Biological Resources Certifications Schemes

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Guidelines for integration to bio-based certification schemes

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☐	**Other**	

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X	**PU**	Public, fully open, e.g. web
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Table of contents

List of figures

List of tables

Publishable executive summary

The BioReCer project has developed a structured framework to integrate sustainability and circularity principles into bio-based certification schemes, ensuring a comprehensive evaluation of biological feedstocks. The work carried out in this deliverable builds upon previous theoretical research to create a practical methodology for existing certification schemes and stakeholders.

To streamline the framework, a thorough review of the initial theoretical assessment was conducted. Requirements that overlapped or addressed similar aspects were consolidated into a unified set of 52 requirements. These were further categorised into basic and advanced criteria, where basic requirements serve as the minimum threshold for compliance, while advanced criteria encourage continuous improvement. This process simplifies the application of the framework while maintaining a high level of robustness, ensuring that sustainability and circularity assessments are both practical and rigorous.

A key component of this work is the integration of quantifiable indicators into the framework. To complement qualitative assessments, the set of previously designed circularity indicators were linked to specific requirements, providing a measurable approach to evaluating sustainability and circularity performance. These indicators cover multiple stages of the bio-based value chains, ensuring that the assessment is holistic and adaptable to different industry contexts. The decision to incorporate both qualitative and quantitative metrics strengthens the credibility of the certification process and enhances transparency for stakeholders.

To support the adoption of the BioReCer framework, guidelines for bio-based certification schemes were developed, outlining a structured compliance methodology. A two-stage approach was introduced, where organizations must first meet all basic requirements before progressing toward advanced criteria. A decision tree was designed to facilitate the assessment process, ensuring clarity for certification bodies. The methodology also emphasizes flexibility, allowing for sector-specific adaptations while maintaining consistency in sustainability and circularity evaluations.

By integrating sustainability and circular economy principles into bio-based certification schemes, the BioReCer framework establishes a standardised approach to assess biological feedstocks. The combination of streamlined requirements, quantitative indicators, and structured compliance guidelines supports WP4 in developing practical guidelines for existing certification schemes.

Structure of the derivable

The aim of this deliverable is twofold: on the one hand, it is to streamline the theoretical framework developed in the project for the evaluation of biological feedstocks in terms of sustainability and circularity, integrating the set of circularity indicators developed in the project into the framework. On the other hand, it is to provide a guide for practical implementation in certification schemes focused on the assessment of biological resources.

The deliverable is structured in four sections. Section 1 provides background information on the work undertaken to date, which forms the basis of this deliverable. Section 2 details the decisions taken to streamline the theoretical framework so that it can be incorporated into certification schemes, and the integration of the quantitative circularity indicators into the qualitative framework. Section 3 details the practical implementation of the framework and the measurement of compliance. The final framework is presented in its entirety. The fourth section is designed to assist in understanding the set of indicators and to aid existing certification schemes in developing complementary materials when integrating the BioReCer framework.

Throughout this deliverable, the term product is used several times. It is important to emphasise that in the context of the BioReCer project, a product is any good that is produced or manufactured by any actor in the supply chain and offered for sale. This can mean a bio-based product intended for consumption, but it also includes the biological feedstocks produced by organisations that are valorised.

1 Introduction

1.1 About the project

The BioReCer project aims to enhance the environmental performance and traceability of biological feedstock used in bio-based industries by strengthening existing certification schemes through tailored guidelines. This approach will increase the added value, usability, and social acceptance of bioproducts.

To achieve this, BioReCer developed a multidimensional assessment framework in D2.2. that provides a comprehensive analysis of biological feedstocks and their associated supply chains. This framework will be validated through four full-scale bio-based systems, ensuring its adaptability across various bio-based value chains. Additionally, the project will establish the BioReCer Innovation Ecosystem Living Lab, a multi-agent platform that will test the framework within real-world bio-based supply chains. The insights gained will be used to enhance current certification schemes by incorporating new sustainability, origin, and traceability criteria for biological resources, ensuring their applicability at both the European and global levels.

The transition to a bio-based economy is expected to generate significant environmental and economic benefits. BioReCer will assess the impact of both existing and adapted certification schemes on consumer preferences, industry stakeholders' willingness to pay (WTP), and the acceptance of novel bio-based value chains, including those that integrate residual feedstock and waste.

To maximise its impact, the project will engage stakeholders through both physical and digital platforms. In WP4, the BioResources Stakeholders Platform (BRSP) will facilitate collaboration and knowledge exchange, while in WP5, the BioReCer ICT Tool (BIT) will extend the project's reach and applicability.

Through this integrated approach, BioReCer aims to drive the sustainable development of bio-based industries while ensuring the credibility and transparency of biological resource certification.

1.2 Integrated BioReCer framework: From theory to practice

Often there is a disconnection between the theoretical advances made by researchers regarding sustainable and circular practices and methodologies and how business and industries can apply them in a practical and easy manner. This comes from the fact that assessing sustainability and circularity are complex issues sometimes perceived as too abstract and not adapted to the realities of industries (Geissdoerfer et al., 2017; Scrase & Sheate, 2002). The ultimate goal of the BioReCer project is to ensure the suitable environmental performance and traceability of the biological feedstock used by bio-based industries by generating guidelines to strengthen current certification schemes. For this purpose, it is important to have a solid theoretical foundation on how to assess this and a practical application of such assessment.

At this point in the project, previous work has been generated as a result of Work Package 2 (WP2) activities. The first, is a theoretical framework with the objective of providing a list of principles, criteria and requirements to evaluate sustainability and circularity that any certification system focused on bio-based products can include. The second, is the development of a comprehensive set of circularity indicators, which encompass the entire life cycle of bio-based products, from raw material extraction to end-of-life (EoL) management, ensuring a holistic approach to circularity assessment. Both works set the theoretical foundations for what is necessary to incorporate into bio-based certification schemes in order to comprehensively assess the sustainability and circularity of biological feedstocks.

The aim of this deliverable is therefore to streamline the previous work, and to present a final BioReCer framework for the evaluation of sustainability and circularity of biological feedstocks. To achieve this, the theoretical qualitative framework presented in *D2.2 - Modified assessment methodologies* was consolidated into a set of 52 requirements that considered all the selected principles and criteria. The set requirements have been categorised into basic (and therefore mandatory) and advance (non-mandatory, self-improving). Finally, the set of circular indicators presented in *D2.3 - Circular indicators* has been combined with the requirements as a way to complement the qualitative evaluation with a qualitative measurement of the biological feedstock's circularity. Thus, this deliverable generates a blueprint for the adaptation of BioReCer framework into existing certification schemes for WP4.

1.3 The relationship between sustainability and circularity

Nowadays, sustainability and circular economy (CE) are two words often shown together in policies, organization strategies, missions and visions, as an objective to achieve in years to come. For none of these words there is a consensus definition nor there is a consensus explanation about their relationship. To begin tackling this relationship, a definition is needed in order to establish the basis upon which this relationship is built. The following explanations outline the basis upon which the BioReCer project is developed, starting with a solid definition as a reference point to analyse this relationship.

First, the concept of CE will be addressed. This concept emerged from the need for efficient consumption of natural resources, which are in a gradual depletion. This is a key factor that affects the effectiveness and continuity of economy and production. Thus, CE attempts to adjust the linear model to a circular one, in order to extend the product life cycle, mostly by applying engineering principles to close or slow the material loops (Geissdoerfer et al., 2017). Some authors suggest that the CE emerged from the concept of Industrial Ecology that aims to simulate biogeochemical cycles by the exchange of materials (as raw materials) from one company to another.

While the concept of CE is widely recognised, there is no consensus on its definition. Currently, over 114 different definitions of CE exist (Nikolaou et al., 2021). One such definition, provided by the European Parliament, defines CE as: "*A model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended.*" (European Commission, 2023).

Secondly, the concept of sustainability is often used interchangeably with sustainable development. The latter has been defined since 1987, when the United Nations (UN) World Commission on Environment and Development (WCED) introduced it in the Brundtland Report, *Our Common Future*, stating: "*Sustainable development is development which meets the needs of current generations without compromising the ability of future generations to meet their own needs. It contains within it two concepts: the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given, and the idea of limitations imposed by the state of technology and social* *organization on the environment's ability to meet present and future needs.*" (United Nations, 1987).

Whilst sustainability is a term with over 120 definitions, they share the same idea with sustainable development but differ into the details and perspectives. To give an example of some definitions, the European Commission has presented the working definition: *"Sustainability means prioritising the needs of all life forms and of the planet by ensuring that human activity does not exceed planetary boundaries."*(European Commission, n.d.). Similarly, the United States Environmental Protection Agency (US EPA) defines sustainability as: *"Sustainability is based on a simple principle: Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations"* (US EPA, 2024).

The BioReCer project is aligned with the sustainability EU working definition and the circular economy definition of the European Parliament. Once the definitions have been established, the relationship between sustainability and circular economy will be evaluated. As commented by Geissdoerfer et al. (2017), there are three types of relationships between both concepts: i) conditional relationship, circular economy is a precondition for sustainability; ii) beneficial relationship, where circularity is one of many options that can be applied to foster sustainability; and iii) trade-offs, where circular economy practices bring benefits to sustainability, but it also brings disadvantages that need to be examined carefully.

Considering the above-mentioned definitions, the BioReCer project recognises the impact of circular economy as an element fostering a sustainable system, advocating for the beneficial relationship and allowing them to complement each other. Because of this, moving forward the BioReCer framework will not separate between circular economy and sustainability. An integrated framework will be presented in the following sections.

2 Streamlining the framework

In the context of the BioReCer project, a theoretical framework has been developed to assess the sustainability and circularity of the biological feedstocks. This theoretical framework brings together a set of principles, criteria and requirements based on the three fundamental pillars (environmental, economic and social) and both aspects, sustainability and circularity.

Building on this previous work, this section provides a streamlined version based on the theoretical framework developed in *D2.2. Modified assessment methodologies* and that can be seen in Annex A of this report. It details the process of integrating and unifying the previously identified requirements, with the objective of simplifying the framework for enhanced practical application.

2.1 Unification of requirements

As the initial step in developing the integrated framework, and following the structure defined in *D2.2 - Modified Assessment Methodologies*, the BioReCer framework adopts a hierarchical pyramidal organisation. This structure is composed of pillars, principles, criteria, and requirements. However, unlike the theoretical framework outlined in *D2.2 - Modified assessment methodologies*, an inverse approach will be implemented—starting from the requirements and moving to the pillars. This approach allows for the identification of requirements that align with multiple principles, incorporating both sustainability and circularity aspects simultaneously. As demonstrated in Section 1.2, sustainability and circularity are interlinked rather than independent concepts. Consequently, the final BioReCer framework integrates both aspects, ensuring that all principles and criteria analysed under this scope are reflected in the final set of requirements. In this regard, six sets of requirements, which could be combined into one single requirement, were identified. The unification rationale of the requirements is depicted below.

Water related requirements.

Requirements presented in Figure 1 have been unified, as one establishes the identification of all types of water used by the company, while the other focuses on the consideration of regeneration water, which is inherently covered by the previous requirement.

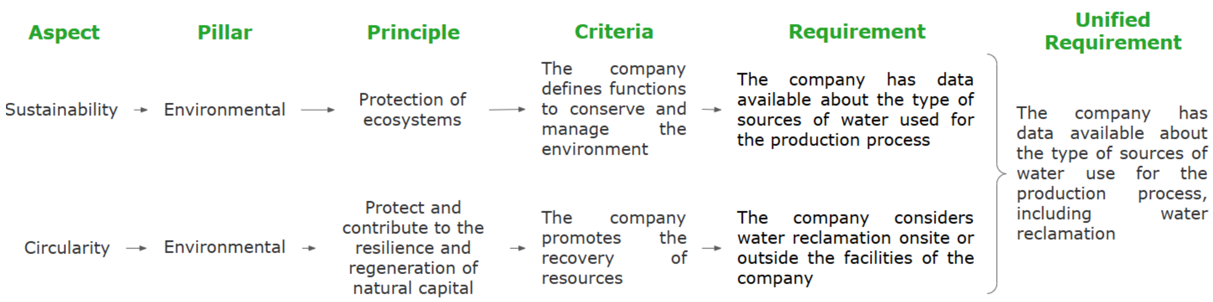

Figure 1. Scheme for unification of water related requirements.

Substance and chemical use related requirements

The requirements in Figure 2 have been unified as they both centre on waste management. The application of the waste hierarchy, which prioritises prevention, reuse, recycling, and valorisation, inherently informs the selection of the most appropriate waste treatment strategies.

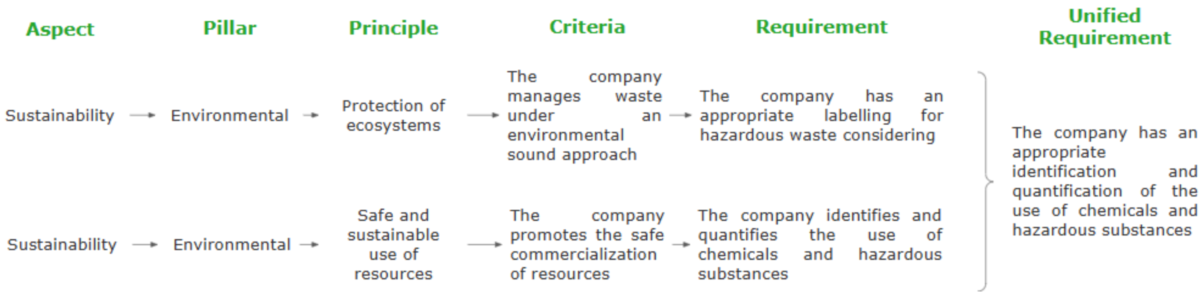

Figure 2. Scheme for unification of substance and chemical use related requirements

Emissions related requirements

The first requirement establishes that the company must propose strategies to protect water, soil, and air quality and prevent negative impacts. The second requirement refers to the identification and characterisation of emissions to comply with established legal thresholds (Figure 3). Both aspects are addressed under Directive 2010/75/EU (2010) as protection strategies not only aim to prevent impacts but must also be based on monitoring and controlling emissions.

