%
Resource use, energy carriers	MJ	15696	13957	-11%
Occupation - for soil erosion and biodiversity	m2a	1.28	2	+57%

18 CIPA Congress 2018, Arcachon May 29 Proceedings
19 Liu EK, He WQ, Yan CR (2014) 'White revolution'to 'white pollution'—agricultural plastic film mulch in China. Environ Res Lett 9(9):091001
20 https://fslci.org/medellindeclaration/
21 https://www.naturalcapitalpartners.com/news-media/post/why-we-need-metrics-not-quick-fixes-to-close-the-plastic-loop)

3.4.2. Packaging

This section summarizes how the LCIA results for the reference product (RP) in the average plastic packaging case study have been achieved. As previously mentioned, the RP can be a virtual product (non-existing) or a real product.

Within the STAR-ProBio project, a virtual product has been defined as a reference product (Plastic packaging).

The functionality of plastic packaging is to preserve goods during transports and storage.

In Europe (2017), the total converter demand for plastic materials reached 51.2 million tons (World production in 2017 = 348 million tons). About 40% (on mass basis) of plastic materials were used in packaging, and LDPE, HDPE, PP, PET and PS are the major plastic materials used in packaging. Plastic packaging is still the dominating fraction in the plastic waste. About 2/3 of plastic waste are caused through packaging. The average share of packaging is about 61.7% (2014).

A screening LCA study aiming at defining the reference product (RP) for the plastic packaging case study has been performed. The average plastic packaging composition reported in Table 26.

Table 26 Material composition of the average plastic packaging[22]

%	Polymer types
32%	LDPE
25%	PP
20%	HDPE
17%	PET
5%	PS
1%	EPS

The European plastic industry has good and long-standing trading relationship with many countries. In Figure 8 the extra EU trade partners are listed.

[22] Source: STAR-ProBio elaboration based on Plastics Europe Market Research Group (PEMRG) and Conversion Market & Strategy GmbH 2017

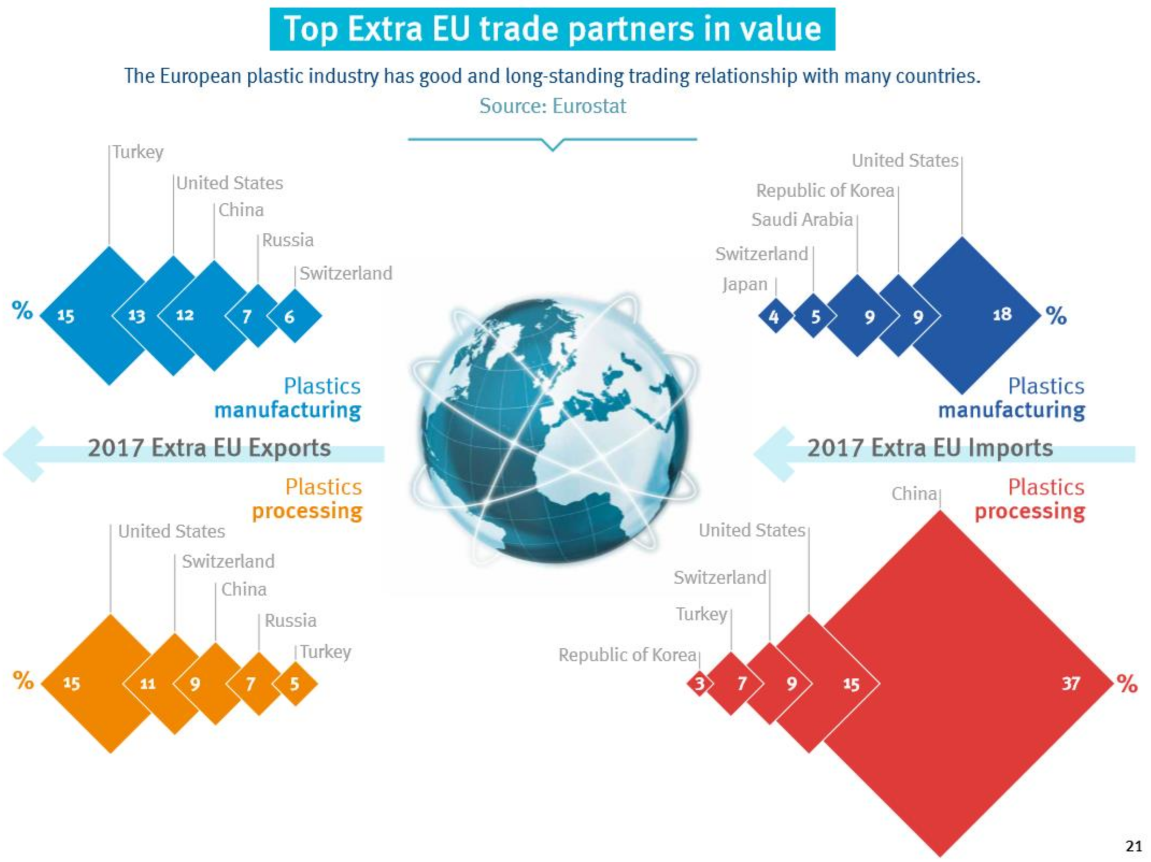


Figure 8 European market of plastics – import and export[23]

Table 27 shows the main characteristics of the "average" plastic packaging.

Table 27 Main characteristics of average plastic packaging

Parameter	Unit	Value	Remark
Material	na	Plastic mix	See the details in table XX
Recycled material in input	%	Unknown for packaging (assumed 2%)	Average value for plastic recycling (source: Mac Arthur Foundation) LDPE recycled (representative material)
Thickness	µm	N.A.	Broad range depending applications
Density	g/cm^3	0.9	(weighted) average density

The functional unit (F.U.) in STAR-ProBio LCA model is defined as the production, use and disposal of 1 kg of (average EU) packaging. The main assumptions of the LCA model are listed below:

- Attributional LCA
- LCA impact categories: those reported in the D2.2 (Selection of environmental indicators and impact categories for the life cycle assessment of bio-based products)

[23] Source: PlasticsEurope "Plastic – the Facts 2018 An analysis of European plastics production, demand and waste data" https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf

- Boundaries: "Cradle to grave"
- F.U. = 1 kg of packaging
- Plastic granule production: avg. industry data (Ecoinvent database based on Plastics Europe Eco-profile).
- Packaging production: avg. industry data of "blow film extrusion" (80% of total packaging - assumption) and of "thermoforming" (20% of total packaging – assumption)
- Transports: material distribution to the converters 250 km (assumption)
- Electricity and heat: avg. EU technology (Ecoinvent and ILCD databases)
- Disposal scenario: average EU (2016) data of plastic packaging waste: 40.8% recycling, 20.4% landfill and 38.8% incineration with energy recovery. Soil contamination excluded
- Inventory data for end of life treatments: Ecoinvent tools based on chemical composition of (disposed) materials and avg. technology
- Impact and benefits modelling (incineration with energy recovery and recycled material): Circular Footprint Formula (CFF) apply used as an all:

$$CFF = \mathbf{Material} + \mathbf{Energy} + \mathbf{Disposal}$$

where:

$$\boldsymbol{Material} = (1-R_1)E_V + R_1 \times \left(AE_{recycled} + (1-A)E_V \times \frac{Q_{Sin}}{Q_p}\right) + (1-A)R_2 \times (E_{recyclingEoL} - E^*{}_V \times \frac{Q_{Sout}}{Q_P})$$

$$\boldsymbol{Energy} = (1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

$$\boldsymbol{Disposal} = (1-R_2-R_3) \times E_D$$

The parameters of CFF are reported in Table 28.

Table 28 Parameters of CFF (Circular Footprint Formula)

Parameter		Value
R1	% recycled material in in input	2%
A	Default value PEF file	0.5
R2	% material to recycling	40.8%
Q_{sin}/Q_p	Default value PEF file	0.75
Qsout/Qp	Default value PEF file	0.75
R3	%aterial to recovery energy	30.8%
LHV	Lower heating value	35.8* MJ/kg
$X_{ER,heat}$	Efficency thermal energy recovery	23.2%*
$X_{ER,elec}$	Efficency electricity recovery	11.5%*

The sensitivity analysis has been carried out between a generic "European LDPE packaging" and a "Chinese" one used in Europe.

The LCA impact categories considered were those reported in D2.2 (Selection of environmental indicators and impact categories for the life cycle assessment of bio-based products). Impacts and benefits of end of life have been modelled applying the Circular Footprint Formula (CFF)[24] reported below. The Integrated formula holds the physical reality of using recycled materials in a product and clarifies the impacts due to EoL processes (e.g. recycling, landfilling) and the benefits on material and energy system level as well (i.e. produced recyclate and recovered energy that avoid primary production). This covers the true downcycling effects on recyclate quantity and quality - including the changes in the inherent properties of material – as well as energy recovery. As for mulch film, RP the LCA impact categories 5 and 10 (Table 29) were not determined due to the lack of data about the country where land occupation occurs and the circular indicators from 12 to 17 were not calculated since the scope of application is under discussion/development.

In Figure 9, the system boundaries for RP (plastic packaging) are shown.

[24] Product Environmental Footprint Category Rules Guidance – Ver. 6.3 May 2018

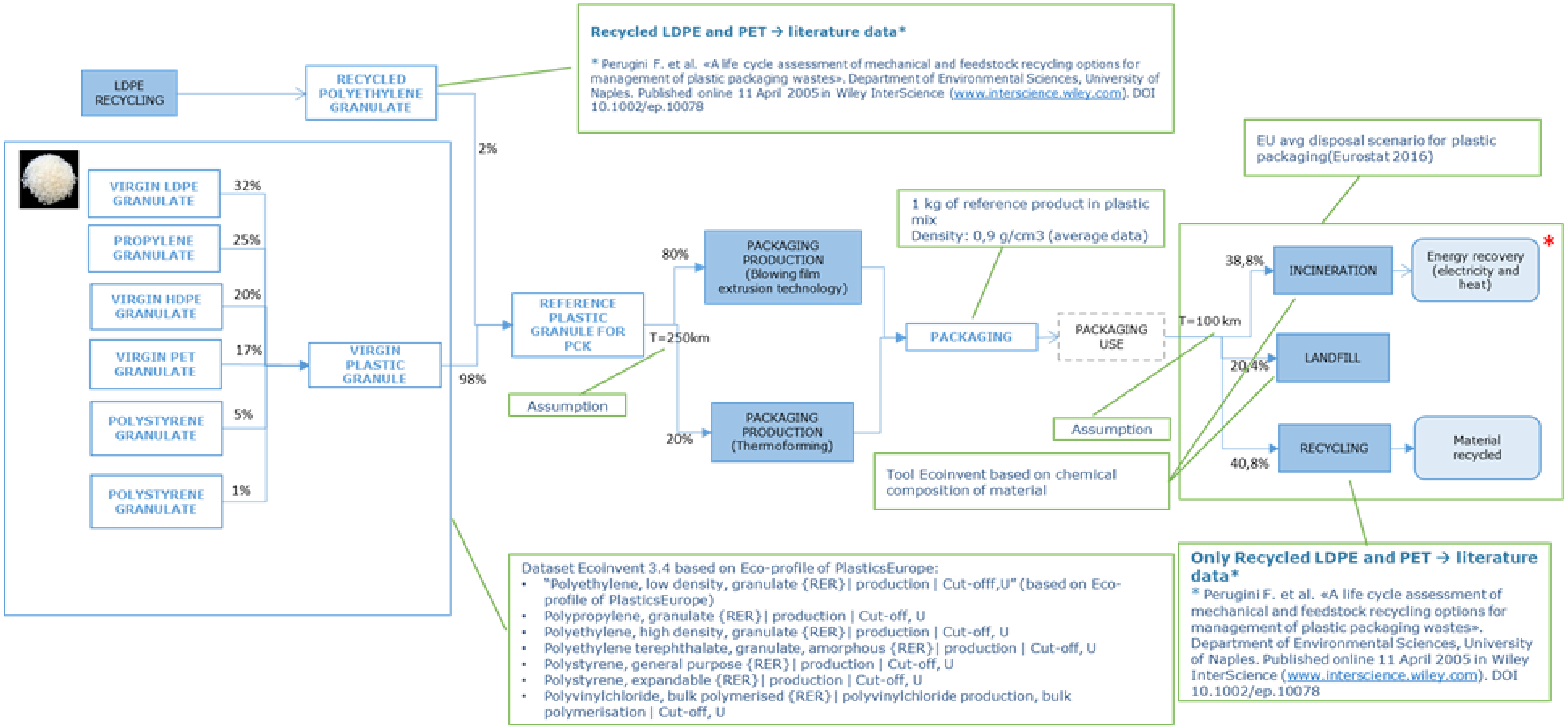


Figure 9 System boundaries for mulch film RP (some inventory data are also shown)

Table 29 The data reference to F.U. 1 kg of packaging[25]

Life cycle stage	Process/material	Inventory Amount	Source/Dataset
Upstream	Virgin plastic production	0.98	• Polyethylene, low density, granulate {RER}| production | Cut-off, U • Polypropylene, granulate {RER}| production | Cut-off, U • Polyethylene, high density, granulate {RER}| production | Cut-off, U • Polyethylene terephthalate, granulate, amorphous {RER}| production | Cut-off, U • Polystyrene, general purpose {RER}| production | Cut-off, U • Polystyrene, expandable {RER}| production | Cut-off, U • Polyvinylchloride, bulk polymerized {RER}| polyvinylchloride production, bulk polymerization | Cut-off, U Dataset Ecoinvent 3.4
	Recycled PE granule	0.02 kg	
	Recycling LDPE process (process yield: 97%)	Electricity=0.76 kWh/kg Tap water=2.6 kg/kg Steam=0.32 kg/kg Diesel=0.00047 kg/kg	• Database Ecoinvent 3.4
Core	Granule Transport	250 km	Assumption
	Packaging production (blowing film)	80%	Assumption Processing data: dataset Ecoinvent 3.4
	Packaging production (thermoforming)	20%	Assumption Processing data: dataset Ecoinvent 3.4
Downstream	Transport of waste	100 km	Assumption
	Packaging to incineration with energy recovery	38.8%	Database Ecoinvent 3.4
	Packaging to landfill	20.4%	Database Ecoinvent 3.4
	Packaging to recycling (only PET and PE)	40.8%	Database Ecoinvent 3.4

[25] The LCA analysis has been performed with the software SimaPro 8.0.5

The preliminary LCIA absolute results and contribution analysis for the RP (1 kg of plastic packaging) are showed in Figure 10.

