Biological Resources Certifications Schemes

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☐	**DEC**	Websites, patent fillings, videos, etc.
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Publishable executive summary

WP3 (Product Tacking and Traceability (T&T) for Circular Value Chain Integration) addresses the growing demand for traceability, transparency, and sustainability in bio-based industries by introducing a biological feedstock label. This label provides a structured framework to enhance data reliability, certification compliance, and environmental accountability across diverse biological supply chains, including agriculture, fisheries, forestry, and urban bio-waste.

Deliverable D3.3 focuses on reporting the reliability, conformity, and performance of the biological feedstock label, demonstrating how it integrates into BioReCer's T&T system by embedding circular economy objectives within certification schemes. To meet stringent regulatory and sustainability requirements, the deliverable describes the methodology for label development, traceability protocols, digital integration strategies, and sector-specific adaptability. Key achievements of D3.3 include:

- Granular traceability framework: The label provides batch-level traceability specifically tailored for BioReCer biological feedstocks, accurately recording their origin, transformation processes in real time.
- Electronic Identification Passport (EIP): A digital passport linked to each batch, ensuring secure, immutable, and auditable records.
- Digital Product Passport (DPP) integration: Enabling product-level sustainability tracking, ensuring that feedstock traceability, certification updates, and environmental performance indicators remain accessible throughout the product lifecycle.
- Certification alignment: The label integrates sector-specific standards, making compliance verification more efficient.

By embedding sustainability criteria, and traceability standards, the biological feedstock label enhances trust and accountability across bio-based supply chains. The findings from D3.3 contribute to the standardization of traceability practices, supporting policy compliance, consumer confidence, and industry-wide adoption of sustainable feedstock management.

This deliverable represents a significant step forward in the BioReCer project, and certifies that biological feedstocks meet the highest standards of reliability, sustainability, and market acceptance in Europe and beyond.

1 Biological feedstock label: Introduction

In a rapidly evolving global landscape, where sustainability and accountability are paramount, the biological feedstock label emerges as a critical mechanism for addressing significant challenges faced by bio-based industries. As the world increasingly shifts towards a circular and bioeconomy, the demand for transparency, traceability, and conformity across supply chains has grown exponentially [1]. The biological feedstock label is not merely a label; it represents a comprehensive framework designed to bridge the gap between environmental goals, regulatory compliance, and stakeholder engagement. It signifies a commitment to promoting responsible production and consumption patterns by providing a clear and reliable record of the journey of bio-based materials from their origins to end-users.

In this section, we underscored the importance of the biological feedstock label as a cornerstone of sustainability initiatives. It tackles pressing issues such as the fragmentation of supply chain data, the variability of biological materials, and the complexities of meeting diverse regulatory standards. By utilising innovative technologies, the label integrates real-time data capture, circularity metrics, and advanced verification mechanisms to support a transparent and reliable bio-based value chain [2]. Beyond its technical capabilities, the label develops trust among stakeholders, including producers, manufacturers, policy makers, and consumers, thereby catalysing the adoption of sustainable practices at every stage of the supply chain.

Through this deliverable, D3.3, the biological feedstock label is meticulously developed to align with the unique requirements of various bio-based sectors, such as fisheries, forestry, agriculture, and urban bio-waste. This document delineates the principles, methodologies, and architectural frameworks that form the backbone of the label, confirming that it not only serves as a tool for traceability but also as a driver for innovation, compliance, and environmental stewardship. The biological feedstock label encapsulates a vision for a sustainable future, where bio-based industries can thrive while maintaining their commitment to ecological and social responsibilities.

1.1 Definition and importance

The biological feedstock label is more than a simple identifier; it is a dynamic and multifaceted tool designed to enhance the traceability, transparency, and accountability of bio-based products. At its core, the label acts as a "passport" for biological feedstocks, documenting their journey from origin to end use. This comprehensive traceability is pivotal in addressing the growing demand for sustainable practices.

The importance of the biological feedstock label lies in its ability to provide stakeholders with critical information about the provenance, quality, and sustainability of the materials used in the production chain. By clearly outlining the origins and transformations of these materials, the label empowers producers, regulators, and consumers to make informed decisions. For producers, it helps in optimizing supply chains and meeting compliance standards. Regulators benefit from a transparent record that simplifies monitoring and enforcement. Consumers gain confidence in the sustainability and ethical sourcing of the products they use.