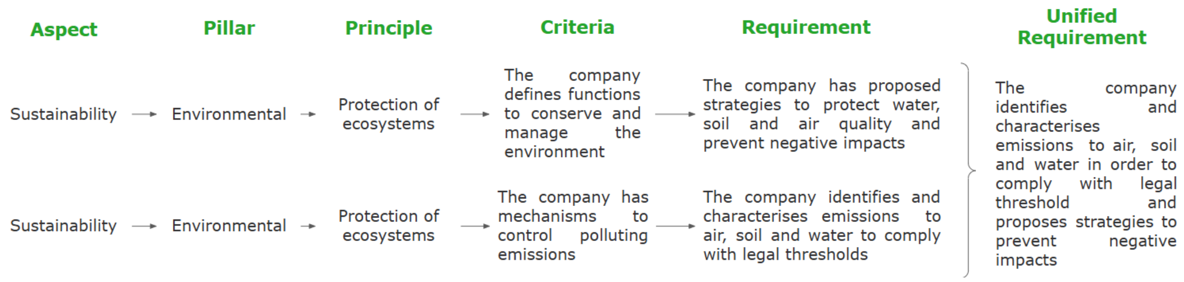

Figure 3. Scheme for unification of emissions related requirements

Waste related requirements

Requirements in Figure 4 have been unified, as identifying and classifying hazardous waste ensures compliance with labelling regulations and safe management, while quantifying chemical substances helps control hazardous materials. Since both points are addressed in Directive 2012/18/EU (2012), they have been unified into a single requirement.

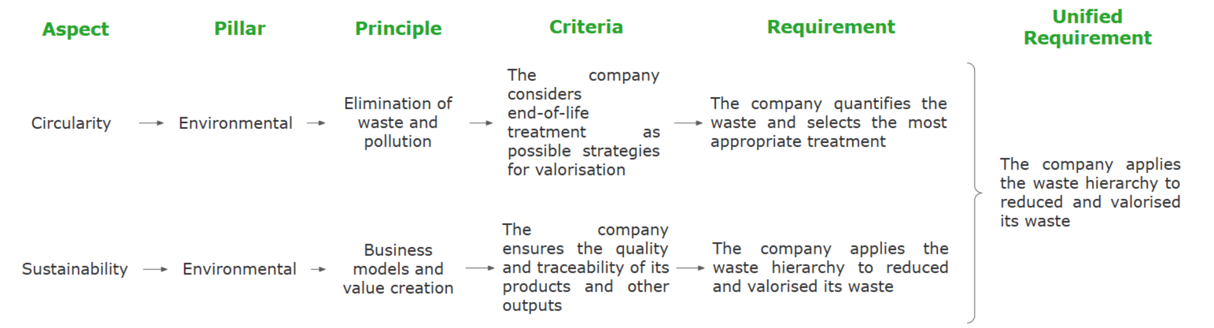

Figure 4. Scheme for unification of waste related requirements

Promotion of bio-based and non-virgin materials related requirements

Both requirements shown in Figure 5 focus on reducing the use of new resources and minimising the environmental impact of material production, one by promoting bio-based materials and the other by utilising non-virgin materials. Therefore, they have been unified into a single requirement that enhances resource efficiency and waste reduction.

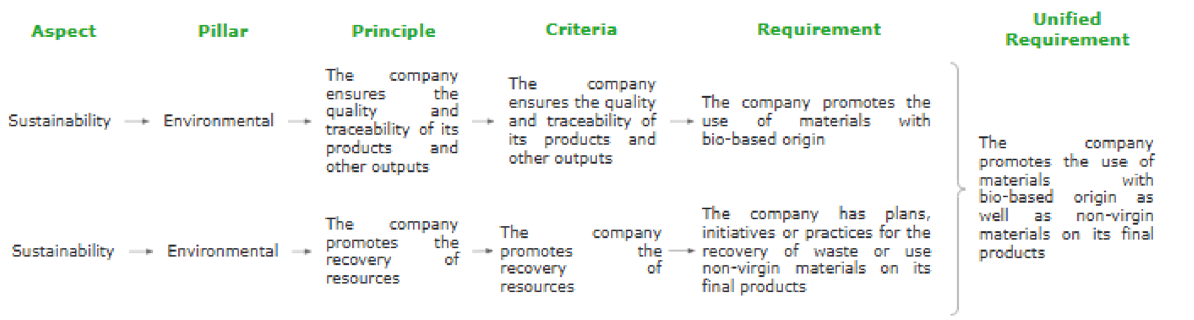

Figure 5. Scheme for unification of promotion of bio-based and non-virgin materials related requirements

Promotion of research and training requirements

Both requirements presented in Figure 6 aim at the organisation allocating resources to research, the second requirement associated with the sustainability aspect also includes allocating resources for training. Both requirements can be unified then into a single one that considers the use of resources not only for research and development but also for employee training.

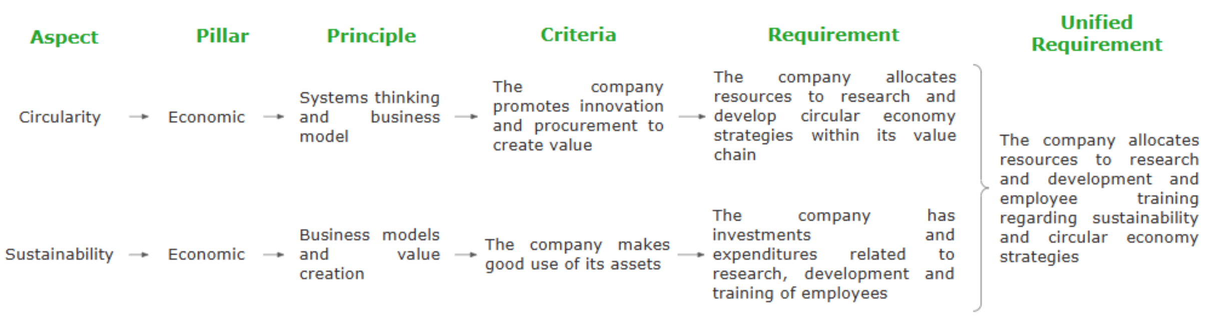

Figure 6. Scheme for unification of promotion of research and training

In the theoretical framework (presented in *D2.2 - Modified assessment methodologies*), a total of 58 requirements were identified, with 42 related to sustainability and 16 to circularity. Following a detailed analysis of these requirements, the final framework consolidates them into a set of 52 requirements. This refined set encompasses all previously selected principles and criteria, ensuring a comprehensive and cohesive approach. The resulting framework is illustrated in Figure 7, providing a clear representation of how sustainability and circularity aspects have been incorporated.

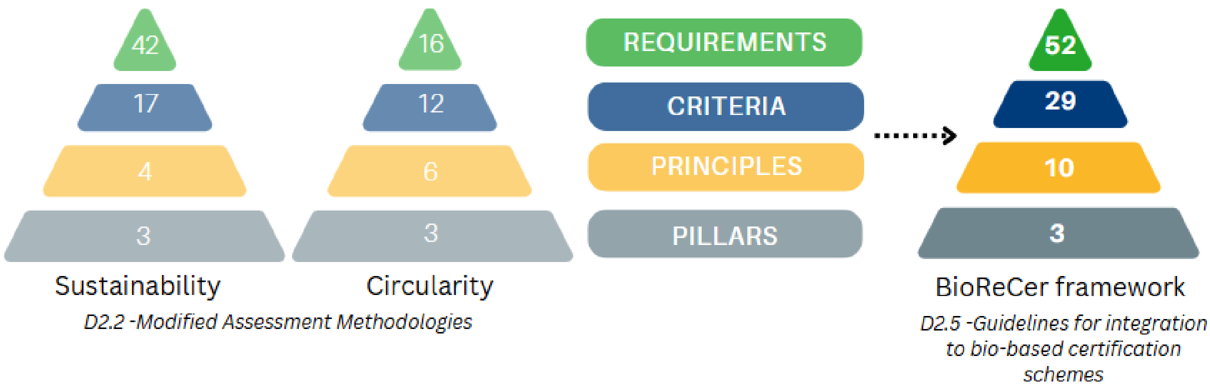

Figure 7. Structure of the integrated assessment framework of the BioReCer project

2.2 Characterisation of requirements: basic/advance

Once the requirements that make up the final framework were defined, the next step was to establish their hierarchy. This is a fundamental step in laying the foundation for assessing sustainability and circularity, as well as for integrating biomass into certification schemes. To achieve this, the requirements were classified into two categories: i) basic, which are considered mandatory, are defined as essential conditions for certification; and ii) advance, which are non-mandatory, allowing organisations to improve their practices without serving as an exclusionary criteria.

While preparing *D2.2. Modified assessment methodologies,* a thorough analysis of European Directives and Regulations was conducted setting the basis for the classification presented in this section. Consequently, those requirements covered by European Directives and Regulations were classified as basic. Likewise, other requirements have also been classified as basic, as they are considered essential within the BioReCer project since they encompass fundamental actions towards sustainability and circularity practices. The latter actions include promoting the use of bio-based materials and, waste valorisation, ensuring the traceability and tracking of resources and materials, prioritising the use of reused/recycled materials, identifying emissions reductions, avoided emissions, waste prevention or reduction, and improvements in biodiversity, among other critical environmental impacts.

The proposed classification (i.e., basic/advance) has been defined considering the difficulty of establishing minimum and mandatory standards within the framework applicable across all industries. Thus, it should be remarked that the bio-based sector encompasses a diverse range of industries, varying in size and type. Additionally, its complexity is further intensified by the valorisation of biological feedstocks, which introduces additional layers of challenges. One of the challenges faced by the BioReCer project is to generate results applicable to a wide spectrum of organisations with differing levels of intricacy. To achieve this, the project has established a continuous loop of information exchange and communication with external stakeholders and case study leaders ensuring a collaborative and inclusive approach. Firstly, the classification was shared with case study leaders to gather a first round of feedback, where the focus was to make the proposed requirements clear and understandable. Secondly, once corrections were made, the framework was shared for a second round of feedback with the case study leaders and a selection of key external stakeholders, where the focus was to ensure and test requirements' comprehensibility and level of compliance, taking into account the diversity across sectors. Finally, the proposed classification integrated all the feedback provided by case study leaders and stakeholders with the aim of ensuring the framework's practical application.

Consequently, after the aforementioned collaborative process, from the 52 established requirements, 29 have been categorised as basic requirements while 23 have been classified as advance requirements. These are presented in Table 1.

Table 1. Classification of requirements as basic or advance in the BioReCer framework.

Requirement	**Type**
The company has data available about the type of sources of water use for the production process, including water reclamation	Basic
The company has a plan to manage resources and water efficiently	Basic
The company identifies the water sources affected by runoffs and discharges	Basic
The company identifies and characterises emissions to air, soil and water in order to comply with legal threshold and proposes strategies to prevent negative impacts	Basic
The company shall provide the most updated Environmental Impact assessment (EIA) of the area before starting its operations	Basic
The company shall indicate whether it adopts ecosystem regeneration and rehabilitation measures	Basic
The company uses and has appropriate maintenance for machinery, processing, disposal containers, and facilities for handling products, materials, and wastes (excluding legal and safety matters)	Advance
The company measures its greenhouse gases (GHG) and has established a reduction plan	Basic
The company shall have evaluations about the state of the biodiversity within the area and a plan to maintain and improve biodiversity	Basic
The company shall identify whether its operation is happening in a protected area	Basic
The company has some kind of treatment technology to prevent emissions to	Basic

the environment	
The company measures the noise and odour to ensure that they are under the legal threshold	Basic
The company has an appropriate identification and quantification of the use of chemicals and hazardous substances	Basic
The company promotes the use of materials with bio-based origin as well as non-virgin materials on its final products	Basic
The company applies the waste hierarchy to reduce and valorise its waste	Basic
The company characterises the introduced genetically modified species	Basic
The company quantifies non-indigenous/invasive species and pathogens introduced into the ecosystem	Basic
The company considers the resilience of the ecosystem to ensure sustainability	Basic
The company establishes and monitors key performance indicators to ensure a responsible use of resources and avoid the degradation of ecosystems	Basic
The company has an energy efficiency plan in place	Advance
The company identifies whether action has been addressed to ensure food security in biomass production systems	Basic
The company has established measures to track the disposal of by-products and waste	Basic
The company has established measures to improve product traceability	Basic
The company allocates resources to research and development and employee training regarding sustainability and circular economy strategies	Advance
The company has good management of the unsold finished goods, prevention of waste generation	Basic
The company has in place measures to ensure the optimization of cost (operational, infrastructure, waste treatment)	Advance
The company achieves goals of reduction or substitution of resources	Basic
The company must ensure that subcontractors also comply with the requirements of the certification schemes	Advance
The company has fully documented property rights	Basic
The company is a legally defined entity with a clear and documented legal record	Basic
The company takes into consideration green procurement criteria in the selection of its suppliers	Advance

The company complies with certification schemes and standards verified by a third-party	Advance
The company has in place specific measures to promote a healthy work-life balance that goes beyond what it is established in national regulation, ILO standards, WHO guidelines, etc	Advance
The company has a Health and Safety plan in place	Basic
The company provides accident insurance coverage and adequate compensation for all workers	Advance
The company has effective complaints and grievance mechanisms and take measures to resolve the reported complaints and grievances	Advance
The company ensures equality and no-discrimination in all aspects, regardless of gender, race, ethnicity, religion, age, disability, or any other diversity dimension	Basic
The company keeps records on work-related accidents or incidents	Basic
The company promotes the participation of its employees on certified training activities and competencies	Advance
The company has created new job positions in line with the needs of the implemented circular economy strategies	Advance
The company contributes to enhancing the employment rate in the sector	Advance
The company ensures the payment of wages that meet or exceed industry minimum standards	Advance
The company has collaborations with other companies aiming at the good use of resources	Advance
The company is able to demonstrate that the implementation of plans, initiatives and practices on circular economy has resulted in economic benefits	Advance
The company has contracts with suppliers selling products/materials certified as circular	Advance
The company is willing to share information publicly about its activities related to the circular economy	Advance
The company has identified the environmental benefits resulting from the implementation of circular economy strategies (reduction, recycling, recovering…)	Basic
The company can demonstrate that its products have the same characteristics and quality as its conventional counterparts	Advance
The company has plans, initiatives or practices to ensure the increase of resource productivity	Advance
The company has defined strategies to promote a system thinking of processes and the analysis of material loops	Advance

The company has participated in awareness campaigns to promote the benefits of the circular economy	Advance
The company has programmed training activities for workers to tackle with the specificities of circular technologies and/or strategies	Advance

2.3 Quantification of requirements: circular indicators in the framework

Once adapted and integrated into a certification scheme, the BioReCer framework will be able to assess the sustainability and circularity of a biological feedstock through an audit process. Within the BioReCer project, WP4 will integrate and adapt the proposed framework. For this, practical guideline documents on how to comply and verify the integrated framework will be developed. As the framework is constructed as a set of requirements to be met, the first step is to determine compliance qualitatively (i.e., with documentary evidence). However, as mentioned above, the BioReCer project has developed a set of quantitative indicators. These indicators are based on many of the principles and criteria on which the BioReCer framework is built, being linked to some of the established requirements. Thus, in this section, the rationale behind linking the circular indicators designed in deliverable *D2.3 - Circular indicators* with the final integrated framework is explained.