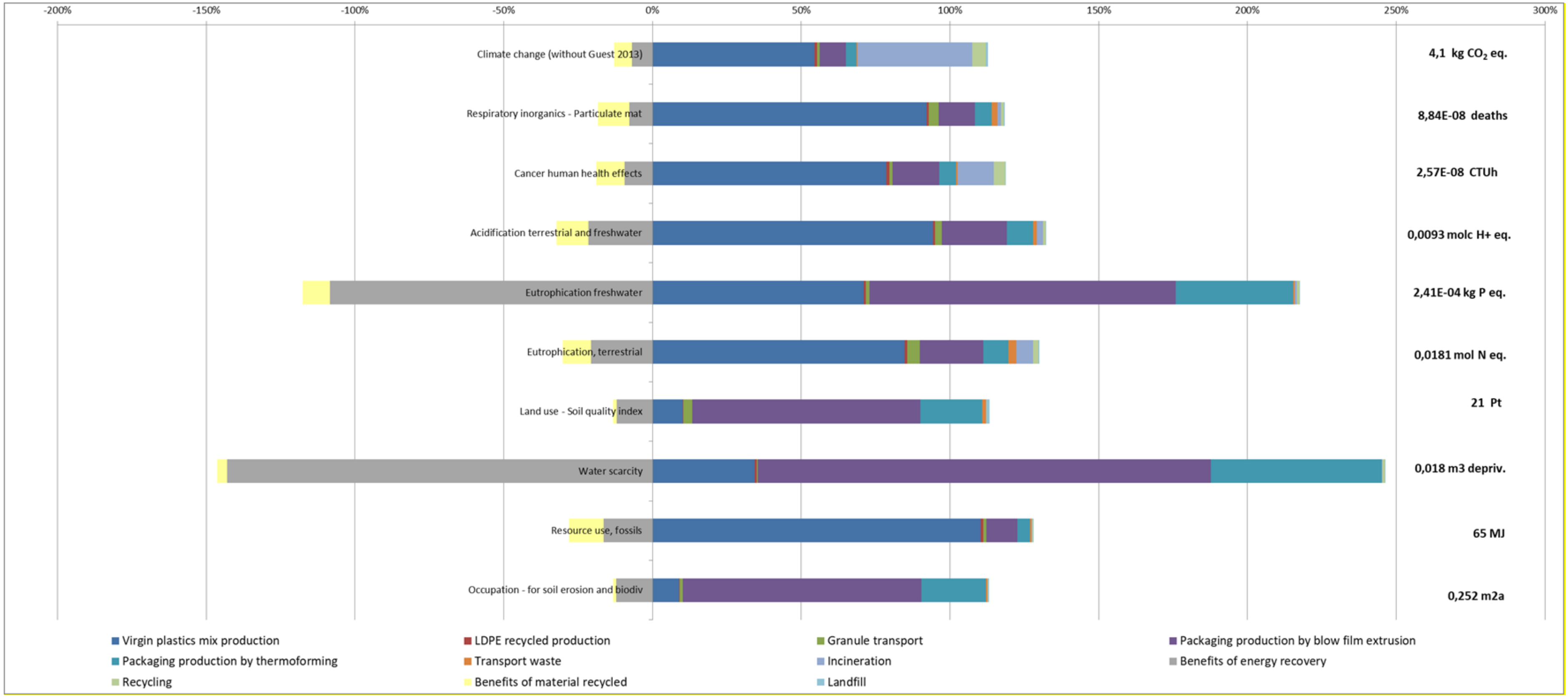


Figure 10 Absolute LCIA results for RP (packaging)

Below, the main assumptions for Chinese Packaging and European packaging in LDPE are reported.

Chinese packaging

- Inventory data for LDPE granule Production: database NREL (reference year: 2014)
- Electricity consumption: mix China (0.912 kwh/kg PE)
- Packaging production: avg. industry data of "blow film extrusion" (80% of total packaging - assumption) and of "thermoforming" (20% of total packaging – assumption) with the Chinese electricity mix
- Transports: assumption
- Use of packaging: in Europe
- Disposal scenario: average EU (2016) data of plastic packaging waste: 40.8% recycling, 20.4% landfill and 38.8% incineration with energy recovery. Soil contamination excluded.

European packaging

- LDPE granule production: avg. industry data (Ecoinvent database based on Plastics Europe Eco-profile).
- Packaging production: avg. industry data of "blow film extrusion" (80% of total packaging - assumption) and of "thermoforming" (20% of total packaging – assumption)
- Transports: assumption
- Electricity and heat: avg. EU technology (Ecoinvent and ILCD databases)
- Disposal scenario: average EU (2016) data of plastic packaging waste: 40.8% recycling, 20.4% landfill and 38.8% incineration with energy recovery. Soil contamination excluded.

The results of sensitivity analysis are shown in Figure 11.

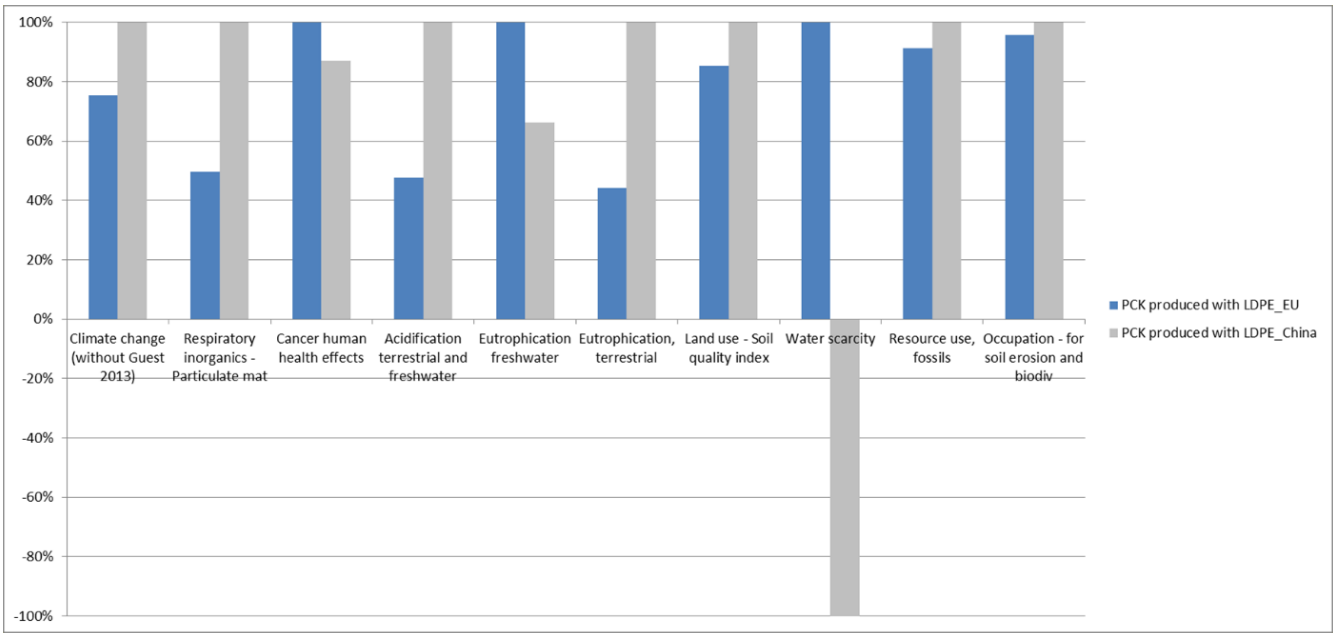


Figure 11 Sensitivity analysis results

The negative value for the "Water scarcity" indicator is linked to an equivocal water balance in the Ecoinvent dataset related to China's electricity mix. Anyhow, comparative results showed that significant differences (20-50%) may occur for Climate Change, Particulate matter, Acidification and Eutrophication, mainly because of the different electricity mix in Europe and in China. In any case, this simplified sensitivity analysis is just to point out that the attention needs to be paid in the definition of the reference product (RP). Further details on this relevant aspect are discussed in §3.5.

For those products whose definition of the RP could be difficult to estimate (e.g. construction materials) an I-O (Input-Output) database could be used for upstream stages LCIA results estimation (e.g. EXIOBASE database http://www.exiobase.eu/index.php/9-blog/27-creea-booklet).

3.5. Feasibility of sustainability thresholds definition

LCA analysis does not provide any info about environmental sustainability of a product (i.e. how far we have to go in reducing the burdens to be sustainable) rather if it is more or less burden compared to an equivalent product. For example, it is possible to have products that burden the environment 10%, 20% or even 50% less than the common option (e.g. average impact of the sector), but it is not possible tell whether these products are really are "sustainable".

Long-term, sustainable consumption would mean that every person on the planet can consume a range of products and services and that the cumulated burden of the totality of all those products does not exceed the given natural buffering capacities of the planet (Planetary boundaries = "safe operating space for humanity").

Judging sustainability or non-sustainability then depends on a number of very heterogeneous factors including:

1. What range of products is consumed by a person
2. How often per time unit those products are consumed (consumption intensity)
3. How we manufacture those goods (and dispose of them)
4. How many people there are on the planet
5. The extent of the natural buffering capacities of the planet (which may not be constant)

LCA currently is focused on points one and three but completely ignores time aspects and thus consumption intensity as long as the aspects reported in points 4 and 5.

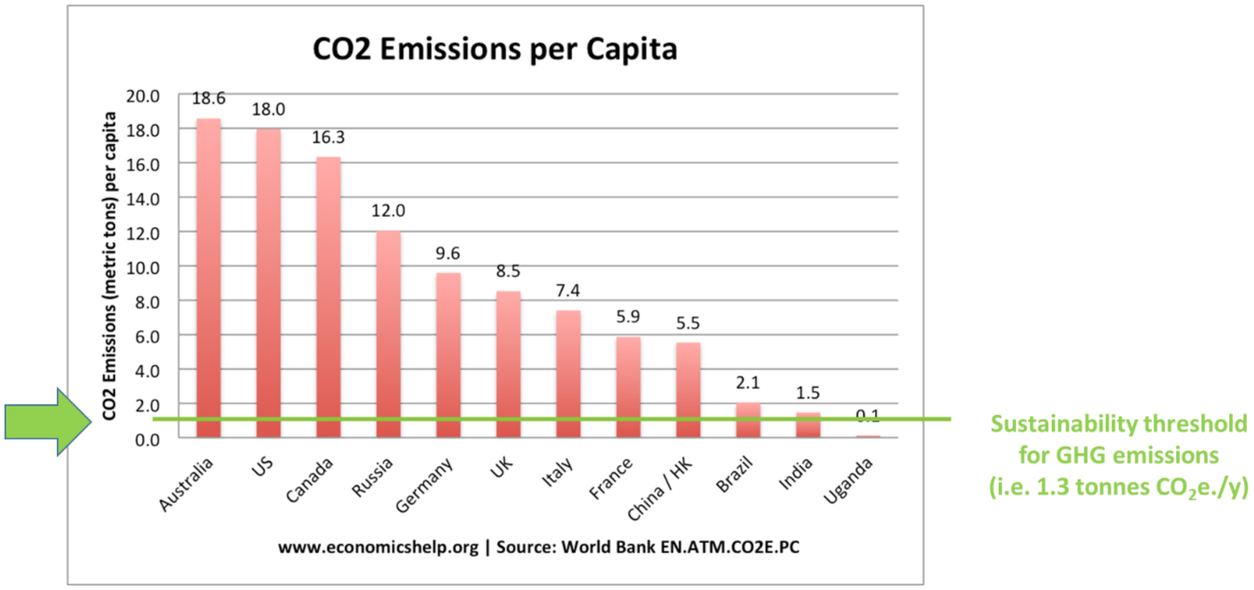
The above list indicates clearly that "sustainability" can only be judged appropriately, if the annual amount of inflicted damages is assessed. It is necessary to weigh this sum total against the natural buffering capacities of the planet. It means that it is important to look not at the consumption intensity of one product alone, but of all consumption. For this reason, it would be completely wrong to label one single product as "sustainable" or "not sustainable". Only whole lifestyles (with set boundary conditions on total population and state of the planet) could be labeled sustainable.

Taking into account these considerations, it is recommended that future policy design adopts the following approach for establishing thresholds:

Assuming to know the buffering capacity of the planet for GHG emissions, i.e. max amount of GHG/y that do not cause an increase of the average temperature of the planet, and divide such amount for the planet population, as result we obtain the “sustainable threshold” per capita for GHG emissions (Figure 12). This can be considered as the (annual) budget of each citizen on the planet, so our “Sustainable budget”. It possible reach it through infinite combinations of goods/behaviors depending of the lifestyle.

For Global Warming the impact category “sustainable budget” is around 1,3 metric ton CO_2e/y per citizen up to 2050 and when considering 10 billion of people (source: http://www.doka.ch/publications.htm)

Figure 12 GHG emission per citizen (different countries) compared to the "sustainable budget" (represented by the green row in the graph)



Literature research has been performed so as to identify the sustainability threshold in LCA. Table 30 reports the Planetary boundaries (or sustainability thresholds) for some impact categories generally used in LCA.