Furthermore, the biological feedstock label is instrumental in tackling several long-standing challenges in the bio-based sector:

Fragmented data: The lack of unified systems for tracking materials often leads to inefficiencies and mistrust [3]. The label integrates data from multiple sources, providing a seamless and reliable record. In the context of bio-based supply chains, data fragmentation refers to the disjointed and siloed nature of information across various stages and stakeholders. This fragmentation often results from the involvement of multiple suppliers, manufacturers, and distributors, each utilizing distinct systems and processes for data management. Such a lack of integration can lead to several challenges:

- Decreased visibility: Fragmented data hampers the ability to gain a comprehensive view of supply chain activities, making it difficult to track and manage processes effectively. This lack of visibility can result in inefficiencies and increased risks [4].
- Operational inefficiencies: Disjointed processes and errors stemming from fragmented data can lead to operational inefficiencies, affecting overall productivity and performance within the supply chain.
- Rising costs: Fragmentation can lead to stockouts, delays, and quality issues, escalating costs and impacting profitability.

Addressing data fragmentation is crucial for enhancing the efficiency and reliability of bio-based supply chains. Implementing integrated data-sharing solutions and adopting standardized processes can mitigate these challenges, leading to improved transparency, operational efficiency, and cost-effectiveness.

Feedstock variability: Biological feedstocks, such as lignocellulosic biomass, exhibit inherent variability in their physical and chemical properties [5]. This variability arises from several factors:

- Environmental factors: Conditions like soil quality, temperature, and rainfall during the growth period significantly influence biomass composition. For instance, variations in soil nutrients can affect the lignin and cellulose content of the feedstock.
- Seasonality: The time of harvest plays a crucial role in determining feedstock quality. Seasonal changes can lead to differences in moisture content and structural composition, impacting the efficiency of subsequent conversion processes.
- Sourcing methods: Different harvesting, collection, and storage practices contribute to variability. For example, the method of cutting and handling biomass can introduce contaminants, affecting overall chemical composition.

This variability poses challenges for bio-based product manufacturing processes, which often require consistent material properties to operate efficiently. To address these challenges, the biological feedstock label captures detailed information about the feedstock's origin, growth conditions, and handling practices. By documenting these nuances, the label supports quality assurance efforts, enabling producers and processors to adjust their methods to accommodate variability. This comprehensive tracking facilitates more efficient and reliable bio-based product manufacturing, contributing to the overall sustainability of bio-based industries [6].

Regulatory complexity: Navigating the regulatory landscape in bio-based industries presents significant challenges due to the diversity and overlap of regulations across different regions. This complexity can impede innovation and increase administrative burdens for companies striving to comply with varying standards.
A study analysing the bio-based industry in Europe highlighted that the multitude of regulations and standards can act as barriers to market entry and growth. The lack of harmonization across sectors and value chains often leads to increased costs and delays in product development and commercialization [7].
Similarly, the U.S. Food and Drug Administration (FDA) has issued draft guidance on the labelling of plant-based alternatives to animal-derived foods, reflecting the evolving regulatory environment that companies must navigate to maintain compliance [8].
In this context, the biological feedstock label serves as a standardized tool that aligns with key regulatory frameworks, facilitating compliance and reporting. By providing a unified

labelling system, it helps companies streamline their processes, reduce administrative burdens, and enhance transparency across the supply chain. This standardization is crucial for developing innovation and competitiveness in the bio-based sector, enabling companies to focus on sustainable growth while adhering to regulatory requirements.

In addition to these practical benefits, the label contributes to broader sustainability goals by embedding circularity and environmental indicators into its framework. It not only tracks the physical flow of materials but also integrates metrics that reflect their environmental impact, such as water usage, carbon footprint, and waste reduction. This dual focus on traceability and sustainability positions the label as a transformative innovation for advancing the bioeconomy.

Ultimately, the biological feedstock label serves as a foundation for building trust among all stakeholders in the value chain. By providing a transparent, reliable, and comprehensive system for tracking biological resources, it fosters collaboration and drives the adoption of sustainable practices across industries.