As detailed in *D2.3 - Circular indicators*, within the scope of the project, four types of circularity indicators have been defined to measure different aspects of a product life cycle (Figure 8), ensuring a complete evaluation of its circularity.

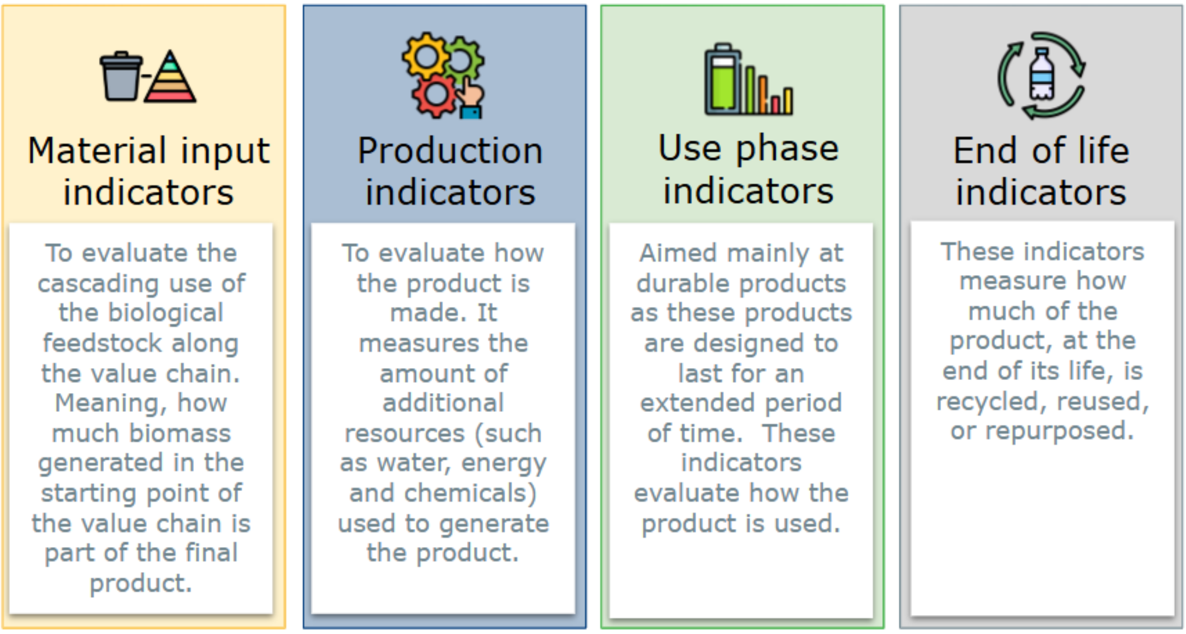

Figure 8. Type of circularity indicators across a product life cycle.

Also, *D2.3 - Circular indicators* defines the different actors that are involved in a bio-based value chain as follows: i) primary producers; ii) waste producers; iii) intermediate producers; and iv) final producers (Figure 9). Unlike *D2.3 - Circular indicators,* to facilitate understanding it was necessary to define a new type of actor in the value chain, the waste producer. For the waste producer, the circular indicators are calculated by applying the same equations since both actors are at the beginning of the value chain, but waste producers do not take resources directly from nature, but the biological feedstock is instead generated as a result of waste management activities. An example of this type of actor is a wastewater treatment plant.

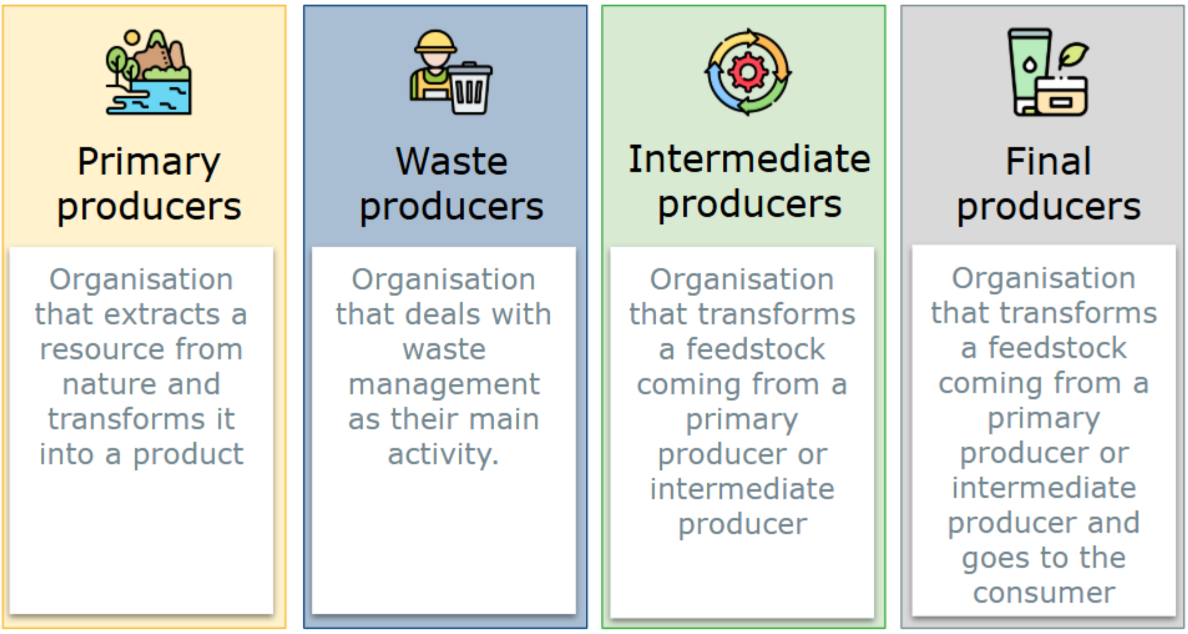

Figure 9. Types of actors in the bio-based value chain.

2.3.1 Relationship between indicators and requirements: Quantifying the BioReCer framework.

Of the 52 integrated requirements included in the BioReCer framework, seven can be directly linked to the circularity indicators. In addition, whilst in some cases more than one quantitative circularity indicator is linked to one single requirement, in other cases several quantitative indicators are linked to the same requirement (Table 2).

The objective of the framework is to assess sustainability and circularity in a robust manner. To achieve this, it is necessary to evaluate not only the product but also the organisation that generates it. For this purpose, some of the presented requirements are focused on broader actions related to the organisation's policies and practices. Examples include assessing biodiversity and emissions, implementing investment plans for sustainable strategies, or providing staff training. These actions are evaluated qualitatively through the submission of documentary evidence.

Furthermore, some requirements are focused on assessing the product, its production process, the incorporation of secondary materials, or the valorisation of generated co-products. In this case, it is possible to establish metrics (in the form of circularity indicators) to analyse product performance. Due to the aforementioned reasons, not all framework requirements have an associated indicator that allows for a quantitative evaluation of their performance

Table 2.BioReCer framework requirements associated with circularity indicators.
Note: the equation number relates to deliverable D2.3 - Circular indicators.

Requirement	Equation num	Circularity indicator	Actor profile	Type of indicator
The company has an appropriate identification and quantification of the use of chemicals and hazardous substances	[40], [41], [42]	Process-function chemical	All	Production
The company promotes the use of materials with bio-based origin as well as non-virgin materials on its final products	[1]	Verified virgin renewable product	Primary producer	Material input
	[2], [16], [17], [18]	Circularity characterisation factor	All	Material input
	[3],[19]	Modified Biomass Utilisation Factor	All	Material input
	[9]	Pre-consumer recycled bio-based content of product	Intermediate and final producer	Material input
	[10],[11]	Recycled fossil-based content of product	Primary, intermediate and final producer	Material input
	[12]	Virgin renewable content of product	Intermediate and final producer	Material input

The company applies the waste hierarchy to reduce and valorise its waste	[2], [16], [17], [18]	Circularity characterisation factor	All	Material input
	[3], [19]	Modified Biomass Utilisation Factor	Primary, waste and intermediate producer	Material input
	[22], [25]	Total production efficiency of the current actor in producing valuable products and by-products	Intermediate and final producer	Material input
	[28]	Modified Biomass Utilisation Factor (for complex biomass mixtures)	intermediate and final producer	Material input
	[29]	Value-based Biomass Utilisation Factor (for complex biomass mixtures)	intermediate and final producer	Material input
The company establishes and monitors key performance indicators to ensure a responsible use of resources and avoid the degradation of ecosystems	[32], [33], [34]	Energy-related indicators	All	Production
	[35], [36], [37], [38], [39]	Water-related indicators	All	Production
	[40], [41],[42]	Process-function chemical indicators	All	Production

The company achieves goals of reduction or substitution of resources	[5], [23]	Value-based Biomass Utilisation Factor	Primary and waste producer	Material input
	[8]	Reused content of product	Intermediate and final producer	Material input
	[9]	Pre-consumer recycled bio-based content of product	Intermediate and final producer	Material input
	[10],[11]	Recycled fossil-based content of product	Intermediate and final producer	Material input
	[12]	Virgin renewable content of product	Intermediate and final producer	Material input
	[13], [15]	Circular Content of Product	Intermediate and final producer	Material input
The company can demonstrate that its products have the same characteristics and quality as its conventional counterparts	[43]	Average Lifetime of product in comparison to industry average	Final producer	Use phase
The company has defined strategies to promote a system thinking of processes and the analysis of material loops	[44]	Designed reusability of a product	Intermediate producer	Use phase
	[45]	Actual reusability of a product	Final producer	Use phase
	[46]	Designed refurbishing and remanufacturing of a product	Intermediate producer	Use phase

	[47]	Actual refurbishing and remanufacturing of a product	Final producer	Use phase
	[48]	Designed Recirculation of product at the EoL as pharmaceutical and fine chemical	Intermediate and final producer	End-of-life
	[49]	Actual Recirculation of product at the EoL as pharmaceutical and fine chemical	Final producer	End-of-life
	[50]	Designed Recirculation of product at the EoL as food and feed	Intermediate and final producer	End-of-life
	[51]	Actual Recirculation of product at the EoL as food and feed	Final producer	End-of-life
	[52]	Designed Recirculation of product at the EoL as bioplastics and polymers	Intermediate and final producer	End-of-life
	[53]	Actual Recirculation of product at the EoL as bioplastics and polymers	Final producer	End-of-life
	[54]	Designed Recirculation of product at the EoL as bulk chemicals and materials	Intermediate and final producer	End-of-life
	[55]	Actual Recirculation of product at the EoL as bulk chemicals and materials	Final producer	End-of-life
	[56]	Designed Recirculation of product at the EoL as energy, heat and fuels	Intermediate and final producer	End-of-life

	[57]	Actual Recirculation of product at the EoL as energy, heat and fuels	Final producer	End-of-life
	[58]	Designed Recirculation of product at the EoL as useful utilisation in biosphere	Intermediate and final producer	End-of-life
	[59]	Actual Recirculation of product at the EoL as useful utilisation in biosphere	Final producer	End-of-life

3 Guidelines for integrating to bio-based certification schemes

This section shows the final iteration of the BioReCer framework, it lists the final 52 integrated requirements, the related circularity indicators and how to determine the level of compliance with the framework.

3.1 Compliance with the BioReCer framework

As presented in section 2.2, the framework requirements have been categorised into basic or advance. Now this categorisation will be used to determine the level of compliance with the framework. Of the 52 requirements presented in this framework, after evaluation, 29 have been classified as basic and 23 have been classified as advanced requirements.

For determining the compliance level with the BioReCer framework, a two-stage process is needed. The first stage is exclusionary and related to the compliance with basic requirements, and the second stage is evaluative and related to the compliance with advance requirements. All basic requirements must be met in order to fully comply with the BioReCer framework, if an organisation fails to comply with any of these requirements, it will not be considered eligible as they establish the minimum threshold (Figure 10). The advance requirements indicate the path the organisation must follow to continue to improve their product and practices. As such, these requirements should be met in a gradual manner based on the context of the organisation and the characteristics of the product being assessed.

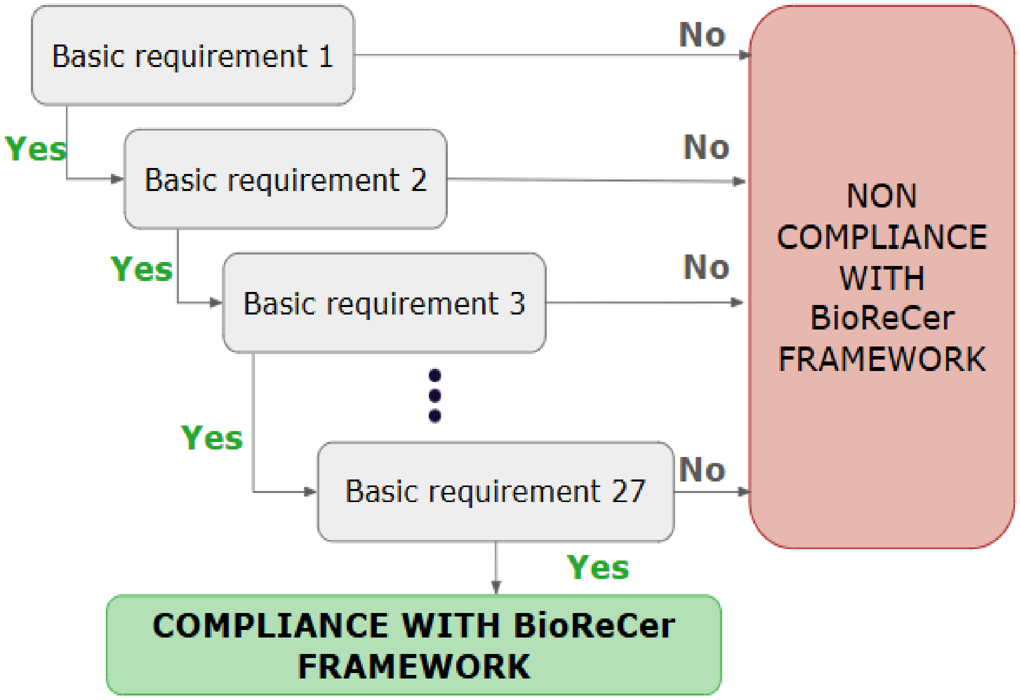

Figure 10. Decision tree to establish compliance with BioReCer framework.