Table 30 Planetary boundaries for some impact categories of Product Environmental Footprint (PEF)[26]

Impact categories compliant with ILCD	Unit	PB estimates per person	PB estimates total
Climate change - GWP	kg CO_2 eq	9.85E+02	6.81E+12
Ozone Depletion Potential	kg CFC-11 eq	7.80E-02	5.39E+08
Photochemical Ozone Formation	kg NMVOC eq	3.80E+00	2.63E+10
Freshwater Eutrophication	kg P eq	8.40E-01	5.81E+09
Marine Eutrophication	kg N eq	2.90E+01	2.01E+11
Freshwater Ecotoxicity	[PAF]*m^3*day	1.90E+04	1.31E+14
Impact categories not compliant with ILCD			
Terrestrial Acidification	mole H+ eq	1.45E+02	1.59E+13
Terrestrial Eutrophication	mole N eq	8.87E+02	1.94E+13
Land Use, soil erosion	Tonnes eroded soil	1.83E+00	1.24E+10
Land Use, biodiversity	m^2*year	1.49E+04	1.03E+14
Water Depletion	m^3	9.93E+01	1.04E+14

[26] Source: JRC Technical Report "Global Environmental Impacts and planetary boundaries in LCA https://ec.europa.eu/jrc/en/publication/global-environmental-impacts-and-planetary-boundaries-lc

To conclude, by knowing the PB (or sustainability thresholds) for each LCA impact category it is possible to define for each product its share (%) compared to the correspondent "sustainable budget" from the following formula:

Share product X = GWP product X / GWP "sustainable budget" x 100

This information could be used for communication purposes through the development of a dedicated label showing the share of the "sustainable budget" the product contributes to (Figure 13)

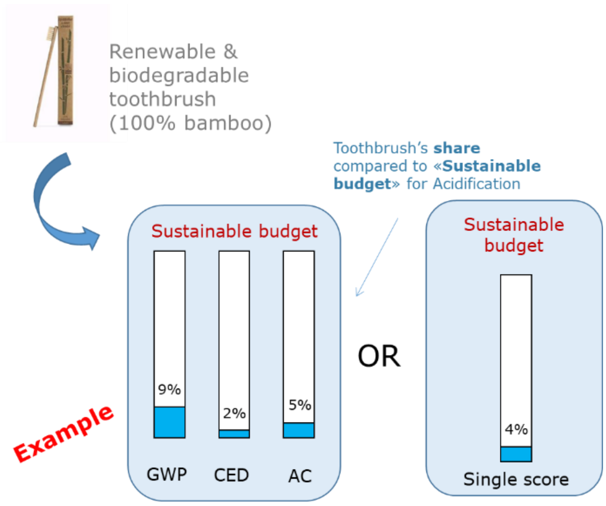


Figure 13 Label showing the impact share of a hypothetic bio-based product compared to the "sustainable budget" (different LCA impact categories)

In this way, each citizen is responsible of his/her actions (i.e. lifestyle) which will cause more or less environmental burdens. The label would become a sort of "Educational tool", able to orient choices toward critical consumption.

A possible application of the described proposal is the development of a smart-phone application able to keep trace and to count the environmental burdens associated with the goods and services of a citizen (Figure 14).

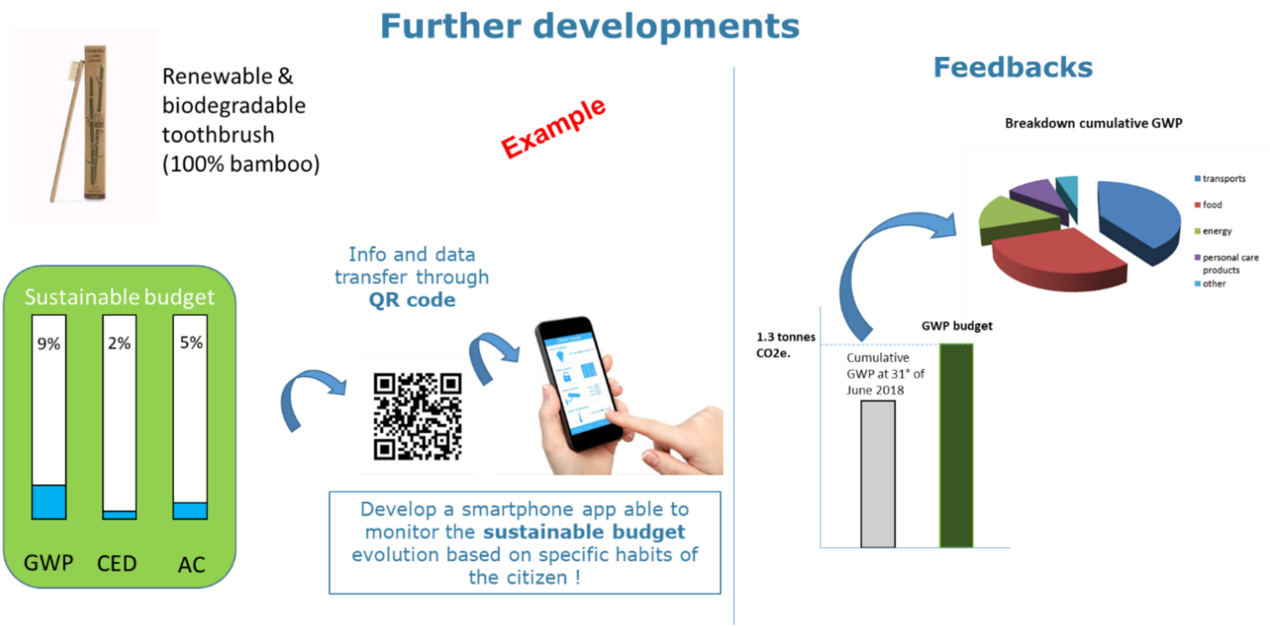


Figure 14 - Scheme showing the functioning and the outcome of a hypothetic smart phone app measuring our lifestyle towards planetary boundaries

3.6. Communication of environmental aspects (i.e. incorporation of LCIA results into a bubble scheme representation)

One of the main gaps among existing environmental labels, such as ISO 14025 Type III (e.g. EPD, Environmental Product Declaration https://www.environdec.com/), is the absence of the reference values respect to which the LCIA results of a certified product can be compared so as to get a more complete picture of its environmental performance.

It is not a coincidence that at the EU level the Product Environmental Footprint (PEF) project aims to define the impacts of the Representative Product (RP), or "benchmark" (i.e. "A standard or point of reference against which any comparison can be made") as previously discussed. In this way, the definition of a RP permits to better contextualize the "meaning" of the LCIA results.

Furthermore, another important aspect regarding the LCA profile of a product which is not caught in the current Type III environmental labels is the magnitude of the LCIA results or, in other words, the importance of each LCA impact category for the analyzed product. Normalization is not a required, but a recommended step in which the life cycle impact assessment results are multiplied by normalization factors 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, dimensionless, normalized life cycle impact assessment results are obtained (Table 31). These reflect the burdens attributable to a product relative to the reference unit, such as per capita for a given year and region. Thus the relevance of the contributions made by individual processes can be compared to the reference unit of the impact categories considered.

Table 31 Final weighting factors of Product Environmental Footprint (PEF)

Impact categories	Final weighting factors
Climate change	22.19
Ozone depletion	6.75
Particulate matter	9.54
Ionising radiation, human health	5.37
Photochemical ozone formation, human health	5.1
Acidification	6.64
Terrestrial eutrophication	3.91
Freshwater eutrophication	2.95
Marine eutrophication	3.12
Land use	8.42
Water use	9.03
Resource use (fossils)	8.92
Resource use (mineral and metals)	8.08

For example, life cycle impact assessment results may be compared to the same life cycle impact assessment results 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. Normalized environmental footprint results do not, however, indicate the severity/relevance of the respective impacts. Finally, weighting is not a required, but a recommended step that may support the interpretation and communication of the results of the analysis. In this step, life cycle impact assessment results, for example normalized results, are multiplied by a set of weighting factors, which reflect the perceived relative importance of the impact categories considered. Weighted life cycle impact assessment results can then be compared to assess their relative importance. They can also be aggregated across impact categories to obtain several aggregated values or a single 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, cultural/political viewpoints, or economic considerations. Weighting is not a required, but an optional step for LCA studies. If weighting is applied, the set of weighting factors should be clearly reported and the single score result shown not alone but along with life cycle impact assessment results prior to weighting. The application of normalization and weighting steps in LCA studies shall be consistent with the defined goals and scope of the study, including the intended applications even if these aspects are out of the scope of Task 8.2. Within the PEF project, a series of weight factors has been developed (Figure 27), although, the aggregation step has not been applied to the RP since just a part of the selected impact categories come from the PEF methodology.

Taking into account these assumptions, a unique scheme for communicating the LCIA results was worked out within Task 8.2, as shown in Figure 15

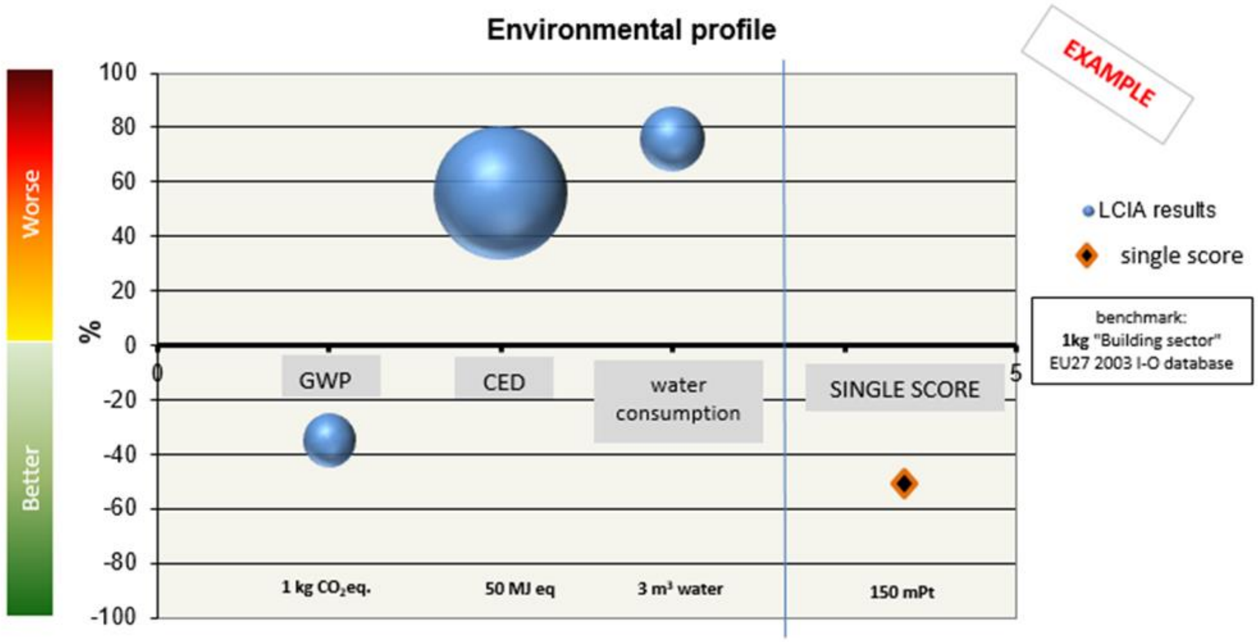


Figure 15 Proposed scheme for LCIA results communication

The scheme provides the following environmental information:

- Absolute LCIA results related to the F.U. of the bio-based product (i.e. figures at the bottom of the graph).
- The percentage positioning of the bio-based product compared to the RP (horizontal axis) or the average impact of the sector the bio-based product belongs to (this will depend on the specific product analyzed).
- The relevance of the LCIA result: the bubble dimensions reflect the magnitude of the impacts (i.e. equivalent citizens).
- (Possible) single score result.

Within an unique graph all the elements characterizing the LCIA results (previously described) can be shown making the environmental label more exhaustive and comprehensive. In reference to the RP, it is important to point out that it can be INFORMATIVE or EVALUATIVE. Due to the weakness and limits associated with the definition of the benchmark considered in the project, it has been proposed to use it as INFORMATIVE rather than evaluative. In the future, when more data are available (see for example PEF project), the benchmark values could be used for judging the environmental profile of a product. However, it is important to point out that the majority of impact categories selected in WP2 (i.e. D2.2) are "biomass-production related" and this could distort the benchmark values if it is largely based on fossil-feedstocks. For these reasons it would be necessary to consider all impact categories generally used in the LCA evaluations including those under development (e.g. littering, which is very relevant for traditional plastic products) when they become available.

3.7. Certification scheme for the environmental qualification of bio-based products

Figure 16 shows the developed certification scheme for the environmental qualification of bio-based products which can be easily extended to address also the social and economic principles, criteria and indicators developed within STAR-ProBio.

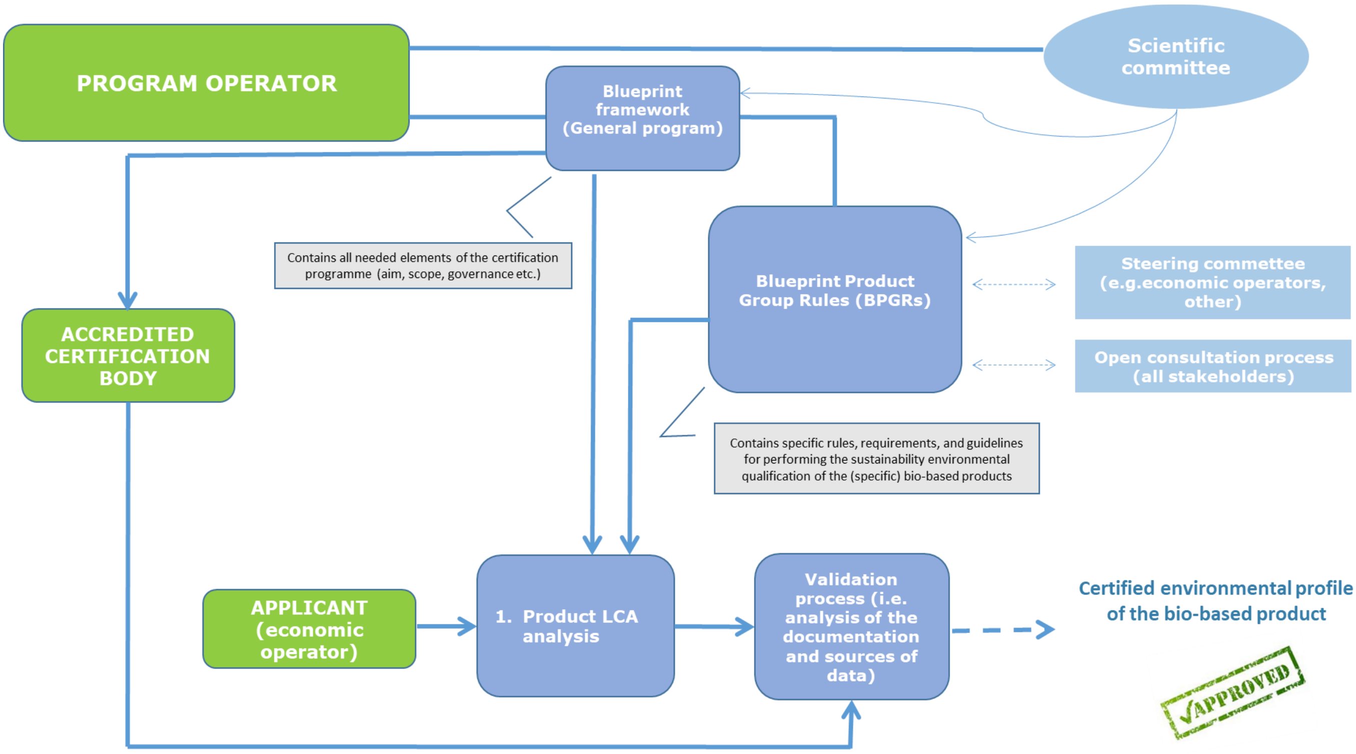


Figure 16 Proposed certification scheme for the environmental qualification of bio-based products

The elements shown in the figure are described as follows:

- Program operator: it is the holder of the certification scheme
- Scientific committee: group of experts in different disciplines (e.g. LCA) who have deep knowledge of economic sectors. They develop principles, criteria and indicators and revise them, as well as the environmental profiles of RPs (i.e. LCIA results of the References Products) and the "Blueprint Product Group rules" for carrying out LCA analysis for each specific product group (e.g. flexible packaging, thin mulch film etc.).
- Steering committee: the definition of the reference products (RP), criteria, indicators etc. and all related discussions must account for the direct involvement of economic operators that produce specific products and other stakeholder. This is the role of the Steering committee.
- Open consultation process: the "rules of the game" for defining the RP and LCA analysis of specific product groups are subject to an open consultation process. It is open to all stakeholders.
- Applicant: is the economic operator (e.g. company) that wants to qualify and certified its product/s environmentally.