1.2 Overview of the biological feedstock label

Designed as a dynamic system, the label functions as a repository of critical information, capturing the lifecycle of biological feedstocks from origin to end-use. Its development addresses fundamental challenges in the bioeconomy, including fragmented supply chain data, variability in material quality, and complex regulatory environments.

At its core, the biological feedstock label integrates technological solutions and sustainability principles to achieve three primary objectives:

Traceability

Traceability enables a detailed understanding of how materials move through each stage of the supply chain. This feature maps the journey of feedstocks from their source to their final application and provides a robust system for capturing and storing critical data at every step. Such transparency is essential for identifying inefficiencies, improving processes, and ensuring compliance with sustainability and regulatory requirements [9].

Through advanced digital technologies, the label collects and integrates a range of data points, including the geographic origin of materials, processing methods, and transformation stages. For instance, in agricultural supply chains, the label might record the location of harvest, soil and crop conditions, and methods used in post-harvest handling. Similarly, in forestry, it could document sustainable logging practices, transportation details, and conversion into secondary products like paper or wood composites. An important dimension of traceability within the label is its ability to identify and address potential points of vulnerability or risk. For example, by tracking the transformation processes of bio-based feedstocks, the system can detect anomalies such as deviations from expected quality standards or gaps in data collection. This capability enhances the reliability of the supply chain, mitigating risks related to fraud, non-compliance, or product recalls.

Moreover, traceability within the biological feedstock label supports end-to-end visibility by connecting data silos and facilitating seamless data exchange between stakeholders. This integration ensures that all parties—producers, processors, distributors, and regulators—have access to a unified, accurate, and real-time dataset. The label leverages centralized blockchain technology to safeguard data integrity, prevent tampering, and create an immutable record of all transactions and transformations.

Traceability also serves as a foundation for creating meaningful sustainability metrics. By capturing the flow of materials and their associated environmental impacts, the label provides stakeholders with actionable insights into areas such as carbon emissions, resource efficiency, and waste generation. These insights not only help companies meet sustainability goals but also demonstrate their commitment to transparency and responsibility to consumers and regulatory bodies.

The traceability function of the biological feedstock label thus represents a critical innovation for bio-based supply chains, addressing both operational and strategic needs. By documenting and validating every stage of the material lifecycle, it strengthens trust, fosters collaboration, and contributes to a more sustainable and accountable bioeconomy.

Conformity

Conformity is a foundational aspect of the biological feedstock label, reflecting its ability to align with established global and regional certification standards. This alignment ensures that the label not only facilitates compliance with regulatory requirements but also promotes harmonization across sectors and geographies, addressing one of the most significant challenges in bio-based supply chains [10].

Alignment with global and regional standards:

The biological feedstock label integrates criteria from well-recognized certification systems, such as the International Sustainability and Carbon Certification (ISCC). These certifications provide robust frameworks for assessing sustainability, traceability, and environmental impact, ensuring that the label meets the expectations of both regulators and stakeholders. For instance:

- ISCC: As a global certification system, ISCC focuses on the sustainability of agricultural and forestry feedstocks, including biogenic waste and residues, non-biological renewable materials emphasizing criteria like greenhouse gas (GHG) reduction, biodiversity protection, and social responsibility (ISCC System Basics [11]). ISCC operates three different certification schemes, namely ISCC EU, ISCC PLUS and ISCC CORSIA, for different markets [12]. ISCC PLUS is the focus under BioReCer project as this is the certification system for all markets not regulated as the food, feed or energy markets.
- EU Organic Certification: This standard confirms that agricultural products comply with the European Union's organic farming regulations, focusing on soil health, biodiversity conservation, and prohibition of synthetic inputs.

The label takes these standards into account, creating a complementary framework that aligns with diverse regional and sectoral requirements.

Simplifying compliance:
For producers and stakeholders, navigating the complex web of certification requirements can be resource-intensive and time-consuming. The biological feedstock label addresses this by acting as a centralized tool that consolidates certification data and compliance metrics. This integration reduces the administrative burden on producers and processors, streamlining the certification process and minimizing the risk of non-compliance.
By embedding certification criteria into the label, stakeholders can access real-time information about the compliance status of feedstocks. For example, a producer can instantly verify whether a batch of biomass meets ISCC PLUS or EU organic standards, reducing delays and errors in certification documentation.