Regarding the presented quantitative indicators, 29 are linked to basic requirements, this means that they must be calculated to achieve compliance with the framework. As the objective of the framework is to help organisations in the bio-based sector to improve their performance, no external threshold or benchmark has been defined. This means that the organisation is responsible for improving their performance based on the results from the calculations of indicators. The type of indicators linked to the basic requirements are material input and production indicators. As explained in detail in *D2.3 - Circular indicators*, a key aspect to measuring the circularity of biological feedstocks is to identify the cascade use of the feedstock as it moves through the value chain transforming into different products. This is the reason why material inputs are considered as a basic part of the BioReCer framework and therefore mandatory. In a similar manner, production indicators measure the efficiency of the additional resources being used (water, energy, and chemicals) to produce such products. As resource reduction is a key principle of both circularity and sustainability, its related indicators must also be a basic part of any framework seeking to assess these aspects.

Seventeen quantitative indicators are linked to advanced requirements, meaning their calculation is not mandatory but encouraged. The type of indicators linked to the advance requirements are use-phase and end-of-life. These indicators are mainly applicable to durable products. Although they target important aspects in closing the value chain loops, under the objective of the BioReCer project they signify a step further in the valorisation strategy for biological feedstocks and therefore characterise as non-mandatory.

The BioReCer framework has established and defined a set of requirements and indicators for the bio-based sector to help determine the sustainability and circularity of biological feedstocks. This framework can be applied in different sectors that generate these resources, such as agriculture, forestry, fishing or waste management. An important first step is to understand how the framework applies to the context and specifics of an organisation and their products. There might be cases where some basic requirements do not apply to a specific organisation or product and by means of proper justification can be excluded when applying the BioReCer framework.

Once the framework has been adapted to the organisation and product, the circular indicators can be calculated. In this case two scenarios must be calculated. The first is the baseline scenario, which will determine where the organisation and product is at this moment regarding its circularity. The second scenario is the best performance scenario, i.e., the best possible practical maximum that can be achieved for the product and the organisation in terms of circularity. Having the start and end points allows the organisation to establish a road map to follow based on the continued improvement principle.

3.2 Final integrated BioReCer framework

Table 3 shows the final iteration of the BioReCer framework, it lists the final 52 integrated requirements, the type of requirement they are (basic or advance) and the related circularity indicators. Note that in the column "quantitative indicator", "n/a" means that there are no related quantitative indicators, while the numbers in brackets indicate the equation number as presented in D2.3 - Circular indicators to calculate the indicators.

Table 3. Final integrated BioReCer framework.
Note: the numbers in brackets are related to equations of deliverable D2.3 - Circular indicators.

	Requirement	Type	Quantitative indicator
1	The company has data available about the type of sources of water use for the production process, including water reclamation	Basic	n/a
2	The company has a plan to manage resources and water efficiently	Basic	n/a
3	The company identifies the water sources affected by runoffs and discharges	Basic	n/a
4	The company identifies and characterizes emissions to air, soil and water in order to comply with legal threshold and proposes strategies to prevent negative impacts	Basic	n/a
5	The company shall provide the most updated Environmental Impact assessment (EIA) of the area before starting its operations	Basic	n/a
6	The company shall indicate whether it adopts ecosystem regeneration and rehabilitation measures	Basic	n/a
7	The company uses and has appropriate maintenance for machinery, processing, disposal containers, and facilities for handling products, materials, and wastes (excluding legal and safety matters)	Advance	n/a
8	The company measures its greenhouse gases (GHG) and has established a reduction plan	Basic	n/a
9	The company shall have evaluations about the state of the biodiversity within the area and a plan to maintain and improve biodiversity	Basic	n/a
10	The company shall identify whether its operation is happening in a protected area	Basic	n/a
11	The company has some kind of treatment technology to prevent emissions to the environment	Basic	n/a
12	The company measures the noise and odour to ensure that they are under the legal threshold	Basic	n/a
13	The company has an appropriate identification and quantification of the use of chemicals and	Basic	[40], [41], [42]

	hazardous substances		
14	The company promotes the use of materials with bio-based origin as well as non-virgin materials on its final products	Basic	[1], [2], [3], [9], [10], [11], [12], [16], [17], [18], [19]
15	The company applies the waste hierarchy to reduce and valorise its waste	Basic	[2], [3], [16], [17], [18], [19], [22], [25], [28], [29]
16	The company characterizes the introduced genetically modified species	Basic	n/a
17	The company quantifies non-indigenous/invasive species and pathogens introduced into the ecosystem	Basic	n/a
18	The company considers the resilience of the ecosystem to ensure sustainability	Basic	n/a
19	The company establishes and monitors key performance indicators to ensure a responsible use of resources and avoid the degradation of ecosystems	Basic	[32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42]
20	The company has an energy efficiency plan in place	Advance	n/a
21	The company identifies whether action has been addressed to ensure food security in biomass production systems	Basic	n/a
22	The company has established measures to track the disposal of by-products and waste	Basic	n/a
23	The company has established measures to improve product traceability	Basic	n/a
24	The company allocates resources to research and development and employee training regarding sustainability and circular economy strategies	Advance	n/a

25	The company has good management of the unsold finished goods, prevention of generation of waste	Basic	n/a
26	The company has in place measures to ensure the optimization of costs (operational, infrastructure, waste treatment)	Advance	n/a
27	The company achieves goals of reduction or substitution of resources	Basic	[5], [8], [9], [10], [11], [12], [13], [15], [23]
28	The company must ensure that subcontractors also comply with the requirements of the certification schemes	Advance	n/a
29	The company has fully documented property rights	Basic	n/a
30	The company is a legally defined entity with a clear and documented legal record	Basic	n/a
31	The company takes into consideration green procurement criteria in the selection of its suppliers	Advance	n/a
32	The company complies with certification schemes and standards verified by a third-party	Advance	n/a
33	The company has in place specific measures to promote a healthy work-life balance that goes beyond what it is established in national regulation, ILO standards, WHO guidelines, etc	Advance	n/a
34	The company has a Health and Safety Plan in place	Basic	n/a
35	The company provides accident insurance coverage and adequate compensation for all workers	Advance	n/a
36	The company has effective complaints and grievance mechanisms and take measures to resolve the reported complaints and grievances	Advance	n/a
37	The company ensures equality and no-discrimination in all aspects, regardless of gender, race, ethnicity, religion, age, disability, or any other diversity dimension	Basic	n/a
38	The company keeps records on work-related accidents or incidents	Basic	n/a

39	The company promotes the participation of its employees on certified training activities and competencies	Advance	n/a
40	The company has created new jobs positions in line with the needs of the circular economy strategies implemented	Advance	n/a
41	The company contributes to enhance the employment rate in the sector	Advance	n/a
42	The company ensures the payment of wages that meet or exceed industry minimum standards	Advance	n/a
43	The company has collaborations with other companies aiming at the good use of resources	Advance	n/a
44	The company is able to demonstrate that the implementation of plans, initiatives and practices on circular economy has resulted in economic benefits	Advance	n/a
45	The company has contracts with suppliers selling products/materials certified as circular	Advance	n/a
46	The company is willing to share information publicly about its activities related to the circular economy	Advance	n/a
47	The company has identified the environmental benefits resulting from the implementation of circular economy strategies (reduction, recycling, recovering…)	Basic	n/a
48	The company can demonstrate that its products have the same characteristics and quality as its conventional counterparts	Advance	[43]
49	The company has plans, initiatives or practices to ensure the increase of resource productivity	Advance	n/a
50	The company has defined strategies to promote a system thinking of processes and the analysis of material loops	Advance	[44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59]
51	The company has participated in awareness campaigns to promote the benefits of the circular	Advance	n/a

	economy		
52	The company has programmed training activities for workers to tackle with the specificities of circular technologies and/or strategies	Advance	n/a

4 Practical guide for Circular Indicators application

This section delves into the practical use of the circular indicators presented in *D2.3 - Circular indicators*, providing a series of steps and some practical examples. The process is divided into seven stages as follows (Figure 11):

1. Identification of the main bio-based product in your organisation.
2. Identification of all other bio-based co-products that are generated. Residues are also included here.
3. Identification of all biological and fossil feedstocks necessary to generate your product, as well as the by-products and residues resulting from the process.
4. Identification of your position (i.e., type of actor according to Figure 9) in the value chain. It should be noted that: i) you are a primary producer if your feedstock comes from natural sources; and ii) you are a waste producer if your primary activity is waste treatment/management; and iii) you are an intermediate producer or final producer when none of the above apply to you.
5. Quantification and characterisation of all your flows. This includes feedstocks, product, co-products, residue, resources (water, energy, chemicals, etc).
6. Review the applicable indicator equations. Gather any additional information necessary for calculation.
7. Calculate all applicable indicators.

Material input and production indicators are calculated by every type of actor in the value chain. Intermediate and final producers are responsible for calculating the use phase and end-of-life indicators. Primary producers, being at the start of the value chain, can access the required information more easily. On the contrary, intermediate and final actors, at more advanced steps in the supply chain, will need to contact their feedstock provider to support the calculation of the previous step(s) in the chain. Likewise, although waste producers are also at the starting point of a value chain, they also may need to request information about their input feedstocks, depending on the type of waste management they provide.

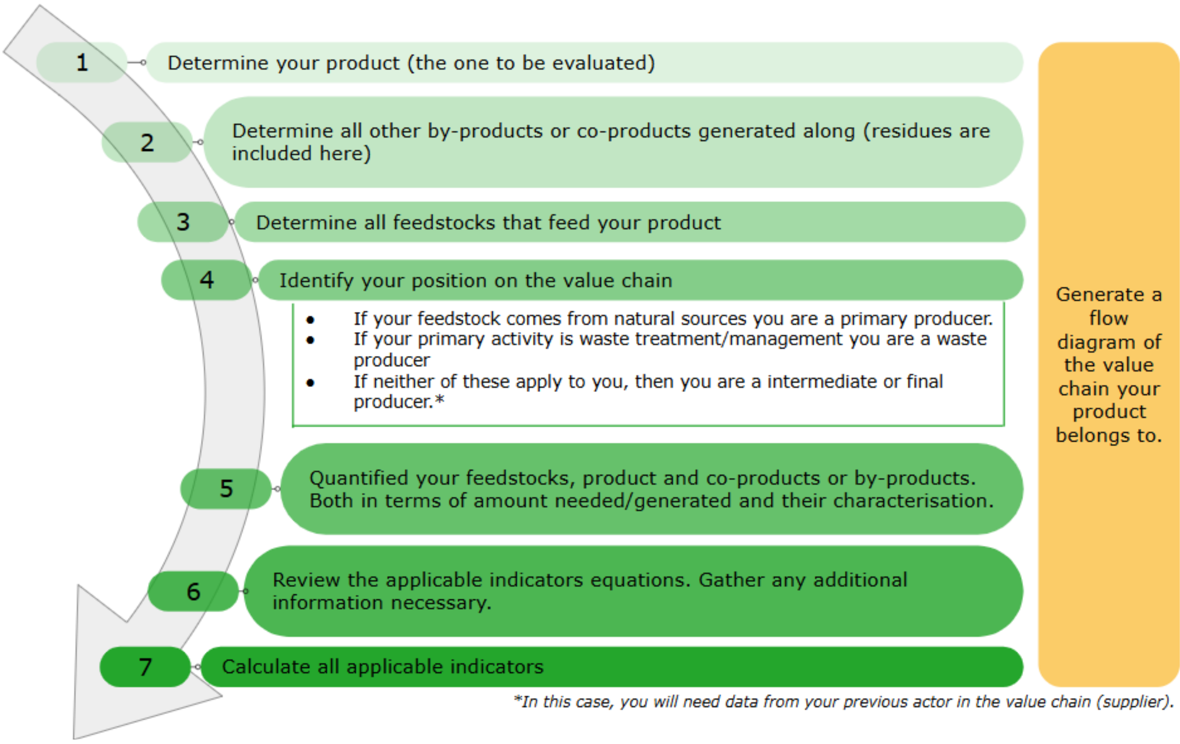

Figure 11. Steps to calculate quantitative indicators.

Finally, a key aspect when measuring circularity is understanding how biological feedstocks are used throughout the value chain. The above-mentioned steps need to be complemented with an overall understanding of the entire value chain. Thus, generating a flow diagram of the value chain is a visual way of understanding the inputs, outputs and flows of a given value chain. The level of detail will depend on the information available. As a minimum, the organisation preparing to apply the BioReCer framework must identify their position in the value chain as well as the steps that precede and follow themselves. Figure 12 shows an example of the flow diagrams for two different value chains.

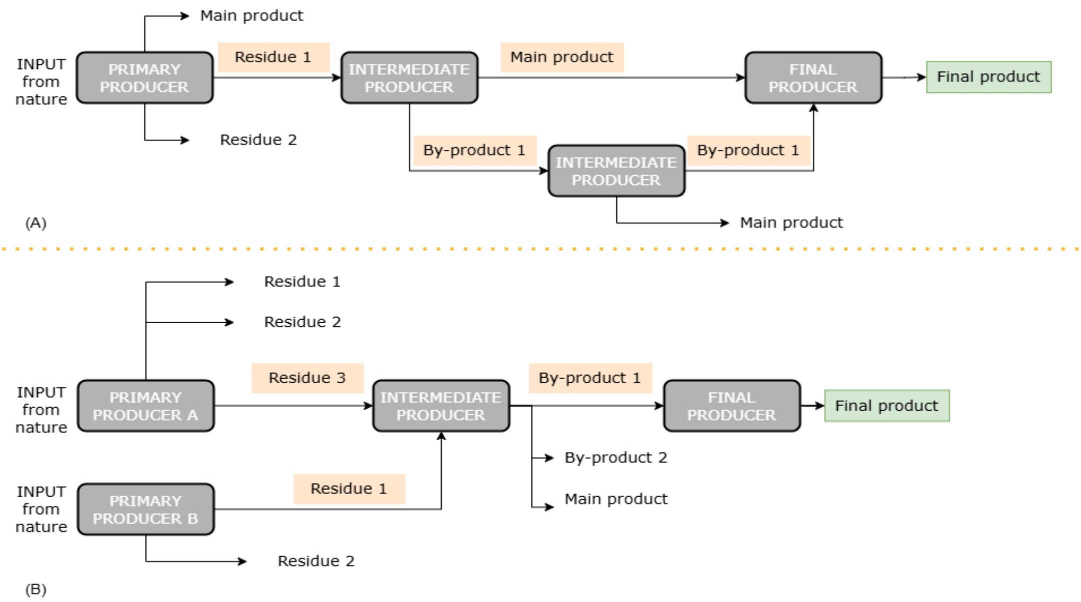

Figure 12. Examples of flow diagrams for bio-based value chains (A) and (B).
Note. the grey boxes represent value chain actors; light orange boxes the biological resources moving through the value chain and green boxes the final products. Note: value chain (A) shows one primary producer, two intermediate producers and a final producer while value chain (B) shows two primary producers, an intermediate producer and a final producer.