- Accredited certification body: is the subject that verifies if the LCA study and the related label meet the certification requirements.

Finally Figures 17 and 18 report the contents of the "General Programme" and "Product Group Rules" of the Blueprint framework for addressing the environmental pillar of sustainability.

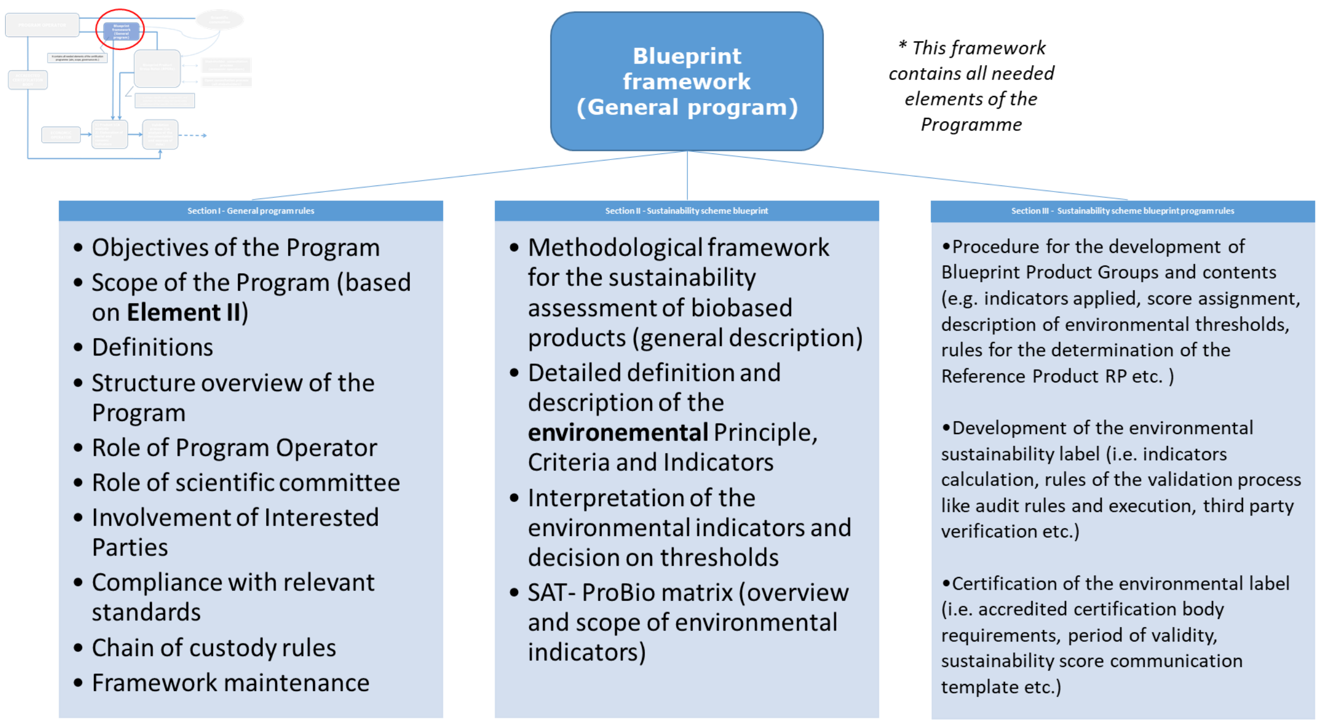


Figure 17 The content of the Environmental blueprint framework (General Programme) for bio-based products

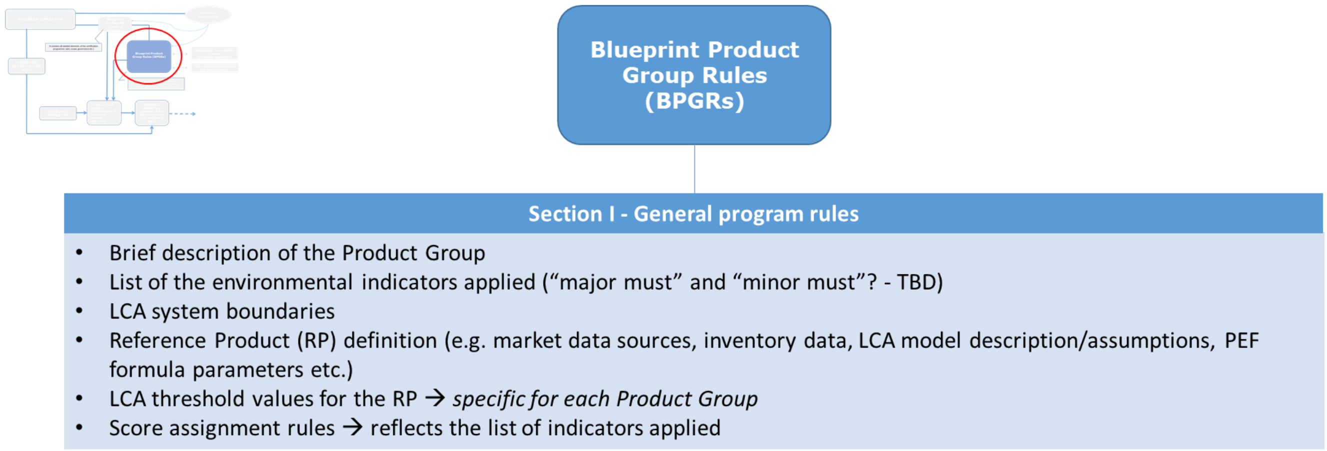


Figure 18 The content of the Environmental blueprint framework (Product Group Rules) for bio-based products

3.8. Certification schemes: socio-economic principles, criteria and indicators and their operationalization

As it was mentioned, the main challenge is to combine the existing sustainable principles, criteria and indicators reported in EN 16751 with the STAR-ProBio project results. Table 32 presents the set of social and economic principles, criteria and indicators reflecting the lastest outcomes of the consortium discussion on these topics and the work done within WP4-6 (D6.3) as well as addresses the key performance social and economic criteria closing identified gaps (§3.1). This set complements current principles, criteria and indicators already considered in EN 16751:2016. The project is ongoing thus they could be subject to changes and/or improvements. Broader insights into environmental and socio-economic implications in the context of regulations and policy on sustainability are presented in chapter 3.9.

Table 32 Principles, Criteria and Indicators, before establishing thresholds, proposed for the socio-economic pillar of sustainability

	PRINCIPLE	CRITERIA	n°	INDICATOR
SOCIAL PILLAR (WP6)	**Child labour**	The economic operator provides information on how child labour is addressed	1	The company describes measures taken to address child labour, including prohibiting policies, evidences (such as records on worker's age), incidents and corrective actions plans and a plan-do-check-act process in place to raise awareness on the topic
	Forced labour	The economic operator provides information on how forced labour is addressed	2	Describe procedures to identify potential impacts and provide water consumption related to their operations. Provide the "Cradle to grave" water use of the bio-based product determined through LCA analysis (i.e. water deprivation)
	Fair salary	The economic operator provides information on how they address fair salary	3	The company provides information regarding the salary of workers, including the percentage of workers whose wages meet at least legal minimum standards, incidents of delayed payments, percentage of workers paid a living wage or receive additional social benefits
	Equal opportunities/ discrimination	Equal opportunities/ discrimination	4	The company describes measures taken to address equal opportunities, including if they have a non-discrimination policy, a system to enforce it, incidents and corrective action plans and a public commitments on this issue
	Health and safety of workers	The economic operator provides information on how they address health and safety of workers	5	The company describes measures taken to address health and safety of workers, including if they comply with local laws, if workers have the needed protective equipment, incidents and corrective plans, a plan-do-check-act process in place to protect workers' health beyond laws and public commitments on this issue
	Health and safety of end users	The economic operator provides information on how they address health and safety of end users	6	The company describes measures taken to address health and safety of end users, including evidence that the product is safe for users, compliance with product safety laws and programmes in place to raise awareness on safety risks associated with the product
	Feedback mechanisms	The economic operator provides information on how they provide feedback mechanisms	7	The company describes measures taken to offer mechanisms for users to provide feedback, including measures to improve the mechanism, if there are surveys related to customers satisfaction and actions taken according to the results of these surveys
	Transparency	The economic operator provides information on how they address transparency	8	The company describes measures taken to address transparency, including if there are compliance with regulations, consumer complaints, sustainability reports with sustainability goals

	Benefits of the product	The economic operator provides information on how they improve the benefits of the product	9	The company describes measures taken to improve the benefits of the product, including if there are surveys to the impact of the product in consumers' satisfaction and the percentage of bio-based material in the product
	Health and safety of local community	The economic operator provides information on how they address health and safety of local community	10	The company describes measures taken to address health and safety of local communities.
	Local employment	The economic operator provides information on how they address local employment	11	The company describes measures taken to address local employment, including public commitments to grow local employment and the number of indefinite or temporary jobs (higher than 6 months) created or lost during the reporting period
	Land use rights	The economic operator provides information on how they address land use rights	12	The company describes measures taken to address land use rights, including percentage of small-scale entrepreneurs who have documented legal rights to land and who feel that their land rights are secured and if the risk of land grabbing if being monitored
	Food security	The economic operator provides information on how they address food security	13	The company describes measures taken to address food security, including measures to improve and ensure local food security, a plan-do-check-act to identify and reduce risks on this topic and percentage of hectares that have changed in the variety of crops and arable land in the region since the appearance of feedstock demand for bio-products
	Economic development	The economic operator provides information on how they address economic development	14	The company describes measures taken to address economic development, including if there is a policy prioritising buying goods and services from local suppliers, contribution to skill development, and the percentage of employees and market share of the company have grown in the last 5 years
	Fair competition in the market	The economic operator provides information on how they address fair competition in the market	15	The company describes measures taken to address fair competition in the market, including incidents regarding anti-competitive behaviour, measures to increase employee awareness in this topic
ECONOMIC	**Produce and trade bio-based products in an economically and financially viable way (EN 16751:2016)**	The economic operator provides information on how fraudulent, deceptive, or dishonest consumer or commercial business practice is addressed	16	List of final, binding and unappealable decisions of an applicable judicial authority against the economic operator for fraudulent, deceptive, or dishonest consumer, or commercial business practice that is prohibited by applicable laws that remain unresolved.
			17	Describe policies and/or practices related to fair business practices (in particular identification of risks and corresponding measures regarding fraudulent, deceptive, or dishonest consumer or commercial business practice).
			18	Keep records of risks identified in indicator 17.
			19	Describe measures taken to reduce identified risks.

3.9. Socio-economic context of environmental impacts

3.9.1. DPSIR analysis

Bio-based products compose the leitmotif of sustainable economy growth and related policy on decreasing dependence on fossils and addressing social challenges. The current EU and global priorities are clearly displayed in main documents, including the EU New Bioeconomy Strategy for a Sustainable Europe (EC 2018), the EC Circular Economy Action Plan (4 March 2019), the UN Sustainability Development Goals (SDGs) and the concept of Planetary Boundaries (PBs).

The starting point of a DPSIR analysis on drivers of sustainability of bio-based products is the natural world of human life and human economic activities, i.e. the ecosystems (natural capital[27]) and ecosystem services (natural resources[28]), followed by economic activities (beneficiaries[29]) and socio-economic implications related to improvement in the quality of ecosystems (management, conservation[30]) (Figure 19) (Gołaszewski et al. 2019). Ecosystem management links economic activities and associated impact to ecosystems with the Earth's system processes including the planet's natural cycles of carbon, water, nitrogen, and phosphorus flows.

[27] Land cover, biodiversity, soil resources, water resources, atmosphere
[28] Natural resources-related provisioning, regulating , supporting and cultural services
[29] Benefits to people, households, communities, industry, government differentiated on a geographically-related level (local, regional, global)
[30] Policies, regulations

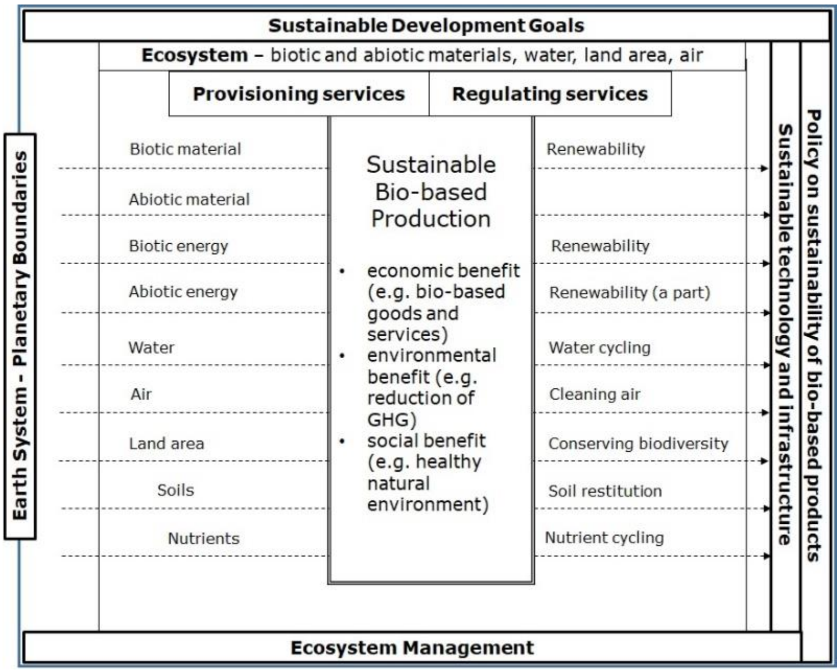


Figure 19 Main components of an ecosystem services in the framework of policy on sustainability of bio-based products

Beneficial or detrimental environmental and socio-economic impacts of bio-based products can be attributed to any stage of value chains, different sectors of economy and societies. Throughout the value chain of bio-based products there is a continuous interaction of human activities with ecosystems. The sustainability aspects presuppose a life cycle process when the natural resources are exploited to manufacture bio-based products and end of life options allow for their restitution. The generic scheme of life cycle provisioning and regulatory services of ecosystems along the value chain of bio-based products is shown in Figure 20 (Gołaszewski et al. 2019). The pivotal influence on the Earth's system processes is associated with the use of primary resources at any stage of the value chain. All the resulting activities, if undertaken, tend to sustain the ecosystem's regulatory and supporting services and to minimize detrimental impact to the Earth's system. In bio-based production the basal primary resource is biomass feedstocks. Even if renewable, the efficient biomass production involves depletion of other natural resources (nutrients, water) and the supplied production means (energy, fuels, fertilizers, pesticides, machinery) that are burdened with accumulated environmental footprints.

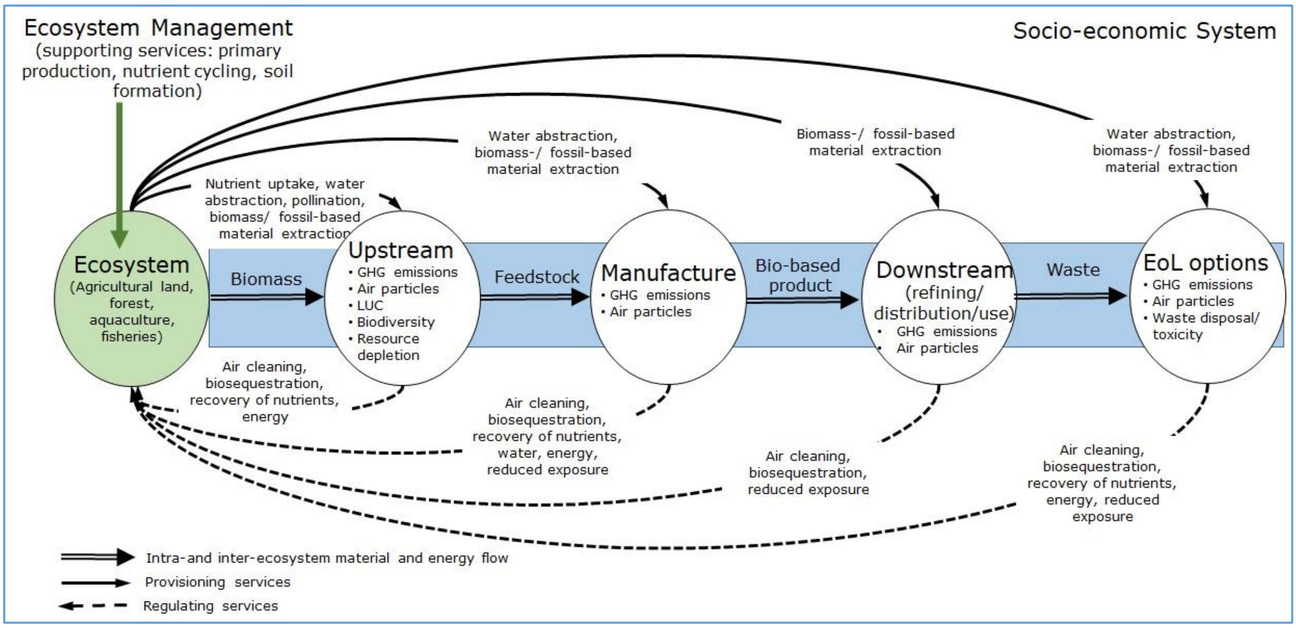


Figure 20 Life cycle provisioning and regulatory services of ecosystem along the value chain of bio-based products

Different stages in the value chain and cross-sectoral effects can generate numerous impacts on sustainability.

- Considering the value chain of a given feedstock, i.e. glucose, it can be derived from a variety of biomasses that can be burdened with different environmental footprints, competition for land and food, and influencing social well-being; material, water and energy required at any stage of life cycle are related to resource use efficiency; loading of nutrients to water bodies that can be attributed to acquisition/harvesting of biomass, manufacturing; in addition the end of life options can also differentiate sustainability measures.
- From the cross-sectoral point of view, the impacts interlink sectors of agriculture, industry (bio-sectors, chemical industry, energy sector), transport, trade, and waste management. Those interlinks can create both benefits and potential risks for the pillars of sustainability, particularly in relation to the SDGs and PBs. In general, biomass and bio-based products impact all the SDGs and PBs even if they are not directly addressed.

In the DPSIR sustainability assessment, the key factors of the flow of causes and effects along the life cycle of bio-based products are presented in Figure 21. Bio-based products rely on ecosystem capital, which is essential for the existence of human beings and economic development. At the same time, the services provided by natural systems are impacted by changes in supply and demand conditions. Disturbances in the ecosystem services effected by economic activities associated with bio-based products can violate sustainability principles in numerous and mutually interlinked ways.

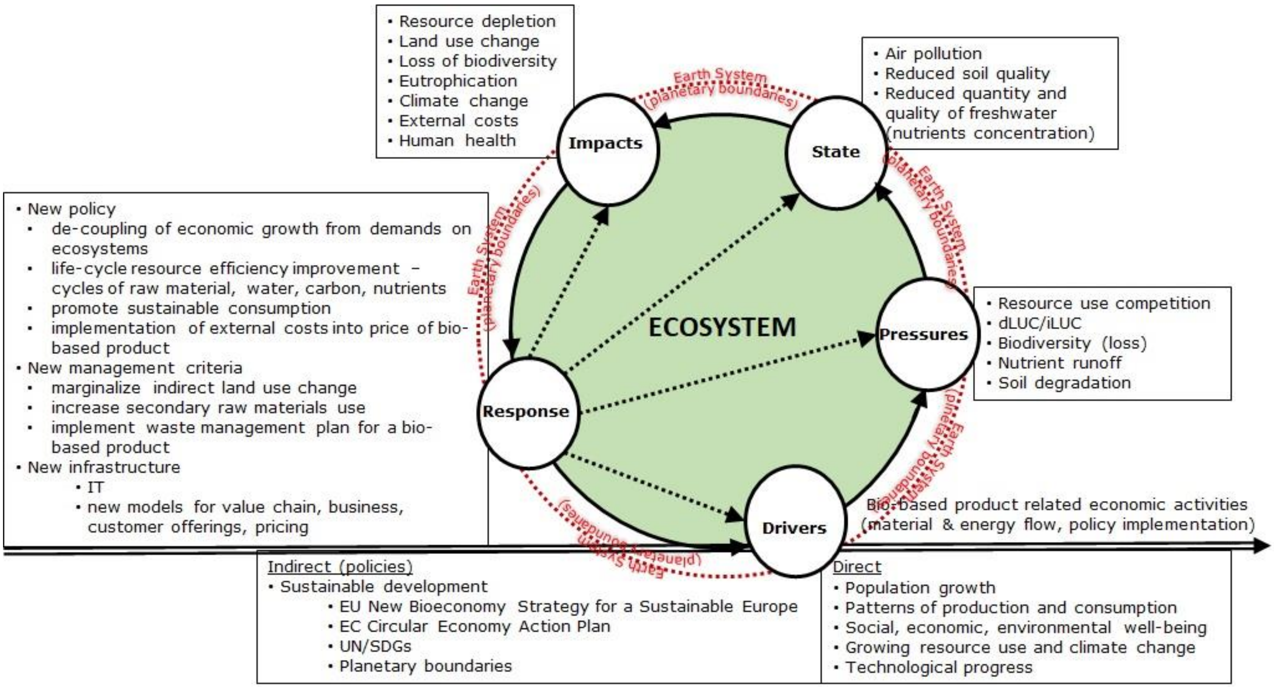


Figure 21 The key factors representing the flow of causes and effects in analysis of sustainability along the life cycle of bio-based products

Drivers and pressures

Driving forces effecting pressures on the environment may differ, depending on the scope of consideration (global, regional, local) and interactions. Driving forces behind the prevention of degradation of the Earth's system and ecosystems can be indirect, such as a policy vision through specific regulations, and direct drivers causing pressures to land and resource use and pollution emissions.

The indirect drivers address all components of the DPSIR model, and result from current normative frameworks of sustainable development related to bioeconomy, circular economy, sustainable development goals (SDGs), and planetary boundaries (PBs). The EU New Bioeconomy Strategy for a Sustainable Europe (EC 2018) underlines expected resultants of the bioeconomy's sustainable development: creation of new jobs, a carbon neutral future, modernization of the EU industrial base, circularity of material and energy flow, and healthy ecosystems including, land degradation neutrality. In connection with other EU policies, i.e., the renewed EU Industrial Policy Strategy (COM(2017)479), the EC Circular Economy Action Plan (COM(2019)190 final) and the Clean Energy for All Europeans Package (COM(2016)860), five objectives were determined: ensuring food and nutrition security, managing natural resources sustainably, reducing dependence on non-renewable unsustainable resources whether sourced domestically or from abroad, mitigating and adapting to climate change, strengthening European competitiveness and creating jobs.

Nowadays, it is generally recognized that a sustainable product is a product made in agreement with the globally shaped sustainable development principles known as the 17 Sustainable Development Goals (SDGs) proclaimed by the United Nations (UN 2015). For bio-based products, the key natural resource is land area under biomass production and land change associated with the driving forces having direct impact on biodiversity and water use, and directly or indirectly affecting GHG emissions. The SDG15 "*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*" is addressed to terrestrial ecosystems, including direct drivers associated with land use and biodiversity while water use is expressed in the SDG7 "*Ensure availability and sustainable management of water and sanitation for all*". Sustainable technology development is addressed in SDG9 "*Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation*". The sustainable technologies for bio-based products along a value chain and related sociotechnical systems (STS) are mostly in the emerging phase and present many weaknesses, including not only market imperfections associated with the burden of environmental externalities but also structural and transformational system failures. Besides there are various institutional constraints, the absence of diversity in the actor base, knowledge gaps and the lack of collaboration among actors (Söderholm et al. 2019). Sustainable production and consumption assuming circularity is pertinent to SDG 12 "*Ensure sustainable consumption and production patterns*". Certain generalization on the applicability of SDGs to bio-based products can be made on the basis of reports by Fritsche at al. (2017) and IRP (2019). Fritsche at al. (2017) have analyzed the interactions between energy, including renewable energy, and land in the context of SDGs by expressing a high relevance to SDG2 "*End hunger, achieve food security and improved nutrition and promote sustainable agriculture*", SDG7 "*Ensure access to affordable, reliable, sustainable and modern energy for all*", SDG11 "*Make cities and human settlements inclusive, safe, resilient and sustainable*", and SDG13 "*Take urgent action to combat climate change and its impacts*" while the other SDGs can be also relevant indirectly. In the Global Resources Outlook (IRP 2019) the direct linkage of resources is reported to 14 SDGs, i.e., environment 6, 13, 14, 15; social 1, 2, 3, 7, 11; and economy related 8,9,10,12 plus SDG17 *Partnerships for the goals* combining three pillars. The other SDGs "4 – *Quality education*", "5 - *Gender quality*" and "16 – *Peace, justice and strong institutions*" are linked indirectly.

Through changes in production and consumption of bio-based products, the mentioned drivers exert pressure on ecosystems and the Earth's system as a whole. Groffman et al. (2006) report three ways of ecological threshold/topping point analysis:

- "*shifts in ecosystem state*" where small pressures in an environmental driver can produce dramatic responses in the ecosystem, e.g., primary production, nutrient cycling;
- "*critical thresholds*" representing the amount of pollutants that an ecosystem can safely absorb before there is a change in the ecosystem. It is used in development of abatement strategies. It is a quantitative estimate of one or more pollutants such as air pollution, N, P, S deposition, below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge;
- "*extrinsic factor thresholds*" where changes in a variable on a large scale alter relationships between drivers and responses on a small scale. For example, the movement of streambed particles in riverine ecosystems can change species interactions and community structure.

Currently, the commonly accepted global thresholds for the most critical impacts on ecosystems are based on the second approach, in the form of the so-called planetary boundaries. PBs were devised by Rockström et al. (2009) and further developed by Steffen et al. (2015). The PBs represent a scientific concept of nine boundaries for systemic processes on the Earth, perceived as a preliminary condition in an assessment of sustainable growth. Safe boundaries, within which humanity can continue to develop, as well as critical thresholds for nine processes have been determined. The Earth's processes include climate change, ocean acidification, stratospheric ozone depletion, nitrogen and phosphorus biogeochemical flow, freshwater use, deforestation and other land-use changes, biosphere diversity, atmospheric aerosol loading and chemical pollution. An additional, tenth planetary boundary related to ecosystem productivity was suggested by Running (2012). The terrestrial net primary plant production (NPP) could indicate the health of ecosystems. Biomass-based production is a part of the Earth's natural cycles and the most critical ones in the context of sustainability assessment of bio-based products are the cycles of water, nitrogen, phosphorus and carbon. However, in the case of 100% bio-based products assuming no impact on land change, the use of renewable energy in manufacture and material circularity the carbon cycle will be close to balance, i.e. close to a net zero carbon footprint.

Important policy drivers on ecosystems and their services are the Mapping and Assessment of Ecosystems and their Services (MAES) designed under an initiative following the EU Biodiversity Strategy to 2020, which contain key actions in the mapping and assessing of ecosystems and their services by 2014, assessing the economic value, and promoting the integration of these values into accounting and reporting systems at the EU and national levels by 2020 (EC 2011, Egoh et al. 2012).