As already mentioned, the indicator to be calculated depends on the position within the value chain (i.e., the type of actor). Hence, Figure 13 to Figure 15 present for each type of actor (primary, waste, intermediate and final producer) the equation number for all applicable indicators as they were presented in *D2.3 - Circular indicators*. The equation number in italic depicts the indicators that are calculated only using data from the own actor, whilst the equation numbers in bold indicate that either data or the indicators from a previous actor are needed for the calculations.

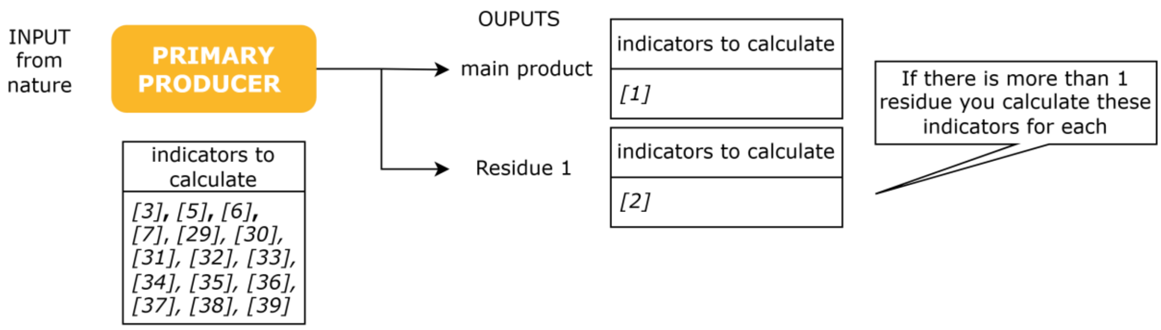

Figure 13. Equation numbers (as shown in D2.3 - Circular indicators) for indicators to be calculated by primary producers.

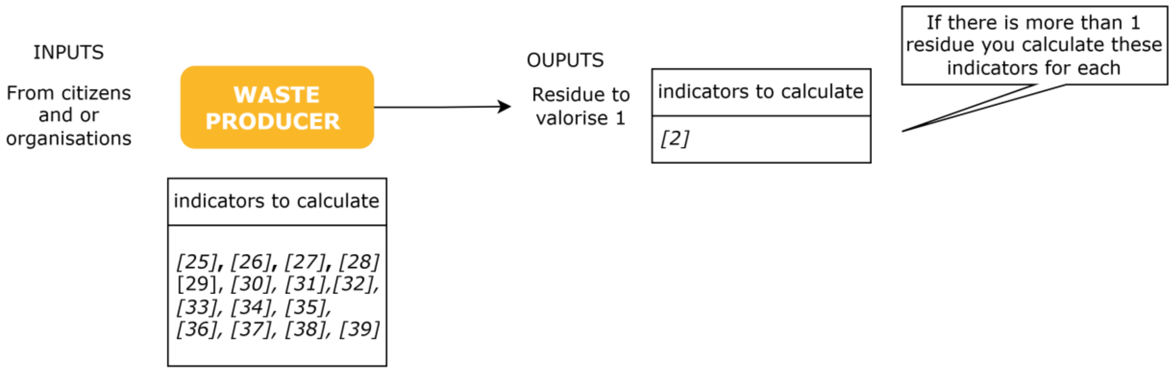

Figure 14. Equation numbers (as shown in D2.3 - Circular indicators) for indicators to be calculated by waste producers.

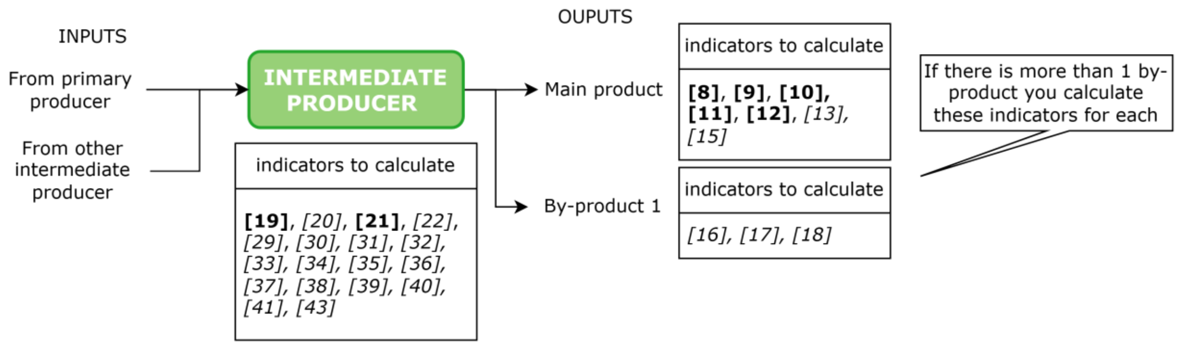

Figure 15. Equation numbers (as shown in D2.3 - Circular indicators) for indicators to be calculated by intermediate producers.

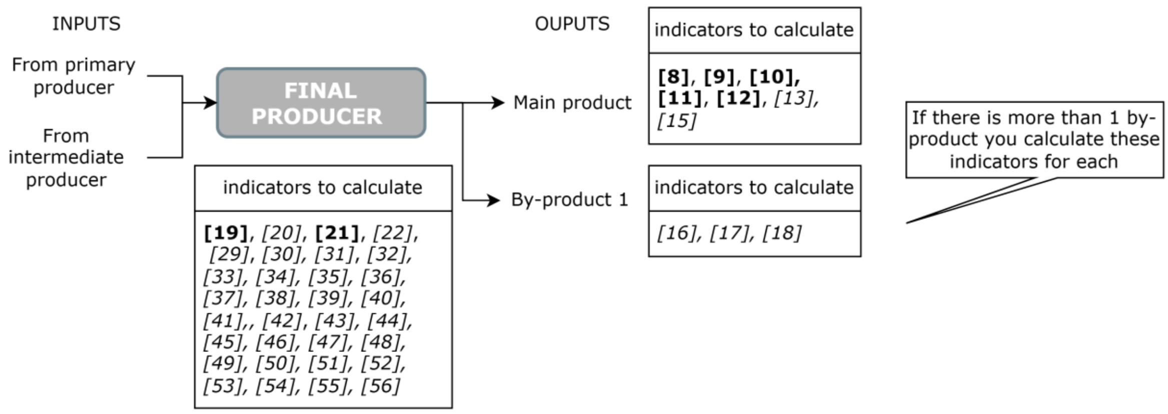

Figure 16. Equation numbers (as shown in D2.3 - Circular indicators) for indicators to be calculated by final producers.

As it can be seen in Figure 14 and Figure 15, since primary and waste producers are the start of the value chains, they do not need indicators from previous actors, unlike intermediate and final producers.

Finally, an example is presented to guide practitioners through calculations of the indicators. Figure 17 presents an example of a value chain, depicting the production of bio-fertilisers (i.e., final product) from different biological feedstocks. In this example, there are two primary producers, an intermediate producer and a final producer; the products that are used along the value chain are highlighted in yellow and green on Figure 17. In this example, the final producer is applying the BioReCer framework, thus needs to calculate the quantitative indicators.

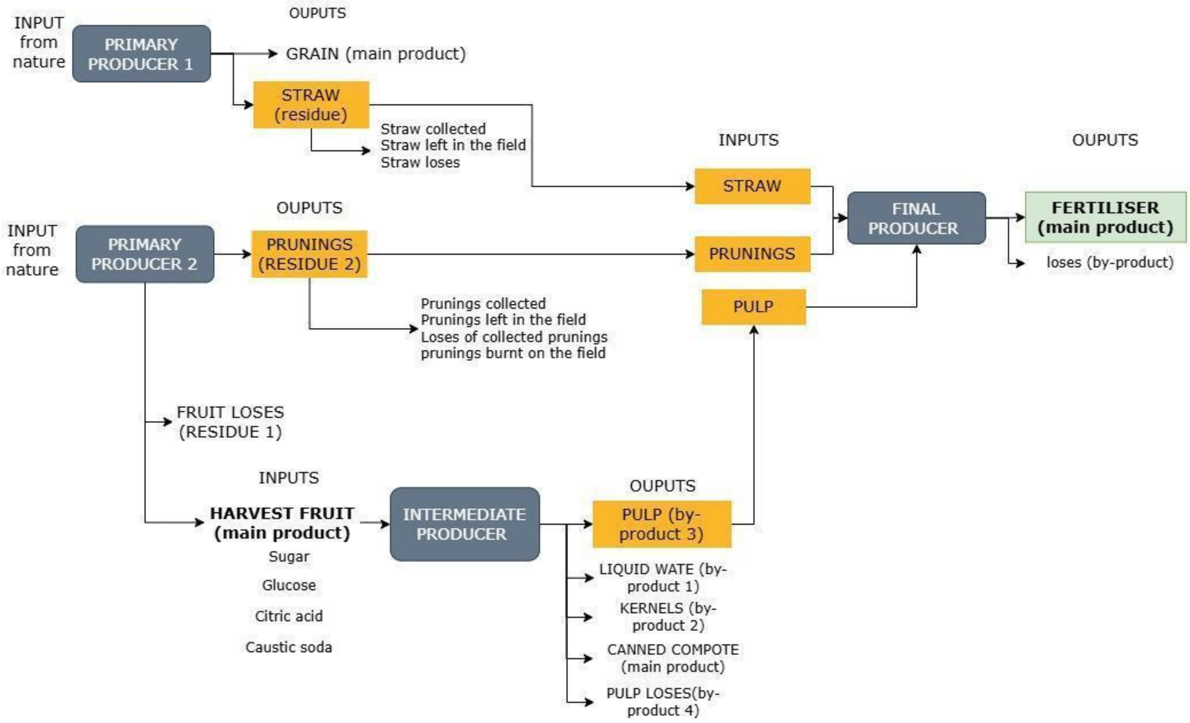

Figure 17. Example of a flow diagram for a bio-based value chain, detailing two primary producers, an intermediate producer and a final producer.

Note: yellow boxes are the biological feedstocks being used in the value chain; green boxes are the final product; and grey boxes are actors.

According to the example, the bio-fertilisers (final product) value chain involves one intermediate product (pulp), and two primary producers (straw and pruning, respectively). Firstly, the producer of bio-fertiliser shall identify the indicators to be calculated as final producer (Figure 16). Secondly, from the identified indicators, some can be directly calculated (see equations number of the indicators in italics of Figure 16 by final producers since necessary data and parameters are controlled by the final producer whilst other indicators (see equations number of the indicators in bold of Figure 16) need data from previous actors in the value chain as follows:

- Primary producer 1 shall provide to the final producer the data or indicators necessary to calculate the specific indicators for the final product: indicators calculated by equations [1];[2];[6];[7].
- Primary producer 2 shall provide to the final producer the data or indicators necessary to calculate the specific indicators for the final product: indicators calculated by equations [1];[2];[6];[7]. Similarly, primary producer 2 shall provide to the intermediate producer the data or indicators necessary to calculate the specific indicator for intermediate product (pulp): indicators calculated by equations [7];[1];[6].

- Intermediate producer shall provide to the final producer the data or indicators necessary to calculate the specific indicators for the final product: indicators calculated by equations [15];[16];[17];[18];[19];[21].

Since only the final producer is applying the BioReCer framework, they need to calculate all the indicators presented in *D2.3 - Circular indicator*s and Annex B of the present document (equation numbers for the indicators are marked in green in Figure 18). The other actors in the value chain are not applying the framework, therefore they only calculate or give the necessary data to the final producer for the indicators whose equations are marked in pink (primary producer 1), purple (primary producer 2) and blue (intermediate producer) in Figure 18.

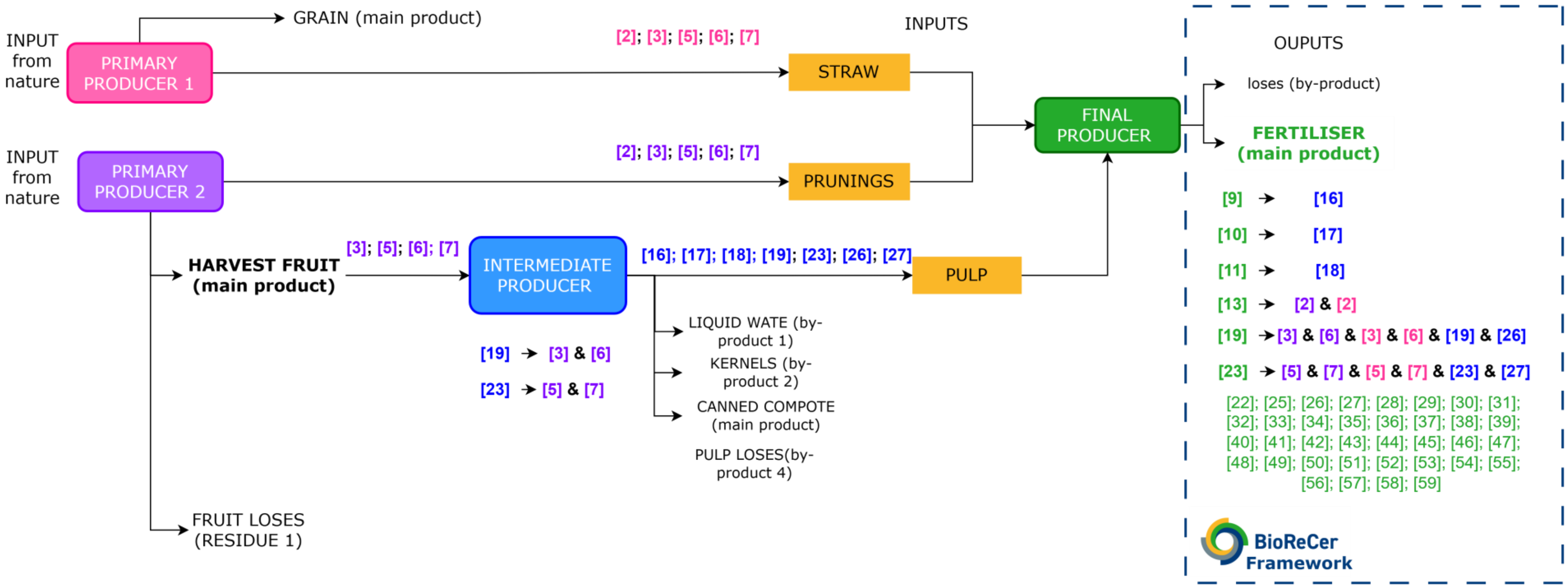

Figure 18. Example of related indicators in a value chain. The number relates to how the indicators are presented in D2.3 - Circular indicators. Note: yellow boxes are the biological feedstocks being used in the value chain; pink numbers refer to Primary producer 1 indicators; purple numbers refer to Primary producer 2 indicators; blue numbers refer to intermediate producer indicators*; and green numbers refer to final producer indicators.*

5 Conclusion

The BioReCer framework represents a significant advancement in integrating sustainability and circularity principles into bio-based certification schemes. By streamlining the theoretical foundations established in previous deliverables (*D2.2 - Modified assessment methodologies* and *D2.3 - Circular indicators*), this report has developed a guideline for existing certification schemes when adapting the framework.