Globally, in the last 50 years, the population has doubled, the GDP has been grown fourfold and the significant increase in socio-economic well-being has been noted. Such trends were associated with a rapid extraction of natural resources and progressed degradation of ecosystems and ecosystem-related human conditions (PBs). This period involved increasing demand to build up new infrastructure, mainly in developing and emerging economies, and outsourcing of more materials and energy intensive production processes by higher income countries to lower income but transitioning countries (IRP 2019). Noticing these threats it was concurrently implemented policy on sustainability, including regulations associated with substitution of fossil fuels with their renewable analogues (RED: 2009/28/EC, REDII: ongoing), i.e. biomass-based bioenergy and biofuels and low carbon economy that has been currently expanded to a broader spectrum of bio-based products in the framework of circular bioeconomy. Thus, the pressure on natural non-renewable resources has been steadily extended to a higher demand on the use of biomass, water and land resources. As the result, the global gross biomass production estimated for the period from 1961 to 2009 grew at the rate of 2% while global trade of biomass grew at a rate of 4% (Haberl et al. 2012). The average person consumed 65 per cent more natural resources in 2017 compared to 50 years ago, despite an increase in per capita GDP of only 50% (IRP 2019).

At the same time the global water use was growing and the process causes numerous impacts such as that 30% of global river basin area has been under severe and mid water stress since 2010 (IRP 2019)[31]. The important pressure on biomass use will be conditioned by the competition between different bio-based sectors while water use related pressures will be affected by competition between consumers and use and deterioration of quality due to pollution from agricultural, manufacture, and municipal activities.

Another resource under pressure interlinked with the population growth and patterns of production and consumption will be the land area dedicated to biomass production. The direct or indirect land use change to other agricultural crops or other functions (e.g. infrastructure, roads, forest and green areas, water) will differentiate the volume of available feedstocks for different bio-based sectors and increase competition for land. Indirectly, the land use change will impact biodiversity, emissions, deforestation, nutrient runoffs and soil fertility. The land-use-related impacts from biomass production are dependent on the type of biomass and agro-technology applied. Intensive production involves higher inputs of industrial products, such as fuels, synthetic fertilizers and pesticides, and relatively higher environmental impacts (emissions, eutrophication, etc.). However, only inappropriate acquisition of primary biomass has a potential of severe impact to ecosystems, while the secondary and tertiary biomass as feedstock or nutrient recovery contributes positively to the overall sustainability assessment of bio-based products. Legally all normative activities related to the improvement of efficiency of biomass use in accordance with the Good Agricultural and Handling Practices (FAO 2016, Urbanowitz and Bishop 2015), dedicated mostly to food sectors, will contribute to decoupling natural resource use and negative environmental impacts from economic growth[32]. The major criteria related to production are associated with the land history and environmental management, application of GMO, soil additives, fertilizers and other agro-chemicals, requirement for water irrigation/fertigation, harvesting and storage infrastructure as well as pre-treatment infrastructure if the process is provided on site. The major criteria related to environmental management are associated with the maintenance of soil quality (agro-chemicals), water and energy use efficiency, waste management and biodiversity. The major socio-economic criteria are associated with awareness of producers (training), worker health, safety and welfare and the guarantee of product quality.

The pressures on ecosystems resulting from the resource acquisition, upstream, manufacture, consumption, and EoL activities are associated with resource use, including direct use of fuels for transportation and storage, energy and water for processing, and land for infrastructure, as well as indirect footprints embedded in the processing utilities and equipment. The environmental impact can be mitigated by closing the loop of material, energy and water flow inside the value chain (cascading, circularity) and minimizing of waste disposal.

[31] Water stress is the ratio withdrawals-to-availability; high water stress is when more that 40% of the water input of a river basin is used.

[32] Relative decoupling – when resource use and associated pressure on the environment or human well-being grows at a slower rate than the activity causing it or absolute decoupling – when resource use and associated pressure on the environment or human well-being declines while the economic activity continues to grow.

State and Impacts

The state of ecosystems is related to the resource depletion, chemical compounds in air (concentration of pollutants) and water (nutrients, hazardous substances, pesticides, etc.), soil detrimental processes (erosion, compaction, desertification, salinization, etc.), and changes in biological composition of different habitats. Eventually, due to progressive degradation of ecosystems, changes in land use and biodiversity loss as well as the triggered competition for resources will impact the change of ecosystem services and restricting the economic growth and social benefits.

Unsustainable practices along the value chain of bio-based products will continue depletion of biotic and abiotic natural resources, increase air emissions and pollution, and impact the availability/productivity and quality of water and soils. The agriculture and bio-based processing related loads of nitrogen, phosphorus and dissolved organic carbon to waters and soils as well as heavy metals from phosphorus fertilizers impact the human life conditions (eutrophication) and health (toxicity), and biodiversity loss[33]. Particular impacts can vary between bio-based products but the important impacts along value chain are quite common. The importance of the impacts corresponds the development of legislation to intervene in protecting the state of the environment, thus leading to the responses.

Resource depletion refers to both renewable (biomass) and non-renewable (fossils, minerals) materials and associated freshwater abstraction, eutrophication of terrestrial and aquatic systems, land use change and related loss of biodiversity. Most of the mentioned impacts contribute to climate change.

Climate change and global warming are resultants of long-term internal and anthropogenic forcing processes. The main anthropogenic factor is the increase in CO_2 and particulate matter level. The bio-based products relate main contribution factors to the phenomena, and at the same time the potential factors for mitigation of the impact can be associated with the use of energy to produce/extract resources and power production processes, land use and deforestation. The main concern of the current policy on sustainability is to increase capturing carbon by ecosystems and in parallel to reduce GHG emissions from bio-based related economic activities. Ecosystem-based adaptation approaches to some extent can buffer the impact of climate change and tackle the threats that climate change poses to peoples' lives and livelihoods (Jones et al. 2012). The benefits of protecting ecosystems often far outweigh the costs while, market systems seldom convey the full social and economic values of ecosystem services. In this sense the findings by Balmford et al. (2002) are still valid "*… retaining ecosystems through a judicious combination of sustainable use, conservation and where necessary, compensation for resulting opportunity costs makes overwhelming economic as well as moral sense*".

[33] Globally, (1) biomass extraction and processing account for more than 30 per cent of greenhouse gas emissions related to resources, not including emissions from land use change; (2) cultivation and processing of biomass are responsible for almost 90 per cent of global water stress impacts; (3) the impact of total land use is highly correlated with agricultural activities and biomass processing; annual cropping system has a higher impact to biodiversity loss than permanent cropping (IRP 2019).

In sustainability assessment, it is important to gather complete information on the impact of bio-based products on the environment. There is no universal approach to sustainability assessment. In general, an environmental assessment is based on the Life Cycle Assessment (LCA), the economic one on the Life Cycle Costing (LCC) and the social one on the social-Life Cycle Assessment (s-LCA). External costs can be generated by every stage of a value chain, and are not included in the price of the product (Olba-Zięty et al 2019). These costs are ultimately paid by society as a result of the loss of production or environmental values of a given ecosystem, as a result of harmful effects on human health, as a result of the reduction of biodiversity, and many others. Rational approach to estimation of external costs associated with bio-based products seems to be crucial to demonstrate win-win situations of sustainable bio-based markets.

Responses

In this report, the response by society (interventions, regulations, implementation) to bio-based economic activities and to the environment is considered in the context of the policy and the legal obligations directed to decreasing the negative pressures, mitigating the state, and to adopting to or reducing the impacts on the state of the environment. They entail enabling policies, counterbalancing, interventions and monitoring.

Plants from land based-biomass provision are the primary service of an ecosystem to bio-based products. Thus, the pressures on the ecosystem, the state and impacts associated with biomass acquisition compose the first set of environmental legislation on sustainability related to agricultural/forestry good practices, water and energy use, soils and habitats. The other stages of the value chain undergo the same regulations depending on the natural resource use as processing materials, water and energy and related effects.

In order to sustain and improve the stocks of land-based natural capital and associated ecosystem services, the main principle involves both the maintenance and improvement of productivity while increasing resilience of land systems and societies dependent on them, with a special emphasis on protection of land tenure rights of vulnerable and marginalized people (Covie et al. 2018). The other two main principles are associated with resource use composing the fundation to the assessment of sustainability of bio-based products, i.e., sustainable consumption and production (SPC[34]) that addresses the full life-cycles of economic activities, and an integral part of it – the life-cycle approaches to resource efficiency, energy, chemicals, and waste management (UNEP 2010, UNEP 2018).

The EU environmental legislation presented in Table 33 creates overarching sustainability related obligations imposed on MS governments, public authorities as well as businesses and individuals. There are also other EU environmental legislations specific to sectors directly or indirectly involved in bio-based production, such as agriculture, forestry, industry, energy and transport.

[34] SCP is defined as *"the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of further generations".* Symposium: Sustainable Consumption. Oslo, Norway; 19-20 January 1994.

Table 33 The EU main environmental directives and regulations relevant to bio-based products.

Sustainability component	Directive/Regulation	Framework for
General (all stages)	2011/92/EU • on the assessment of the effects of certain public and private projects on the environment	• Protection of ecosystems services including water and air through environmental impact assessment before implementing certain projects
Water (all stages)	2000/60/EC Water Framework Directive • on establishing a framework for community action in the field of water policy	• Limiting pollution of water bodies (nutrients, pesticides, agrochemicals) • Regulating water abstraction • Protecting drinking water abstraction from pollution
	2006/118/EC • on the protection of groundwater against pollution and deterioration	• Protecting groundwater
	91/676/EEC • on the protection of waters against pollution caused by nitrates from agricultural sources	• Storage and land spreading of fertilizers
Air (all stages)	2016/2284 • on the reduction of national emissions of certain atmospheric pollutants	• Reduction of emissions
	2010/75/EU • on industrial emissions (integrated pollution prevention and control)	• To prevent, reduce and as far as possible eliminate pollution arising from industrial activities in compliance with the 'polluter pays' principle and the principle of pollution prevention
Ecosystem (land related resource use)	2009/28/EC Renewable Energy Directive • on indirect land use changes (ILUC)	In relation to land use change: • To promote transition from conventional to advanced biofuels • To minimize GHG emissions caused by ILUC
	92/43/EEC • on the conservation of natural habitats and of wild fauna and flora	• Site protection and management
	Regulation (EU) No 1143/2014 • on the prevention and management of the introduction and spread of invasive alien species	• Minimize the threat to biodiversity
	Council Regulation (EC) 73/2009 "Cross-compliance".	• Protection of soil, water and air in farm management
Waste and chemicals (all stages)	Regulation No 1907/2006 • on the Registration, Evaluation, Authorization	• To ensure a high level of protection of human health and the environment from the risks

	and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending certain Directives	that can be posed by chemicals
	2008/98/EC Waste Framework Directive • on waste and repealing certain Directives	• Waste management
Energy (all stages)	2009/28/EC Renewable Energy Directive • on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC	• Energy efficient technologies • To reduce greenhouse gas emissions
	2009/30/EC Fuels Quality Directive • on amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC	• Biomethane as transport fuel • To reduce GHG emissions related to consumption of fuels • Sustainability criteria for biofuels
Eco-design	2009/125/EC Eco-design Directive • on establishing a framework for the setting of eco-design requirements for energy-related products	• To improve the environmental performance of energy related products (ERPs) through eco-design.

Regarding the PBs, SDGs, the EU environmental legislation and the ecosystem-based DPSIR analysis, the principles and criteria for development of horizontal sustainability of bio-based products have been grouped into five categories (Gołaszewski et al. 2019, Ladu et al. 2019). The first three, i.e., sustainable material, manufacturing and consumption, provide circularity and are framed in the SDG12 *Sustainable consumption and production* (SCP)[35] (UNEP 2018). The other two, i.e. sustainable ecosystems and communities, are addressed directly in SDG15 *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss* and SDG11 *Sustainable cities and communities*.

1. Sustainable consumption and production (SCP)

    1.1. Sustainable Material (bioresources) (natural, renewable, carbon neutral) – to substitute synthetic materials in products

    - Material efficiency (material intensity/productivity and associated GHG emissions intensity/productivity).
    - Legality, land rights.
    - Traceability.

    1.2. Sustainable Manufacturing (cascading, (re)circularity, resilient production systems) – to produce in harmony with nature, to reduce resource use and environmental footprint

    - Use of environmentally friendly technologies.
    - Resource efficiency (efficient use of material, water, energy, secondary resource use as well as labour capital and infrastructure - a balance between functionality, recirculation and product lifespan is required by eco-design).
    - Operational efficiency (reducing costs and waste).
    - Water rights.
    - Renewability.
    - Responsibility along the whole value chain through close collaboration with stakeholders .

    1.3. Sustainable Consumption – to promote consumption that contributes to reduction of the personal carbon footprint

- A shift of behavior to bio-based products and reduction of waste by improving availability, accessibility and quality of consumer information, enhancing communication to drive behavioral changes

2. Sustainable Ecosystems (management activities) – to slow down or to reverse ecosystem degradation associated with resource extraction, manufacturing and consumption

    - Land neutrality (avoid, reduce, reverse land degradation)[36]

[35] UNEP 2018. "*Sustainable consumption and production address the full life-cycles of economic activities: the extraction of resources, their processing into materials and products, and the subsequent use and discarding of those products. It can also be broken down into specific economic activities to do more and better with less and identify priorities according to their environmental impacts and resource demands.*"
[36] Can be monitored with indicators such as land cover (LC), land productivity (NPP) and carbon stocks (SOC).

- Biodiversity
- Water cycle
- Carbon cycle
- Nutrients cycles

3. Sustainable Communities – to promote sustainable development of local societies through sustainable lifestyle that contributes to improvement of local life and job conditions and to the reduction of local (directly) and global (indirectly) carbon footprint.

    - Attempts to reduce the use of natural resources by individuals or general society.
    - Providing access to bio-based products, green jobs and healthy workplace and livelihood.

The full life cycles of economic activities in accordance with SDGs is addressed to in the concept note of the UN (UNEA 2018) on *innovative solutions for environmental challenges and sustainable consumption and production*. It sets out focus areas for consideration by member states based on criteria of global relevance: (i) environmental challenges related to poverty and natural resources, (ii) life cycle approaches to resource efficiency, energy, chemicals and waste management, and (iii) innovative sustainable business development at a time of rapid technological change.

Many of the above mentioned criteria are normalized or are in the course of normalization by the EN, ISO, ASTM or national standardisation bodies (Table 34). Concurrently, there is only a single horizontal standard EN 16751:2016 dedicated to sustainability of bio-based products and a single horizontal standard ISO 13065:2015 dedicated to sustainability of bioenergy. Those standards present generalized approach to assessment of sustainability of bio-based products and bioenergy without defined thresholds, thus they are only indicative in the context of making claims on the sustainability of bio-based products or single operations across value chains. The standards are complemented with the context-specific regulations i.e., relevant standards and technical specifications, which are suitable for making claims on sustainability via certification and labelling. The relevant regulations are addressing mainly sustainability of material use in association with production media (energy, water), requirements and guidelines for LCA, EoL options, sustainability communications of B2B and B2C.

Table 34 The horizontal standards addressing sustainability of bio-based products and relevant context-specific regulations.

Aspect of standard (addressed to)	Standard	Scope	Criteria
Bio-based products	EN 16751:2016 "Bio-based products. Sustainability criteria" by CEN/TC411 "Bio-based products"	• To set horizontal sustainability criteria applicable to only the bio-based part of all bio-based products, excluding food, feed and energy.	Environmental • Climate protection and air quality • Water • Soil • Biodiversity • Energy and material resources • Waste

		• To provide sustainability information about the biomass production only or in the supply chain for the bio-based part of the bio-based product.	Social • Land use rights and LUC • Water use rights • Local development Economic • Economic sustainability
Bioenergy	ISO 13065:2015 "Sustainability criteria for bioenergy"	• To provide a framework for considering environmental, social and economic aspects that can be used to facilitate the evaluation and comparability of bioenergy production and products, supply chains and applications	Environmental • GHG • Water • Soil • Air • Biodiversity • Energy efficiency • Waste Social • Human rights • Labour rights • Land use rights and LUC • Water use rights Economic • Economic sustainability
Standards/Technical reports relevant to the above horizontal standards on sustainability of bio-based products			
Terminology	EN 16575:2014 Bio-based products – Vocabulary		
Raw material (bio-based content)	EN 16640:2017 Bio-based products – bio-based carbon content – Determination of the bio-based carbon content using the radiocarbon method		
	EN 16785:2017-1 Bio-based products – bio-based content. Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis		
	EN 16785:2017-2 (part2) Bio-based products – bio-based content. Part 2: Determination of the bio-based content using the material balance method		
Raw material (sustainably produced biomass)	NEN/NTA 8080-1:2015 Sustainably produced biomass for bioenergy and bio-based products. Part 1: Sustainability requirements		
	NEN/NTA 8080-2:2015 Sustainably produced biomass for bioenergy and bio-based products. Part 2: Chain-of-custody requirements		
LCA	ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework		
	ISO 14040: 2005 Environmental management – Life cycle assessment – Requirements and guidelines		
	EN 16760:2015 Bio-based products – Life Cycle Assessment		
LCI for EoL	CEN/TR 16957:2016 Bio-based-products – Guidelines for Life Cycle Inventory for the End-of-life phase		
EoL: composting, biodegradation (packaging)	EN 13432:2000 Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance packaging		
EoL: organic	ISO 18606:2013 Packaging and the environment - Organic recycling		

recycling (packaging)	
EoL: compostability (all plastics)	EN 14995:2006 Plastics - Evaluation of compostability - Test scheme and specifications
	ISO 17088: 2008 Specification for compostable plastics (procedures and requirements for the identification and labelling of plastics, and products made from plastics, that are suitable for recovery through aerobic composting)
EoL: home compostability (plastics)	AS 5810:2010 (Austria) Biodegradable plastics – biodegradable plastics suitable for home composting
	NF T 51-800: 2015 (France) Plastics — Specifications for plastics suitable for home composting
EoL: biodegradability in soil (mulch film)	EN 17033:2018 Plastics - Biodegradable mulch films for use in agriculture and horticulture - Requirements and test methods
Consumer satisfaction	ISO 9001:2015 Quality management systems — Requirements
Sustainability communication/ quantification	ISO 14063: 2006 Environmental management – Environmental communication – Guidelines and examples (confirmed in 2010)
	ISO 14067:2018 Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification
	ISO 14020: 2000 Environmental labels and declaration (including: ISO 14021 on self-declared environmental claims, ISO 14024 on environmental labelling, and ISO 14025 on environmental declaration)
	EN 16848:2016 Bio-based products – Requirements for Business to Business communication of characteristics using data sheet
	EN 16935:2017 Bio-based products – Requirements for Business to Consumer communication and Claim

The processing stages of bio-based products are indirectly related to material and media use and EoL options. Excluding directives and best practices, there is no specific standard addressing sustainable manufacturing. In this context, the current standards focus on ecosystem-based natural resource use and efficiency and waste management, although any processing stage involves the use of other resources, including labour as well as technical and information resources. This means that sustainable manufacturing must respond at first to the economic challenge followed by environmental and social challenges by producing wealth, ensuring development and competiveness, by minimal use of natural resources and management to reduce environmental impacts, and by improvement of quality of life and jobs. Such an approach requires integration techno-economic assessment with environmental, economic and social impacts (Gołaszewski et al. 2019a). Jayal et al. (2010) present the time-related evolution of different manufacturing concepts, beginning from traditional (substitution based), lean (waste reduction based), green (3R: reduce, reuse, recycle) and sustainable (6R: reduce, reuse, recycle, recover, redesign, remanufacture), and their contributions to stakeholder value, and the closed-loop system involving 6R.

The model 6R interlinks the sustainable manufacturing with sustainable consumption (SPC of SDG12) through product lifecycle management (PLM), beginning from sustainable material use (efficiency, renewability, cascading) to EoL options (circularity) or final waste disposal if it occurs. From the consumer’s point of view, clear and reliable information on sustainability is required to make sustainable purchasing choices (EC 2014).

An array of the above activities shapes ecosystems through positive or negative impacts on functions of ecosystem services and finally on general society. In regulations on sustainability of bio-based products and bioenergy (ISO 13065:2015) the ecosystem is used in the context of ecosystem services, biological diversity "*variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems…*", and protected area "*long-term conservation of nature and ecosystem services* …", while a the single indicator is addressing biodiversity in standard ISO 13065 and two indicators are dedicated to availability of water and biodiversity in standard EN 16751:2016.

With economic activities, a sustainable ecosystem able to thrive and support itself without outside influence or assistance does not exist. The key characteristics of terrestrial ecosystem sustainability are associated with biological diversity, availability of land area and available unpolluted water source. Therefore, any ecosystem-related managerial activity should contribute to the ecosystem's equilibrium through regulations associated with material, manufacturing, and consumption to balance information on land use, biodiversity, the cycling of material, water, carbon and nutrients.

The overarching component in sustainability assessment of bio-based products is associated with the general society. The process begins with the impact of bio-based production on local communities (e.g. production/extraction of raw material, location of processing plant) followed by regional and global dimensions. The concept of a sustainable society is not new. In 1993, Viederman suggested the following definition "*A sustainable society is one that ensures the health and vitality of human life and culture and of nature's capital, for present and future generations. Such a society acts to stop the activities that serve to destroy human life and culture and nature's capital, and to encourage those activities that serve to conserve what exists, restore what has been damaged, and prevent future harm*". The assessment related to sustainable communities involves criteria of improvement of local conditions for healthy life, providing opportunity for jobs in bio-based sectors, and assuring the healthy workplace. All these improvements should be accompanied with the reduction of carbon footprint on the local, regional and global levels.

A scheme compiling sustainability assessment categories and environmental services is presented in Figure 22. Sustainable bio-based products involve maintaining cultural services of an ecosystem. The provisioning services are associated with the material, water or energy outputs from ecosystems at any stage of a value chain and waste management. At the same time the natural regulatory and supporting services of ecosystems tend to balance the outputs. Due to imbalance in those services, the regulatory services tend to minimize the impact of bio-based products on ecosystems caused by SCP and communities.

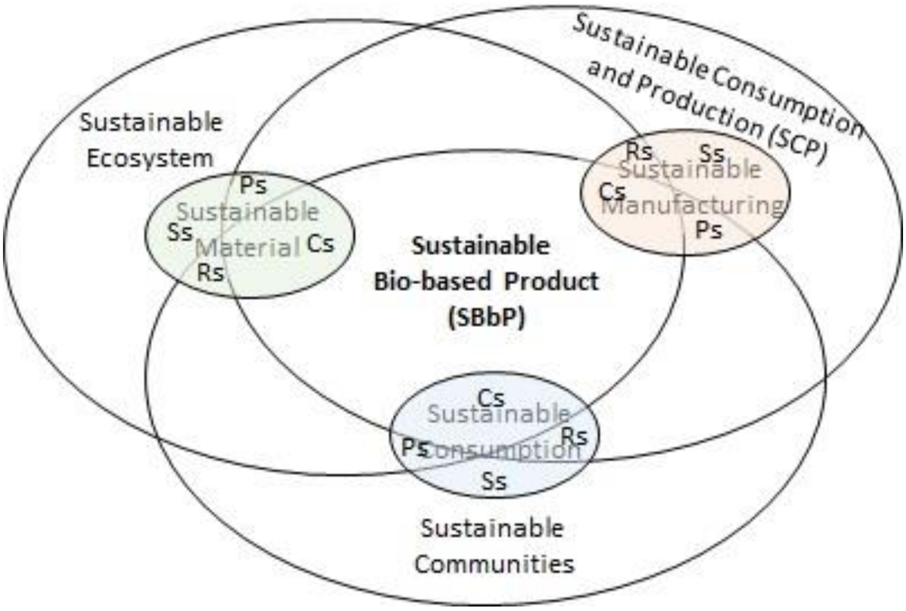


Figure 22. Compilation of the sustainability assessment categories and ecosystem services in the process of sustainability assessment of bio-based products (Ps, Rs, Ss, Cs – provisioning, regulating, supporting, and cultural services of ecosystems, respectively)

In general, the scheme presented in Figure 6 corresponds directly to the concept of sustainability as an intersection of the three pillars: economic, social and environmental. The only difference is that the all three pillars in the context of recommendations for regulations on bio-based products assume sustainability. Therefore, the three main categories represent 1) sustainable SCP related to life-cycle economic activity along value chain, 2) sustainable ecosystem to maintain the balance of environmentally related components impacted by economic activity, and 3) sustainable communities to assess societal well-being. Besides, the SCP is composed of three components, i.e. 1.1) sustainable material adhering fully to sustainable ecosystem and partly to other categories, 1.2) sustainable manufacturing adhering fully to the SCP and partly to other categories, and 1.3) sustainable consumption adhering fully to sustainable communities and partly to other categories. Currently, normative documents (policy, reports, standards) on material, manufacturing and consumption are developed separately. This concept is an attempt to integrate all above components under one category of sustainability – the SCP. Consequently, the SCP category is interrelated with ecosystem services and communities.

The essential DPSIR processes for the above categories of sustainability of bio-based products are set in Table 4.

An indirect driver of the SCP is the current policy on sustainability (circular economy, bioeconomy, SDGs, PBs). The volume of biomass-based raw material acquired from the ecosystem is driven by the availability of land and potential land use changes to satisfy the demand. Manufacturing is propelled by the supply of locally available resources and the availability/advancement of technology that will allow to gain an advantage in a given bio-based market. Consumption of bio-based products begins with a distribution network and finish in waste management. Regarding the ecosystem, the drivers will be associated with the growing demand for land and resources and the impact of climate change on resource availability. The communities will be driven by the increased demand for sustainable bio-based products and maintaining well-being in the environmental, economic and social sense.

The pressures on material use can involve a growing demand for biomass and higher prices, changes in the share of a given crop in crop rotation, and related decrease in land availability. Manufacturing of bio-based products will cause increased emissions and the use of production media such as water and energy as well as the pressure for secondary material use. The consumption-related pressure will be on the infrastructure of distribution and waste collection systems as well as emissions from EoL treatments. Those pressures will impact the ecosystem by nutrient uptake, withdrawal of water and changes in biodiversity and communities by changing the pattern of production and consumption, local businesses and employment.

The material related state is associated with the accumulation of chemical compounds in soils and waters. Activities associated with manufacture and consumption can negatively impact air and water quality by particulate matter, GHG and SO_2 emissions. Positive or negative conditions can be generated by EoL options. As the impacts affect the ecosystem, they result in air pollution, depletion of freshwater and decreasing fertility of soils. From the community’s point of view, they impact working and living conditions.

The ecosystem-related impacts due to the SCP involve climate change, depletion of biotic and abiotic resources, eutrophication, land use change effects and loss of biodiversity. Asa result, the processes impact the quality of life and human health.

The key response actions are related to policy regulations on sustainable development, including (1) SCP-related decoupling of economic growth from resources use, (2) ecosystem related decoupling of economic growth from environmental pressures and impacts, and (3) communities-related decoupling of resource use from well-being. Other important responses are associated with sustainable material, manufacturing and consumption by consecutive development of regulations on sustainable practices in agriculture (GAP[37]) and forestry (PEFC[38], FSC[39]), eco-design[40] of new products and waste management (WFD[41]). The land-related responses tend to be focused on the use of suitable land and adequate plants and techniques to mitigate or restore the state of environment. In order to reduce environmental impacts by manufacturing of bio-based products, the eco-design as a response action implements requirements on improvement of resource efficiency throughout the life cycle including local sourcing of material, cascading, and secondary material use. Regarding consumption, progress in sustainability requires development of models and processes for extended product lifetime, reusability, recyclability and recoverability supported by building public awareness and promoting sustainable consumption.

In the context of new regulations, the overall approach to value chains of bio-based products requires regulations to contain considerations related to levelized life-cycle costs, internalisation of external costs, traceability of sustainability and certificates and policy-related leakage effects. Besides, development of new management criteria for building new market and marketing models and development of horizontal legislation to cover the minimum requirement on sustainability are needed. The associated policy on funding programs for development of new technologies should be strictly focused on pro-environmental solutions. Alternative approach to the above responses shared in the society is to do nothing, and this includes including like the lack of sustainable policy goals, lack of political will and institutional capacity, and lack of enforcement of current regulations on sustainability.

A summary of generalized DPSIR processes in the sustainability assessment of bio-based products is presented in Table 35.

[37] Good Agricultural Practices
[38] Programme for the Endorsement of Forest Certification
[39] Forest Stewardship Council
[40] Eco-design – to comply with minimum requirements related to improve resource efficiency throughout the product's lifecycle.
[41] Waste Framework Directive

Table 35 The generic set of DPSIR processes in assessment of sustainability of bio-based products.