A key achievement of this deliverable is the unification of requirements into a comprehensive set of 52 requirements, categorised into basic (mandatory) and advanced (non-mandatory). This classification ensures that certification schemes can establish a minimum compliance threshold while promoting continuous improvement and best practices in the sector. Furthermore, the integration of quantitative circularity indicators strengthens the framework, providing a means to measure circularity.

The development of guidelines for integrating the framework into existing certification schemes is another major outcome. The two-stage compliance approach—which includes a go/no-go evaluation for basic requirements and an evaluative process for advanced criteria—allows for flexibility while maintaining rigorous standards. Additionally, the decision tree for compliance assessment provides certification bodies with a clear methodology for determining an organisation’s eligibility. The section on practical circularity indicators calculations supports WP4 in developing practical guidelines for existing certification schemes for the integration of the BioReCer framework.

List of abbreviations

BIT	BioReCer ICT Tool
BRSP	BioResources Stakeholders Platform
CE	Circular Economy
EoL	End-of-life
EIA	Environmental Impact assessment
GHG	Greenhouse Gases
UN	United Nations
US EPA	United States Environmental Protection Agency
WCED	World Commission on Environment and Development
WP	Work package
WTP	Willingness to pay

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Annex A: Theoretical sustainability and circularity framework

The theoretical framework developed in *D2.2 - Modified Assessment Methodologies* is presented in a graphical manner here.

Aspect	Pillar	Principle	Criteria	Requirement
Sustainability	Environmental	**Protection of ecosystems**	The company defines functions to conserve and manage the environment	The company identifies the water sources affected by runoffs and discharges
				The company has proposed strategies to protect water, soil and air quality and prevent negative impacts
				The company uses and has appropriate maintenance for machinery, processing, disposal containers, and facilities for handling products, materials, and wastes
				The company shall indicate whether it adopts ecosystem regeneration and rehabilitation measures
				The company shall provide the most updated Environmental Impact assessment (EIA) of the area before starting its operations
				The company has data available about the type of sources of water used for the production process
			The company develop strategies of mitigation and adapting to climate change	The company measures its carbon emissions and has established a reduction plan
			The company ensures the preservation of ecosystem diversity	The company shall have evaluations about the state of the biodiversity within the area and a plan to maintain and improve biodiversity
				The company shall identify whether its operation is happening in a protected area
			The company has mechanisms to control polluting emissions	The company measures the noise and odour to ensure that they are under the legal threshold
				The company identifies and characterizes emissions to air, soil, and water to comply with legal thresholds
				The company has some kind of treatment technology to prevent emissions to the environment
			The company manages waste under an environmental sound approach	The company applies the waste hierarchy to reduced and valorised its waste
				The company has an appropriate labelling for hazardous waste considering aspects of classification and managements
			The company identifies genetically modified species when utilised	The company characterizes the introduced genetically modified species
			The company restricts the use of invasive species and pathogens	The company quantifies non-indigenous/invasive species and pathogens introduced into the ecosystem

Aspect	Pillar	Principle	Criteria	Requirement
Sustainability	Environmental	**Safe and sustainable use of resources**	The company ensures the continuous provision of resources by preserving the resilience of ecosystems	The company considers the resilience of the ecosystem to ensure sustainability
				The company establishes and monitors key performance indicators to ensure a responsible use of resources and avoid the degradation of ecosystems
			The company promotes the management of natural resources sustainably	The company has an energy efficiency plan in place
				The company has a plan to manage resources and water efficiently
			The company promotes the safe commercialization of resources	The company identifies and quantifies the use of chemicals and hazardous substances
				The company identifies whether action has been addressed to ensure food security in biomass production systems

Aspect	Pillar	Principle	Criteria	Requirement
Sustainability	Environmental	**Working conditions and society**	The company complies with the labor conditions established by the regulatory framework	The company has a Health and Safety plan in place
				The company provides accident insurance coverage and adequate compensation for all workers
				The company allows work and personal life combination by limiting standard working hours as per national regulation, ILO standards, WHO guidelines, etc
				The company has effective complaints and grievance mechanisms and take measures to resolve the reported complaints and grievances
				The company ensures gender equality
				The company keep records on work-related accidents or incidents
				The company promotes the participation of its employees on certified training activities and competencies
			The company contributes to job creation and helps to meet community needs	The company contributes to enhance the employment rate in the sector
				The company ensures the payment of wages that meet or exceed industry minimum standards

Aspect	Pillar	Principle	Criteria	Requirement
Sustainability	Environmental	**Business models and value creation**	The company ensures the quality and traceability of its products and other outputs	The company promotes the use of materials with bio-based origin as well as non-virgin materials on its final products
				The company has established measures to track the disposal of by-products and waste
				The company has established of measures to improve product traceability
			The company makes good use of its assets	The company has investments and expenditures related to research, development and training of employees
				The company has good management of the unsold finished goods, prevention of generation of waste
				The company has in place measures to ensure the optimization of cost (operational, infrastructure, waste treatment)
				The company must ensure that subcontractors also complies with the requirements of the certification schemes
			The company respects private property	The company has fully documented property rights
			The company respects promotes transparency	The company is a legally defined entity with a clear and documented legal record
			The company promotes corporate social responsibility	The company takes into consideration green procurement criteria in the selection of its suppliers
				The company complies with certification schemes and standards verified by a third-party

Aspect	Pillar	Principle	Criteria	Requirement
Circularity	Environmental	**Elimination of waste and pollution**	The company considers end-of-life treatment as possible strategies for valorization	The company quantifies the waste and selects the most appropriate treatment
			The company monitors the reduction of environmental impacts after the application of circular economy strategies	The company has identified the environmental benefits resulting from the implementation of circular economy strategies (reduction, recycling, recovering,…)

Aspect	Pillar	Principle	Criteria	Requirement
Circularity	Economic	**System thinking and business model**	The company promotes strategies of industrial symbiosis	The company has collaborations with other companies aiming at the good use of resources
			The company has an appropriate circular business stewardship to create value	The company is able to demonstrate that the implementation of plans, initiatives and practices on circular economy has resulted in economic benefits
			The company promotes innovation and procurement to create value	The company allocates resources to research and develop circular economy strategies within its value chain
				The company has contracts with suppliers selling products/materials certified as circular
			The company promotes its transparency in terms of circularity	The company is willing to share information publicly about its activities related to the circular economy

Aspect	Pillar	Principle	Criteria	Requirement
Circularity	Social	**Social procurement**	The company has communication and education programmes	The company has participated in awareness campaigns to promote the benefits of the circular economy
				The company has programmed training activities for workers to tackle with the specificities of circular technologies and/or strategies
			The company has created employment and skills opportunities	The company has created new jobs positions in line with the needs of the circular economy strategies implemented

Aspect	Pillar	Principle	Criteria	Requirement
Circularity	Environmental	**Availability of resources by keeping them at their highest value and utility at all times**	The company promotes the substitution of virgin materials by secondary raw materials	The company achieves goals of reduction or substitution of resources

Aspect	Pillar	Principle	Criteria	Requirement
Circularity	Environmental	**Protect and contribute to the resilience and regeneration of natural capital**	The company promotes the recovery of resources	The company has plans, initiatives or practices for the recovery of waste or use non-virgin materials on its final products
				The company considers water reclamation onsite or outside the facilities of the company

Aspect	Pillar	Principle	Criteria	Requirement
Circularity	Economic	**Value creation**	The company designs and manufactures products and assets taking into account circular economy strategies	The company can demonstrate that its products have the same characteristics and quality as its conventional counterpart
			The company strategically promotes the creation of added value	The company has plans, initiatives or practices to ensure the increase of resource productivity
				The company has defined strategies to promote a system thinking of processes and the analysis of material loops

Annex B: List of circular indicators

Presented here is the list of circular indicators developed *in D2.3 – Circular indicators*. The equation number listed are the same as in the above-mentioned deliverable. For more detailed on how the indicators were constructed please go to *D2.3 – Circular indicators*.

Material Input Indicators

Selected indicators for Primary Producers of bio-based products and by-products only:

Verified virgin renewable product (%) – for main products:

$$\mathbf{VVREN(P)} = \frac{\mathbf{m_{VVEN(P)}}}{\mathbf{m_P}} \times \mathbf{100} \qquad \textbf{(1)}$$

Where,

VVREN(P): the verified virgin renewable product of primary producers in %;

$\mathbf{m_{VVEN(P)}}$: the dry mass of verified virgin renewable content of the primary producer's product, in kg or other mass unit;

$\mathbf{m_P}$: the total dry mass of the product generated by the primary producer, in kg or other mass unit.

Circularity characterisation factor of residue (%) – for primary producer's by-products:

$$\mathbf{CCF(R)} = \frac{\mathbf{RENR + SRR + UNAVR + 0.5 \times AVR}}{\mathbf{3}} \qquad \textbf{(2)}$$

Where,

CCF(R): the circularity characterisation factor of the residue generated by primary producers and that is further utilised, in %;

RENR: the percentage of residue that is validated as renewable, in %;

SSR: the percentage of residue that is sustainably removed for further utilisation in line with the sustainable removal rate, in %;

UNAVR: the percentage of residue that is characterised as unavoidable residue, in %;

AVR: the percentage of residue that is characterised as avoidable residue, in %.

Modified Biomass Utilisation Factor of Primary Producers:

$$\mathbf{MBUF_0} = \frac{\mathbf{m_{BBP}} + \mathbf{m_{RtPFC}} + \mathbf{m_{RtFF}} + \mathbf{m_{RtBPP}} + \mathbf{m_{RtBCM}} + \mathbf{m_{RtEHF}} + \mathbf{m_{RtUF}}}{\mathbf{m_{TO}}} \tag{3}$$

Where,

$MBUF_0$: the modified biomass utilisation factor for primary producers, unitless (defined as a ratio);

m_{BBP}: the dry mass of the main bio-based product generated, in kg or other mass unit;

m_{RtPFC}: the dry mass of the generated residue that is provided as feedstock for the generation of pharmaceuticals and fine chemicals, in kg or other mass unit;

m_{RtFF}: the dry mass of the generated residue that is provided as feedstock for the generation of food and feed, in kg or other mass unit;

m_{RtBPP}: the dry mass of the generated residue that is provided as feedstock for the generation of bioplastics and polymers, in kg or other mass unit;

m_{RtBCM}: the dry mass of the generated residue that is provided as feedstock for the generation of bulk chemicals and materials, in kg or other mass unit;

m_{RtEHF}: the dry mass of the generated residue that is provided as feedstock for the generation of energy, heat and fuels, in kg or other mass unit;

m_{RtUF}: the dry mass of the generated residue that is usefully utilised in biosphere according to the sustainably remaining residue rate, in kg or other mass unit;

m_{TO}: the total dry mass of outputs (all products and by-products) generated by the primary producer, in kg or other mass unit.

The total mass of outputs generated by the primary producer can be calculated as follows:

$$\mathbf{m_{TO}} = \mathbf{m_{BBP}} + \mathbf{m_{RtPFC}} + \mathbf{m_{RtFF}} + \mathbf{m_{RtBPP}} + \mathbf{m_{RtBCM}} + \mathbf{m_{RtEHF}} + \mathbf{m_{RtUF}} + \mathbf{m_W} \tag{4}$$

Where,

m_W: the dry mass of remaining outputs (e.g., products, by-products, etc.) that are not usefully utilised neither in the biosphere nor in the technosphere (often referred as waste), in kg or other mass unit. *An example is the mass of residues that is burnt onsite, or residue left onsite that exceeds the sustainably remaining residue rate*.

Based on **equation (3)**, the value-based biomass utilisation factor – adapted by the Bioresource Utilisation Index – can be calculated using the **equation (5)** below.

Value-based Biomass Utilisation Factor following the bio-based value pyramid:

$$\mathbf{VMBUF_0} = \frac{\mathbf{m_{BBP} + m_{RtPFC} \times 1 + m_{RtFF} \times 0.8 + m_{RtBPP} \times 0.6 + m_{RtBCM} \times 0.4 + m_{RtEHF} \times 0.2 + m_{RtUF} \times 1}}{\mathbf{m_{TO}}} \quad \textbf{(5)}$$

The primary producer should provide the contribution of each individual product and by-product to the total generated output to the relevant downstream supply chain actor(s), calculated as follows:

$$\mathbf{BO(X)_{n+1}} = \frac{\mathbf{m_X}}{\mathbf{m_{TO}}} \times \mathbf{100} \quad \textbf{(6)}$$

$$\mathbf{VBO(X)_{n+1}} = \frac{\mathbf{m_X}}{\mathbf{m_{TO}}} \times c_X \times \mathbf{100} \quad \textbf{(7)}$$

Where,

$BO(X)_{n+1}$: the product/by-product X that will be utilised as input by the next actor as a percentage of the total produced output, in %;

m_X: the dry mass of the relevant product or by-product X in which the downstream actor is interested (e.g. m_{BBP}, m_{RtPFC}, m_{RtFF}, m_{RtBPP}, m_{RtBCM}, m_{RtEHF}, m_{RtUF}), in kg or other mass unit;

$VBO(X)_{n+1}$: the value-added of the product/by-product X that will be utilised as input by the next actor as a percentage of the total produced output, in %;

c_X: the coefficient assigned to the utilisation of product or by-product X based on the bio-based value pyramid.

<u>Selected indicators of **bio-based products** – related to all types of pre- and post-consumer producers use for intermediate and final producers.</u>

Each supply chain actor receiving feedstock for the generation of their products should perform a characterisation of their inputs (i.e., feedstocks) and outputs (i.e. products and by-products) to calculate the circularity indicators presented in **equations (8)-(28)**.

Reused content of product (%):

$$\mathbf{REUC(P)} = \frac{\mathbf{m_{REUC(P)}}}{\mathbf{m_P}} \times \mathbf{CC(P)_{n-1}} \qquad \mathbf{(8)}$$

Where,

REUC(P): the reused content of product, in %;

$\mathbf{m_{REUC(P)}}$: the dry mass of product that originates from reused inputs, in kg or other mass unit;

$\mathbf{m_P}$: the total dry mass of product, in kg or other mass unit;

$\mathbf{CC(P)_{n-1}}$: the circular content – equation (15) – of the specific reused input obtained by the previous actor that provides this input, in %.