Bio-based products	SCP Sustainable Consumption and Production			Ecosystem	Communities
	Material	**Manufacture**	**Consumption**		
	Resource extraction, raw material acquisition (biomass)	Upstream (feedstock) Production Downstream (refining)	• Bio-based product distribution and use • EoL activities	• Provisioning services • Regulating services • Supporting services • Cultural services	• Well-being
Drivers	SCP • Policy on sustainability (circular economy, bioeconomy, SDGs, PBs)			• Impact of climate change • Demand for land • Growing resource use	• Environmental, economic and social well-being • Societal demand for bio-based products
	• Land availability • Land use change • Soil quality	• Location of processing plant vs. local biomass availability • Technological progress	• Development of distribution network (transport, storage) • Development of waste treatment technologies		
Pressures	SCP • Resource use competition			• Nutrient uptake • Water abstraction • Changes in biodiversity	• Patterns of production and consumption • Local businesses and employment
	• Demand for biomass • Price of raw material • Share of a given crop in crop rotation • Decreased land availability	• Emissions from production • High water, energy use • Secondary material use	• Distribution infrastructure • Waste collection infrastructure • Emissions from waste treatment		
State	• High level of chemicals, water, energy inputs • GHG emissions and nutrient loadings	• Water quality • Air quality • Particulate matter • GHG emissions • SO_2 emission	• EoL treatments (e.g. 6R)	• Air pollution • Reduced quantity and quality of freshwater • Degradation of soils	• Living conditions • Working conditions

Impacts	• Land use change • Diversity of farmland habitats	• Efficiency of manufacturing • Cascading	• Circularity • Health toxicity	• Climate change • Resource depletion • Eutrophication • dLUC/iLUC effects • Biological structure of habitats and loss of biodiversity • Ecotoxicity • Value of ecosystem services	• Quality of life • Human health
Responses	SCP: • Policy on resource decoupling (economic growth vs. resource use) • Social responsibility			• Policy on impact decoupling (economic growth vs. environmental pressures and impacts) • Life cycle resource use to restitute of ecosystems – cycling carbon, water and nutrients	• Policy on well-being decoupling (resource use vs. well-being) • Protection and enhancement of local ecosystems • Public procurement of sustainable bio-based products (conservation of resources, minimize of emissions)

	• GAP (agriculture), PEFC, FSC (forestry)
	  • Use of suitable land
	  • Use of adequate techniques
	  • Grown plants with soil and water remediation potential (e.g. uptake of heavy metals by willow)
		• BAT (Best Available Technologies), eco-design
		  • Materials and energy from local resources
		  • Life cycle resource efficiency improvement
		  • Increasing secondary material use
		  • Recommendations for EoL options
			• WFD (Waste Framework Directive)
			• Consumer models and processes for EoL options (durability, reusability, recyclability, recoverability)
			• Building public awareness
			• Promote sustainable consumption		

	Overall responses in relation to policy and legislation on sustainability of bio-based products: • Building consensus for minimum criteria horizontal legislation • Policy-related leakage effects • Implementation of new models for value chain, business, customer offerings, consumer EoL approach, pricing • Levelized life-cycle costs • Internalization of external costs • Traceability of sustainability and certificates • R&D – new technologies				

3.9.2. DPSIR-related summary and recommendations

Sustainable consumption and production (SCP) cover the whole value chain, beginning from resource acquisition, its conversion to materials and products, and consumption. The key policy related to SCP is to decouple economic growth from resource use. Another approach deals with social responsibility, and relates SCP with ecosystems and communities by imposing ethical obligation on any engaged stakeholders who impact ecosystems to act for the benefit of the general society.

Materials are used to manufacture bio-based products or deliver services. Sustainable Materials present positive impact on ecosystems and communities. Such materials have low environmental impacts throughout the life cycle and do not harm the health of workers and people. They are renewable and consume a low amount of other ecosystem renewable resources such as carbon, water and nutrients. Depending on the product's functionality, materials can be manufactured into frail or durable products. The materials embodied in bio-based products have ant ability to be extracted at the EoL for reuse, secondary use, or decomposition to simpler compounds and further treatment, while the ultimate EoL option is energy recovery.

In the context of regulations, sustainable material should comply with to the precautionary principle that it is safe to be processed and final products will be safe when released to the public use by not impacting quality of life (health, air and water quality, standard of living, communities, human rights, legal rights, privacy, etc.), or to the environment by not causing detrimental effects in ecosystems (air pollution, water pollution, soil pollution, global warming, resource depletion, land degradation and biodiversity loss, etc.).

Manufacturing is the biological or chemical processing or formulation of products. Sustainable manufacturing is the production of products using non-polluting, energy and natural resources conserving, and economically sound and safe processes (Sengupta et al. 2018). Rosen and Kishawy (2012) pointed to the importance of integrating sustainability with manufacturing and design, along with other objectives such as function, competitiveness, profitability and productivity. The authors provide the key external and internal components of sustainable manufacturing, including sustainability indicators, policies and procedures; company procedures, culture and conditions for sustainability; sustainable design; supplier attitudes and support for sustainability; customer attitudes and support for sustainability; environmental controls, monitoring, remediation; community engagement for sustainability.

Taking into account these contributions, the regulations should relate sustainable manufacturing indicators with sustainable design and engaged actors, i.e. suppliers, consumers, and communities through eco-efficient practices that minimize generation of waste and adopt pro-environmental technologies. Consequently, current and ongoing standardisation processes and related policies like GAP, RED, WFD and the eco-design of bio-based products have to be harmonized with resource efficiency policy.

The efficient resource use and mitigation of detrimental impacts on ecosystems can be affected and handled by the pattern of consumption. In assumptions, the sustainable consumption of bio-based products shall contribute to minimization of environmental impacts so that the natural capital and ecosystem's services can satisfy human needs of the present and next generations. This can be achieved by practices that contribute to saving resources where waste disposal and environmental pollution are minimized.

The regulations related to sustainable consumption of bio-based products should contribute to building public awareness and promoting sustainable consumption, including the active involvement in EoL activities, to prolong bio-based product durability and facilitate reusability, recyclability and recoverability.

The main policy related to sustainable ecosystems is on decoupling economic growth from environmental pressures and impacts. Economic activities influence many of the Earth's physical and biological processes organized into ecosystems. Therefore, it is important to control the impacts so that ecosystems can operate in a sustainable way, without severe loss or change of function (Goymer 2014). Nutrient cycling is essential for continuous supporting of ecosystems as well as to prevent the toxic accumulation.

The activities related to managing and sustaining ecosystems should focus on maintaining the natural capital and ecosystem's services related to the quality of air (emissions), water (eutrophication) and soil (nutrient depletion) by balancing the nutrients absorbed by plants and returning them back to the environment at the end-of-life. These activities involve cycling of water and nutrients: carbon, nitrogen, phosphorus and sulphur in ecosystems. The cycles of these nutrients interact in numerous ways, i.e. the cycle of one nutrient is controlling the influence of the other nutrients. In biomass production, nitrogen, phosphorus and sulphur are limiting factors of plant growth, and their uptake is correlated with carbon sequestration. At the EoL stage, when bio-based products undergo natural decay of organic part, carbon is released and sulphur dioxide and nitrogen oxide are emitted. The process can cause disturbances in other cycles. For example, in some areas it can induce acid rains and affect the provisioning services in both terrestrial and aquatic ecosystems (Freney and Galbally 1982). Rational management of ecosystems is not to turn nutrients into pollutants. Thus, regulations on resource productivity and EoL processes associated with decomposition (chemical or physical processes) and biodegradation (breakdown of materials by microorganisms) of bio-based products are crucial in the context of resource efficiency, releasing available nutrients, and to close nutrient cycles in the ecosystems.

The main policy on sustainable communities is associated with activities that support decoupling of resource use from well-being. It means that all the natural, human and financial capital of the communities is adequate to available resources. Sustainable communities have healthy and safe living and working places including access to nutritious, uncontaminated food, clean air and water.

The bio-based products related regulations on sustainable communities should the support acceptance of a lifestyle oriented towards protection and enhancement of local and regional ecosystems and biological diversity, conservation of water, land, energy, and non-renewable resources, including maximum feasible reduction, recovery, and reuse and recycling of waste, utilization of prevention strategies and appropriate technology to minimize pollution emissions, and use of renewable resources no faster than their rate of renewal (ISC 2019).

The gaps in the current legislations on sustainability of bio-based products identified in the framework of the STAR-ProBio project and described in §3.1 can be extended by other issues indicated by the DPSIR analysis that lack a current policy on sustainability of bio-based products.

1. Current and ongoing standardization and related policies like GAP, RED, WFD and the eco-design of products have to be harmonized with a resource efficiency policy.
2. Implementation of new models for value chains, businesses, customer offerings, consumer EoL approach and pricing, e.g.:
    a. development of new business models that assume selling services instead of products (impact on environment, local economy and communities)
    b. shifting tax burden from labour to resource use and eco-system services
    c. integration of the environmental accounts into certification scheme
3. Levelized life-cycle costs that enable comparison between bio-based products made from different feedstock.
4. Internalization of externalities that can be negative, i.e., external costs that are associated with uncompensated social or environmental effects, or positive, i.e., external benefits that are associated with positive social and environmental effects.
5. R&D related development of new technologies for SCP.

Summary

The EU Bioeconomy Strategy by 2030[42] (2018) defines "the European way: being economically viable with sustainability and circularity in the driver's seat". In order to meet the headline target, the key focus is on carbon neutrality with "negative emissions" and carbon sinks; turning bio-waste, residues and discards into valuable resources; another key objective is to maintain the healthy ecosystems, including land degradation neutrality. The EU policy on bioeconomy is in accordance with the UN's 2030 Agenda for Sustainable Development[43] with 17 Sustainable Development Goals and with 169 targets providing a new global policy framework towards ending poverty, fighting inequalities and mitigating climate change. The EU is supporting the implementation of the Agenda by monitoring SDGs with the use of the EU SDG indicator set. This set comprises 100 different indicators, including 41 multi-purpose indicators, assuming that there is an upper limit of indicators for an effective monitoring and communication[44].

Against this policy background, bio-based products shall be coherent with and contribute to the European sustainable and circular bioeconomy framework, and form part of a broader framework by complying with global SGDs and planetary boundaries.

This report proposes the set of environmental, social and economic principles, criteria and indicators that are consistent with the current sustainability schemes, the way of their operationalization, monitoring and communication to consumers. In order to have a complete view of the certification scheme Task 8.7 develops documentation (CoC) needed for tracing sustainability of bio-based products according to the LCA model from cradle to cradle (circularity).

[42] Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the Regions. COM(2018) 673. 11 October 2018.
[43] 70/1. Transforming our world: the 2030 Agenda for Sustainable Development. Resolution adopted by the General Assembly on 25 September 2015.
[44] Indicators for monitoring the sustainable development goals (SDGS) in an EU context. EC 28 April 2017.

The key contributions to the development of the blueprint of sustainability of bio-based products compose the outputs from STAR-ProBio work packages WP1-7. The delivered reports contain a thorough analysis of the existing certification and standardization landscape as the starting point for the development of coherent principles, criteria and indicators as well as and their implementation into certification practice. In the course of numerous meetings, and internal discussions supported by suggestions of internal and external experts, novel concepts were proposed on the sustainability assessment of a whole supply chain in association with EoL options and circularity of material and energy. The compilation of these suggestions is presented in this report but the main challenge of this project is to combine the results obtained into a coherent certification scheme that will enhance the sustainability assessment of bio-based products and associated policies.

There is common agreement in the STAR-ProBio consortium that implementation of the above recommendations and amendments into the current sustainability certification schemes will be associated with the assessment of policy impacts studied in WP9. It will be done through three integrated instruments: a SAT-ProBio blueprint for sustainability assessment of bio-based products; a SAT-ProBio tool for demonstration of the sustainability assessment of the STAR-ProBio case studies, i.e. bio-based polymers and fine chemicals; and a SyD-ProBio tool for the policy impact assessment. The concept of SAT-ProBio has already started early in the project. As a result, different versions of a master document aiming at the description of the SAT-ProBio blueprint and its several elements have been drafted. The concept of combing the assessment of sustainability of bio-based product with the policy impact assessment was proposed by external reviewers of the project as it was progressing. Currently, the foundation for the development of the blueprint of certification scheme for sustainability of bio-based products and policy impact assessment is provided in the third version of the approach, in the form of an internal STAR-ProBio working document WP8 "SAT-ProBio Blueprint scoping paper" and a draft of the Project Plan for launching the CEN Workshop Agreement. The scoping paper provides methodical background for incorporation of the STAR-ProBio results into the sustainability assessment framework of SAT-ProBio alongside three components: (1) Technical requirement for the assessment of bio-based products (CWA), 2) Guidelines for a certification scheme based on the proposed framework (Rules of game), and 3) Application of the proposed certification scheme to bio-based case studies (Product Category Rules). The Project Plan for the CEN or CENELEC Workshop on "Sustainability qualification framework for bio-based products" under the acronym: SAT-ProBio provides detailed information on the assumed procedure. The Workshop lays down sustainability principles, criteria and indicators for bio-based products. The standard describes a methodological framework for qualifying the sustainability of bio-based products. It will be based on both CEN/TC 411 work and the work of the STAR-ProBio consortium.

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STAR-Pro Bio – H2020 project Sustainability Transition Assessment and Research of Bio-based Products

Technical Work Packages

WP1: Screening and analysis of existing sustainability schemes for the bioeconomy
WP2: Upstream environmental assessment
WP3: Downstream environmental assessment
WP4: Techno-economic assessment
WP5: Market assessment
WP6: Social assessment
WP7: ILUC risk assessment for bio-based products
WP8: Sustainability scheme blueprint for bio-based products
WP9: Analysis of regulations, (eco)labelling and policy initiatives

Deliverables cited in the report

D1.1: Report on identified environmental, social and economic criteria/ indicators/ requirements and related "Gap Analysis"
D1.3: Identification of case studies and stakeholders
D2.1" Report summarizing the findings of the literature review on environmental indicators related to bio-based products
D2.2: Selection of environmental indicators and impact categories for the life cycle assessment of bio-based products
D3.1: Expanding environmental sustainability criteria to address the manufacturing and other downstream processes for bio-based products
D5.1: Acceptance factors among consumers and businesses for bio-based sustainability schemes
D6.1: Preliminary draft of 'value items' list
D6.2: Stakeholders' map and validated list of 'value items'
D6.3: Criteria and indicators developed for conducting SLCA social impact assessment

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