Pre-consumer recycled bio-based content of product (%):

$$\mathbf{PRRECBBC(P)} = \frac{\mathbf{m_{PRERECBBC(P)}}}{\mathbf{m_P}} \times \mathbf{CCF(BBB)_{n-1}} \qquad \mathbf{(9)}$$

Where,

PRRECBBC(P): the pre-consumer recycled bio-based content of product, in %;

$\mathbf{m_{PRERECBBC(P)}}$: the dry mass of product that originates from pre-consumer recycled bio-based inputs, in kg or other mass unit;

$\mathbf{CCF(BBB)_{n-1}}$: the circularity characterisation factor of pre-consumer bio-based by-product obtained by the previous actor (i.e. the supplier of pre-consumer recycled bio-based input), in %.

Post-consumer recycled fossil-based content of product (%):

$$\mathbf{PORECFBC(P)} = \frac{\mathbf{m_{POERECFBC(P)}}}{\mathbf{m_P}} \times \mathbf{CCF(FBB)_{n-1}} \qquad \mathbf{(10)}$$

Where,

PORECFBC(P): the post-consumer recycled fossil-based content of product, in %;

$\mathbf{m_{PRERECFBC(P)}}$: the dry mass of product that originates from post-consumer recycled fossil-based inputs, in kg or other mass unit;

CCF(FBB)$_{n-1}$: the circularity characterisation factor of post-consumer fossil-based by-product obtained by the previous actor (i.e. the supplier of post-consumer recycled fossil-based input), in %.

Post-consumer recycled bio-based content of product (%):

$$\mathbf{PORECC(P) = \frac{m_{POSTRECC(P)}}{m_P} \times CCF(POB)_{n-1}} \qquad \textbf{(11)}$$

Where,

PORECC(P): the post-consumer recycled content of product, in %;

m$_{POSTRECC(P)}$: the dry mass of product that originates from post-consumer recycled inputs, in kg or other mass unit;

CCF(POB)$_{n-1}$: the circularity characterisation factor of post-consumer by-product obtained by the previous actor (i.e. the supplier of post-consumer recycled input), in %.

Virgin renewable content of product (%):

$$\mathbf{VRENC(P) = \frac{m_{VRENC(P)}}{m_P} \times VVREN(P)} \qquad \textbf{(12)}$$

Where,

VRENC(P): the virgin renewable content of the product, in %;

m$_{VRENC(P)}$: the dry mass of product that originates from virgin renewable inputs, in kg or other mass unit.

Content of Primary Producers' Circular Residue in Product (%):

$$\mathbf{PPRESC(P) = \frac{m_{PPRESC(P)}}{m_P} \times CCF(R)} \qquad \textbf{(13)}$$

Where,

PPRESC(P): the content of primary producer's circular residue in product, in %;

m$_{PPRESC(P)}$: the dry mass of product that originates from circular residual inputs obtained by primary producers, in kg or other mass unit.

The total dry mass of product generated can be calculated as follows:

$$\mathbf{m_P} = \begin{array}{c}\mathbf{m_{REUC(P)}} + \mathbf{m_{PRERECBBC(P)}} + \mathbf{m_{PRERECFBC(P)}} \\ + \mathbf{m_{POSTRECC(P)}} + \mathbf{m_{VRENC(P)}} + \mathbf{m_{PPRESC(P)}} + \mathbf{m_V}\end{array} \quad \textbf{(14)}$$

Where,

$\mathbf{m_V}$: the dry mass of product that originates from virgin non-renewable inputs (whether they are fossil-based or unverified renewable), in kg or other mass unit.

Circular Content of Product (%):

$$\mathrm{CC(P)} = \mathbf{REUC(P)} + \mathbf{PRRECBBC(P)} + \mathbf{PORECFBC(P)} + \mathbf{PORECC(P)} + \mathbf{VRENC(P)} + \mathbf{PPRESC(P)} \quad \textbf{(15)}$$

Where,

CC(P): the circular content of the product, in %.

Selected indicators of **by-products** sent for further utilisation in a different supply chain actor:

Circularity characterisation factor of pre-consumer bio-based by-product (%):

$$\mathbf{CCF(BBB)_n} = \frac{\mathbf{RCSR_{BBB}} + \mathbf{UNAVR_{BBB}} + \mathbf{0.5} \times \mathbf{AVR_{BBB}}}{\mathbf{2}} \quad \textbf{(16)}$$

Where,

$\mathbf{CCF(BBB)_n}$: the circularity characterisation factor of pre-consumer bio-based by-product generated by the current supply chain actor, in %.

$\mathbf{RCSR_{BBB}}$: the portion of the total dry mass of bio-based by-product that originates from validated renewable inputs and circular secondary resources, in %. $RCSR_{BBB}$ is the equivalent of equation (15) for the by-product – meaning that for each by-product, equations (8)-(15) need to be calculated;

$\mathbf{UNAVR_{BBB}}$: the portion of the total dry mass of bio-based by-product that is characterised as unavoidable by-product, in %;

$\mathbf{AVR_{BBB}}$: the portion of the total dry mass of bio-based by-product that is characterised as avoidable by-product, in %.

Circularity characterisation factor of post-consumer fossil-based by-product (%):

$$\mathbf{CCF(FBB)_n = UNAVR_{FBB} + 0.5 \times AVR_{FBB}} \quad \textbf{(17)}$$

Where,

$CCF(FBB)_n$: the circularity characterisation factor of post-consumer fossil-based by-product generated by the current supply chain actor, in %.
$UNAVR_{FBB}$: the portion of the total dry mass of fossil-based by-product that is characterised as unavoidable by-product, in %;
AVR_{FBB}: the portion of the total dry mass of fossil-based by-product that is characterised as avoidable by-product, in %.

Circularity characterisation factor of post-consumer bio-based by-product (%):

$$\mathbf{CCF(POB)_n = \frac{ROFR_{POB} + SRUR_{POB} + UNAVR_{POB} + 0.5 \times AVR_{POB}}{3}} \quad \textbf{(18)}$$

Where,

$CCF(POB)_n$: the circularity characterisation factor of post-consumer by-product generated by the current supply chain actor, in %.
$ROFR_{POB}$: percentage of the organic fraction of post-consumer by-product validated as renewable, in %.
$SRUR_{POB}$: percentage of post-consumer by-product that is sustainably recovered for further utilisation, in %.
$UNAVR_{POB}$: the portion of the total dry mass of post-consumer by-product that is characterised as unavoidable by-product, in %;
AVR_{POB}: the portion of the total dry mass of post-consumer by-product that is characterised as avoidable by-product, in %.

Biomass Utilisation Contribution of Intermediate (and Final) Producers:

$$\mathbf{BUC_n = EF_{n(t)}\ x\ BO(X)_{n-1}} \quad \mathbf{(19)}$$

Where,

BUC_n: the biomass contribution factor of intermediate and final producers by the current actor, unitless (defined as a ratio);

$BO(X)_{n-1}$: the product/by-product X that is further utilised by another actor as a percentage of the total primary producer's generated output as calculated by the previous actor, in %;

$EF_{n(t)}$: the total production efficiency of the current actor in producing valuable products and by-products, unitless (estimated as a ratio) and calculated using **equation (20)** below.

Total production efficiency of the current actor in producing valuable products and by-products:

$$\mathbf{EF_{n(t)} = \frac{\begin{gathered}(m_{BBP1} + \cdots + m_{BBPz}) + (m_{BBtPFC1} + \cdots + m_{BBtPFCz}) + (m_{BBtFF1} + \cdots + m_{BBtFFz}) \\ + (m_{BBtBPP1} + \cdots + m_{BBtBPPz}) + (m_{BBtBCM1} + \cdots + m_{BBtBCMz}) \\ + (m_{BBtEHF1} + \cdots + m_{BBtEHFz}) + (m_{BBtUF1} + \cdots + m_{BBtUFz})\end{gathered}}{m_{TBI}}} \quad \mathbf{(20)}$$

Where,

m_{BBP1z}: the dry mass of the main bio-based product(s) generated originating from the utilised biomass, in kg or other mass unit;

$m_{BBtPFCz}$: the dry mass of the generated by-product(s) originating from the utilised biomass that is provided as feedstock for the generation of pharmaceuticals and fine chemicals, in kg or other mass unit;

m_{BBtFFz}: the dry mass of the generated by-product(s) originating from the utilised biomass that is provided as feedstock for the generation of food and feed, in kg or other mass unit;

$m_{BBtBPPz}$: the dry mass of the generated by-product(s) originating from the utilised biomass that is provided as feedstock for the generation of bioplastics and polymers, in kg or other mass unit;

m_{RtBCM}: the dry mass of the generated by-product(s) originating from the utilised biomass that is provided as feedstock for the generation of bulk chemicals and materials, in kg or other mass unit;

$m_{BBtEHFz}$: the dry mass of the generated by-product(s) originating from the utilised biomass that is provided as feedstock for the generation of energy, heat and fuels, in kg or other mass unit;

m_{BBtUFz}: the dry mass of the generated by-product(s) originating from the utilised biomass that is usefully utilised in biosphere according to the sustainably remaining residue rate, in kg or other mass unit;
m_{TBI}: the total dry mass of biomass input to the current actor used to generate all the above products and by-products, in kg or other mass unit.

Value-based Biomass Utilisation Contribution (VMBUC)n:

$$\mathbf{VBUC_n = VBO(X)_{n-1}\ x\ VEF_{n(t)}} \quad \textbf{(21)}$$

Where,
$VBUC_n$: the contribution of the current actor to the value-added of the actual biomass utilisation, in %.
$VBO(X)_{n-1}$: the value-added of the utilised product/by-product X as a percentage of the total primary producer's generated output as calculated by the previous actor, in %;
$VEF_{n(t)}$: the total production efficiency of the current actor in producing valuable products and by-products sent to added value applications, unitless (estimated as a ratio) and calculated using **equation (22)** below.

Total production efficiency of the current actor in producing valuable products and by-products sent to added value applications:

$$\mathbf{VEF_{n(t)} = \frac{\sum_{i=1}^{z} m_{BBPi} + \sum_{i=1}^{z}(m_{BBtPFCi} \times 1) + \sum_{i=1}^{z}(m_{BBtFFi} \times 0.8) + \sum_{i=1}^{z}(m_{BBtBPPi} \times 0.6) + \sum_{i=1}^{z}(m_{BBtBCMi} \times 0.4) + \sum_{i=1}^{z}(m_{BBtEHFi} \times 0.2) + \sum_{i=1}^{z}(m_{BBtUFi})}{m_{TBI}}} \quad \textbf{(22)}$$

The pre-consumer producer should provide the contribution of each individual product and by-product in relation to the total primary producer's generated output (m_{TO}) to the relevant downstream supply chain actor(s), calculated as follows:

$$\mathbf{BO(X)_{n+1} = \frac{m_X}{m_{TO}} \times 100} \quad \textbf{(23)}$$

$$\mathbf{VBO(X)_{n+1} = \frac{m_X}{m_{TO}} \times c_X \times 100} \quad \textbf{(24)}$$

Where,
$BO(X)_{n+1}$: the product/by-product X that will be utilised as input by the next actor as a percentage of the total primary producer's generated output, in %;

m_X: the dry mass of the relevant product or by-product X in which the downstream actor is interested (e.g. m_{BBP}, m_{RtPFC}, m_{RtFF}, m_{RtBPP}, m_{RtBCM}, m_{RtEHF}, m_{RtUF}), in kg or other mass unit;

$VBO(X)_{n+1}$: the value-added of the product/by-product X that will be utilised as input by the next actor as a percentage of the total primary producer's generated output, in %;

c_X: the coefficient assigned to the utilisation of product or by-product X based on the value based pyramid.

There are certain supply chain actors that receive feedstocks, such as **sewage sludge, OFMSW, and organic liquid waste**, which are complex mixtures of various biomass sources that have undergone significant transformations. These types of feedstocks are challenging to trace back to their primary production. In this deliverable, for biorefineries receiving these types of feedstocks, the cascading stage of feedstock utilization is considered to start at the point of their input, rather than tracing back to the virgin biomass production. In these cases, instead of using **equations (19)-(24)**, **equations (25)-(28)** are used as presented below.

Modified Biomass Utilisation Factor for supply chain actors dealing with complex biomass mixtures:

$$\mathbf{MBUF_0} = \frac{\mathbf{m_{PFC} + m_{FF} + m_{BPP} + m_{BCM} + m_{EHF} + m_{UF}}}{\mathbf{m_{TBI}}} \tag{25}$$

Where,

$MBUF_0$: the modified biomass utilisation factor, unitless (defined as a ratio);

m_{PFC}: the (dry) mass of the generated (by-)product sent to pharmaceuticals and fine chemicals production, in kg or other mass unit;

m_{FF}: the (dry) mass of the generated (by-)product sent to food and feed production, in kg or other mass unit;

m_{BPP}: the (dry) mass of the generated (by-)product sent to bioplastics and polymers production, in kg or other mass unit;

m_{BCM}: the (dry) mass of the generated (by-)product sent to bulk chemicals and materials, in kg or other mass unit;

m_{EHF}: the (dry) mass of the generated (by-)product sent to energy, heat and fuels, in kg or other mass unit;

m_{UF}: the (dry) mass of the generated (by-)product that is usefully utilised in biosphere, in kg or other mass unit;

m_{TBI}: the total dry mass of biomass input to the current actor used to generate all the above products and by-products, in kg or other mass unit.

In the Value-based Biomass Utilisation Factor, the coefficients assigned to the different uses of the (by-)products are not the same as in equations (5) and (18), as biorefineries dealing with such complex feedstocks are often restricted from generating products for high-value applications (e.g., food and feed, cosmetics, etc.). Therefore, in these cases, bioplastics and polymers are considered among the highest value applications, with the least favourable being energy, heat, and fuels.

The Value-based Biomass Utilisation Factor for biorefineries dealing with complex mixtures as feedstocks:

$$\mathbf{VMBUF_0} = \frac{\mathbf{m_{PFC} \times 1 + m_{FF} \times 1 + m_{BPP} \times 1 + m_{BCM} \times 0.8 + m_{EHF} \times 0.4 + m_{UF} \times 0.6}}{\mathbf{m_{TBI}}} \quad \textbf{(26)}$$

The current actor should provide the contribution of each individual product and by-product to the total received inputs to the relevant downstream supply chain actor(s), calculated as follows:

$$\mathbf{BO - B(X)_{n+1}} = \frac{\mathbf{m_X}}{\mathbf{m_{TBI}}} \times \mathbf{100} \quad \textbf{(27)}$$

$$\mathbf{VBO - B(X)_{n+1}} = \frac{\mathbf{m_X}}{\mathbf{m_{TBI}}} \times \boldsymbol{c_X} \times \mathbf{100} \quad \textbf{(28)}$$

Where,

$BO\text{-}B(X)_{n+1}$: the product/by-product X that will be utilised as input by the next actor as a percentage of the total received input, in %;

m_X: the (dry) mass of the relevant product or by-product X in which the downstream actor is interested (e.g. m_{BBP}, m_{RtPFC}, m_{RtFF}, m_{RtBPP}, m_{RtBCM}, m_{RtEHF}, m_{RtUF}), in kg or other mass unit;

$VBO\text{-}B(X)_{n+1}$: the value-added of the product/by-product X that will be utilised by the next actor as a percentage of the total received input, in %;

c_X: the coefficient assigned to the utilisation of product or by-product X based on the bio-based value pyramid.

Circular Production Indicators

Average renewable energy consumed in the total production process for the generated product:

$$\mathrm{REC} = \frac{\mathrm{RE_I} - \mathrm{RE_O}}{\mathrm{TE_I} - \mathrm{TE_O}} \times 100 \quad \textbf{(29)}$$

Where,

REC: the average energy consumed by the total production process that is renewable energy, in %;

$\mathbf{RE_I}$: the renewable energy inflow, in MJ or kWh;

$\mathbf{RE_O}$: the renewable energy outflow, in MJ or kWh;

$\mathbf{TE_I}$: the total energy inflow, in MJ or kWh;

$\mathbf{TE_O}$: the total energy outflow, in MJ or kWh.

Energy Intensity to produce the product:

$$\mathrm{EI} = \frac{\mathrm{TE_I}}{\mathrm{n_P}} \quad \textbf{(30)}$$

Where,

EI: the energy intensity during the reference time period, in MJ or kWh;

$\mathbf{TE_I}$: the total energy inflow during the reference time period, in MJ or kWh;

$\mathbf{n_P}$: is the number of unit products, n, produced during the reference time period.

Energy Intensity performance in comparison to industry average:

$$\mathrm{EIP} = \frac{\mathrm{EI}}{\mathrm{EI_{IA}}} \quad \textbf{(31)}$$

Where,

EIP: the energy intensity performance;

$\mathbf{EI_{IA}}$: the industry average energy intensity.

Circular water withdrawal for the total production process for the generated product:

$$\mathbf{CWW} = \frac{\mathbf{CWI}}{\mathbf{TWI}} \times \mathbf{100} \qquad \textbf{(32)}$$

Where,

CWW: the average water withdrawal from circular sources, in %;

CWI: the volume of water inflow from circular sources, in m^3/year;

TWI: the volume of water inflow (external) from all sources (circular and linear), in m^3/year.

Circular water sources include: water from a non-virgin source, including reused or recycled water from a third party, water from a renewable freshwater source, such as surface, ground and harvested rainwater that is renewed by precipitation and the natural water cycle, non-freshwater natural sources such as sea or brackish water, and water in raw materials or extracted from a product.

Circular water discharge for the total production process for the generated product:

$$\mathbf{CWD} = \frac{\mathbf{CWO}}{\mathbf{TWI}} \times \mathbf{100} \qquad \textbf{(33)}$$

Where,

CWD: the average circular water discharges, in %.

CWI: the volume of water discharges considered as circular, in m^3/year.

Circular water discharges include: water that is reused or recycled by another organization or returned to the water source at the same or better quality level as extracted, according to local regulatory limits. Non-circular outflows include: losses and releases such as effluents, spillage, or evaporation that are not returned to the local water source, and water incorporated into products that does not return to the origin at high quality.

Internal water recirculation or reuse in the total production process of the product:

$$\mathbf{IWR} = \frac{\mathbf{TWU}}{\mathbf{TWI}} \qquad \textbf{(34)}$$

Where,

IWR: the ratio of water reused or recycled within the production process of the generated product after being stored and treated as required, dimensionless;

TWU: the total volume of water used and consumed in all processes and operations for the generation of the product, in m^3/year.

Water Intensity to produce the product:

$$\mathbf{WI} = \frac{\mathbf{TW_I}}{\mathbf{n_P}} \quad \mathbf{(35)}$$

Where,

WI: the water intensity during the reference time period, in m^3 or L;

TW_I: the total water inflow during the reference time period, in m^3 or L;

n_P: is the number of unit products, n, produced during the reference time period.

Water Intensity performance in comparison to industry average:

$$\mathbf{WIP} = \frac{\mathbf{WI}}{\mathbf{WI_{IA}}} \quad \mathbf{(36)}$$

Where,

WIP: the water intensity performance;

WI_{IA}: the industry average water intensity.

Circular process-function chemical(s)/material(s) input for the total production process of the generated product:

$$\mathbf{CPFC/M} = \frac{\mathbf{REU_{PFC/M}} + \boldsymbol{REC_{PFC/M}} + \boldsymbol{BBR_{PFC/M}}}{\mathbf{TPFC/M}} \times \mathbf{100} \quad \mathbf{(37)}$$

Where,

CPFC/M: the average circular process-function chemical(s)/material(s) input in the total production process of the product, in %;

$REU_{PFC/M}$: the mass of reused chemical(s)/materials(s) utilised in the total production process of the product, in kg or other mass unit;

$REC_{PFC/M}$: the mass of recycled chemical(s)/materials(s) utilised in the total production process of the product, in kg or other mass unit;

$BBR_{PFC/M}$: the mass of renewable bio-based chemical(s)/materials(s) utilised in the total production process of the product, in kg or other mass unit;

TPFC/M: the mass of all input chemical(s)/material(s) used in the total production process of the product, in kg or other mass unit.

Process-function chemical(s)/material(s) Intensity to produce the product:
$$\mathbf{PFC/MI} = \frac{\mathbf{TPFC/M_I}}{\mathbf{n_P}} \quad \textbf{(38)}$$

Where,

PFC/MI: the process-function chemical(s)/material(s) intensity during the reference time period, in kg or other mass unit;

$TPFC/M_I$: the total process-function chemical(s)/material(s) input during the reference time period, in kg or other mass unit;

n_P: is the number of unit products, n, produced during the reference time period.

Process-function chemical(s)/material(s) Intensity performance in comparison to industry average:
$$\mathbf{PFC/MIP} = \frac{\mathbf{PFC/MI}}{\mathbf{PFC/MI_{IA}}} \quad \textbf{(39)}$$

Where,

PFC/MIP: the process-function chemical(s)/material(s) intensity performance;

PFC/MI_{IA}: the industry average process-function chemical(s)/material(s) intensity.

Use Phase Indicators

Average Lifetime of product in comparison to industry average:

$$\mathrm{ALTR_P} = \frac{\mathrm{LT_P}}{\mathrm{LT_{IA}}} \tag{40}$$

Where,

$ALTR_P$: the lifetime ratio of the product in comparison to industry average, dimensionless;

LT_P: the lifetime of the product, in years;

LT_{IA}: the industry average lifetime of the product, in years.

Designed reusability of a product:

$$\mathrm{DREU_P} = \frac{\mathrm{m_{DREUP}}}{\mathrm{m_{TP}}} \times 100 \tag{41}$$

Where,

$DREU_P$: the percent of the product mass designed for reuse, in %;

m_{DREUP}: the dry mass of product that is designed for reuse, in kg or other mass unit;

m_{TP}: the total dry mass of the product, in kg or other mass unit.

Actual reusability of a product:

$$\mathrm{AREU_P} = \frac{\mathrm{m_{REUP}}}{\mathrm{m_{TP}}} \times 100 \tag{42}$$

Where,

$AREU_P$: the percent of actual reused parts of product, in %;

m_{REUP}: the dry mass of product that is reused, in kg or other mass unit.

Designed refurbishing and remanufacturing of a product:

$$\mathrm{DRR_P} = \frac{\mathrm{m_{DRRP}}}{\mathrm{m_{TP}}} \times 100 \tag{43}$$

Where,

DRR_P: the percent of the product mass designed for refurbishing and remanufacturing, in %;

m_{DRRP}: the dry mass of product that is designed for refurbishing and remanufacturing, in kg or other mass unit.

Actual refurbishing and remanufacturing of a product:

$$\mathbf{ARR_P} = \frac{\mathbf{m_{ARRP}}}{\mathbf{m_{TP}}} \times \mathbf{100} \tag{44}$$

Where,

ARR$_P$: the percent of the product mass that is actually refurbished and/or remanufactured, in %;

m$_{ARRP}$: the dry mass of product that is actually refurbished and/or remanufactured, in kg or other mass unit.

End-of-Life Indicators

Designed Recirculation of product at the EoL as pharmaceutical and fine chemical:

$$\mathbf{DRaPFC} = \frac{\mathbf{dm_{PtPFC}}}{\mathbf{m_{TP}}} \times \mathbf{100} \quad \textbf{(45)}$$

Where,

DRaPFC: the designed recirculation of product at the EoL as pharmaceutical and fine chemical, %;

$\mathbf{dm_{PtPFC}}$: the designed (dry) mass of the product that can be further utilised after the EoL to produce pharmaceuticals and fine chemicals, in kg or other mass unit;

$\mathbf{m_{TP}}$: the total dry mass of the product, in kg or other mass unit.

Actual Recirculation of product at the EoL as pharmaceutical and fine chemical:

$$\mathbf{ARaPFC} = \frac{\mathbf{am_{PtPFC}}}{\mathbf{m_{TP}}} \times \mathbf{100} \quad \textbf{(46)}$$

Where,

ARaPFC: the actual recirculation of product at the EoL as pharmaceutical and fine chemical, %;

$\mathbf{am_{PtPFC}}$: the actual (dry) mass of the product that is further utilised after the EoL to produce pharmaceuticals and fine chemicals, in kg or other mass unit.

Designed Recirculation of product at the EoL as food and feed:

$$\mathbf{DRaFF} = \frac{\mathbf{dm_{PtFF}}}{\mathbf{m_{TP}}} \times \mathbf{100} \quad \textbf{(47)}$$

Where,

DRaFF: the designed recirculation of product at the EoL as food and feed, %;

$\mathbf{dm_{PtFF}}$: the designed (dry) mass of the product that can be further utilised after the EoL to produce food and feed, in kg or other mass unit;

$\mathbf{m_{TP}}$: the total dry mass of the product, in kg or other mass unit.

Actual Recirculation of product at the EoL as food and feed:

$$\mathbf{ARaFF} = \frac{\mathbf{am_{PtFF}}}{\mathbf{m_{TP}}} \times \mathbf{100} \quad \textbf{(48)}$$

Where,

ARaPFC: the actual recirculation of product at the EoL as food and feed, %;

$\mathbf{am_{PtPFC}}$: the actual (dry) mass of the product that is further utilised after the EoL to produce food and feed, in kg or other mass unit.

Designed Recirculation of product at the EoL as bioplastics and polymers:

$$\mathbf{DRaBBP = \frac{dm_{PtBPP}}{m_{TP}} \times 100} \tag{49}$$

Where,

DRaBBP: the designed recirculation of product at the EoL as bioplastics and polymers, %;

$\mathbf{dm_{PtBBP}}$: the designed (dry) mass of the product that can be further utilised after the EoL to produce bioplastics and polymers, in kg or other mass unit;

$\mathbf{m_{TP}}$: the total dry mass of the product, in kg or other mass unit.

Actual Recirculation of product at the EoL as bioplastics and polymers:

$$\mathbf{ARaBPP = \frac{am_{PtBPP}}{m_{TP}} \times 100} \tag{50}$$

Where,

ARaBPP: the actual recirculation of product at the EoL as bioplastics and polymers, %;

$\mathbf{am_{PtBPP}}$: the actual (dry) mass of the product that is further utilised after the EoL to produce bioplastics and polymers, in kg or other mass unit.

Designed Recirculation of product at the EoL as bulk chemicals and materials:

$$\mathbf{DRaBCM = \frac{dm_{PtBCM}}{m_{TP}} \times 100} \tag{51}$$

Where,

DRaBCM: the designed recirculation of product at the EoL as bulk chemicals and materials, %;

$\mathbf{dm_{PtBCM}}$: the designed (dry) mass of the product that can be further utilised after the EoL to produce bulk chemicals and materials, in kg or other mass unit;

$\mathbf{m_{TP}}$: the total dry mass of the product, in kg or other mass unit.

Actual Recirculation of product at the EoL as bulk chemicals and materials:

$$\mathbf{ARaBCM} = \frac{\mathbf{am_{PtBCM}}}{\mathbf{m_{TP}}} \times \mathbf{100} \qquad \textbf{(52)}$$

Where,

ARaBCM: the actual recirculation of product at the EoL as bulk chemicals and materials, %;

am_{PtBCM}: the actual (dry) mass of the product that is further utilised after the EoL to produce bulk chemicals and materials, in kg or other mass unit.

Designed Recirculation of product at the EoL as energy, heat and fuels:

$$\mathbf{DRaEHF} = \frac{\mathbf{dm_{PtEHF}}}{\mathbf{m_{TP}}} \times \mathbf{100} \qquad \textbf{(53)}$$

Where,

DRaEHF: the designed recirculation of product at the EoL as energy, heat and fuels, %;

dm_{PtEHF}: the designed (dry) mass of the product that can be further utilised after the EoL to produce energy, heat and fuels, in kg or other mass unit;

m_{TP}: the total dry mass of the product, in kg or other mass unit.

Actual Recirculation of product at the EoL as energy, heat and fuels:

$$\mathbf{ARaEHF} = \frac{\mathbf{am_{PtEHF}}}{\mathbf{m_{TP}}} \times \mathbf{100} \qquad \textbf{(54)}$$

Where,

ARaEHF: the actual recirculation of product at the EoL as energy, heat and fuels, %;

am_{PtEHF}: the actual (dry) mass of the product that is further utilised after the EoL to produce energy, heat and fuels, in kg or other mass unit.

Designed Recirculation of product at the EoL as useful utilisation in biosphere:

$$\mathbf{DRaUF} = \frac{\mathbf{dm_{PtUF}}}{\mathbf{m_{TP}}} \times \mathbf{100} \qquad \textbf{(55)}$$

Where,

DRaUF: the designed recirculation of product at the EoL as useful utilisation in biosphere, %;

dm_{PtUF}: the designed (dry) mass of the product that can be further utilised after the EoL as useful utilisation in biosphere, in kg or other mass unit;

m_{TP}: the total dry mass of the product, in kg or other mass unit.

Actual Recirculation of product at the EoL as useful utilisation in biosphere:

$$\mathbf{ARaUF} = \frac{\mathbf{am_{PtUF}}}{\mathbf{m_{TP}}} \times \mathbf{100} \qquad \textbf{(56)}$$

Where,

ARaUF: the actual recirculation of product at the EoL as useful utilisation in biosphere, %;

am_{PtUF}: the actual (dry) mass of the product that is further utilised after the EoL as useful utilisation in biosphere, in kg or other mass unit.