Promoting harmonization across sectors:
Harmonization is critical for fostering a cohesive approach to sustainability in bio-based supply chains. The biological feedstock label bridges the gaps between different certification systems, providing a standardized framework that ensures consistency in sustainability and traceability practices. This is particularly important for multinational supply chains, where feedstocks may need to meet varying regional standards [13].
For instance, a biomass producer sourcing feedstocks from multiple countries can rely on the label to confirm compliance with ISCC PLUS standards across all suppliers. Similarly, an agricultural exporter can use the label to demonstrate adherence to EU organic certification requirements, facilitating market access and boosting consumer confidence.

Enabling dynamic certification updates:

As certification standards evolve to address new sustainability challenges, the biological feedstock label is designed to adapt dynamically. This adaptability ensures that the label remains relevant and aligned with the latest regulatory and industry requirements. For example, updates to carbon reduction targets or biodiversity metrics can be seamlessly integrated into the label, maintaining its effectiveness as a compliance tool.

Building trust and market confidence:

The alignment with certification standards enhances the credibility of the biological feedstock label, building trust among stakeholders and consumers. By providing transparent and verifiable information about the conformity of feedstocks, the label strengthens market confidence in bio-based products. This is especially crucial as consumers increasingly demand proof of sustainability and ethical sourcing.

The conformity dimension of the biological feedstock label is a testament to its role as a transformative tool in bio-based industries. By simplifying compliance, promoting harmonization, and adapting to evolving standards, the label supports the BioReCer project's vision of a transparent, sustainable, and accountable bioeconomy.

Performance

The biological feedstock label incorporates a comprehensive set of sustainability metrics that provide actionable insights into the environmental and social impacts of feedstock production, processing, and distribution. These metrics enable stakeholders to assess and improve their practices, aligning with the principles of the EU Circular Economy Action Plan and advancing the goals of a sustainable and resource-efficient economy [14].

Supporting circular economy goals:

The biological feedstock label actively advances circular economy principles through real-time monitoring and dynamic calculation of Circularity Indicators (CIs), as detailed in deliverable D3.2. These CIs, collaboratively developed and operationalized with WP2, encompass a comprehensive set of metrics designed explicitly to measure resource efficiency, material reuse, and waste minimisation throughout bio-based supply chains. By embedding these indicators into the label's cloud-based infrastructure, stakeholders gain immediate insights into the circular performance of their practices, enabling targeted actions to improve sustainability.

By directly integrating CIs into operational monitoring and reporting, the label promotes transparency and continual improvement toward achieving circular economy objectives outlined by the EU Circular Economy Action Plan.

Encouraging stakeholder adoption:

By providing transparent and actionable insights, the label empowers stakeholders to adopt more sustainable practices. Producers, for example, can use the data to identify inefficiencies in resource use or areas of high environmental impact, allowing them to implement targeted improvements. Similarly, regulators and certifiers can rely on the label to verify compliance with sustainability standards, streamlining oversight and reducing administrative burdens.

The social metrics incorporated in the label also ensure that the benefits of sustainability extend beyond environmental performance. For instance, monitoring fair labour practices and community engagement helps create equitable value chains, making trust and collaboration among stakeholders.

Market differentiation and consumer confidence:

The performance metrics of the label offer a competitive advantage for businesses by showcasing their commitment to sustainability. Products labelled with these metrics provide consumers with verified information about environmental and social impacts, increasing market confidence and encouraging informed purchasing decisions.

Adaptability to evolving metrics:

As sustainability goals and regulatory requirements evolve, the label is designed to adapt dynamically. New indicators, such as biodiversity preservation or advanced carbon capture technologies, can be seamlessly integrated into the framework. This adaptability ensures that the label remains relevant and effective in driving continuous improvement across bio-based industries.

The performance dimension of the biological feedstock label is instrumental in fostering sustainable and circular practices. By integrating robust sustainability metrics, it not only supports stakeholders in improving environmental and social outcomes but also contributes to the broader objectives of the EU Circular Economy Action Plan. This integration of performance metrics into a transparent and actionable system ensures that the label is a powerful tool for driving sustainability in bio-based value chains.

1.2.1 Key features and sectoral adaptability

The biological feedstock label in WP3 incorporates several key features designed to enhance its functionality and adaptability across diverse bio-based sectors. These features ensure the label is both comprehensive and flexible, capable of addressing the unique challenges and requirements of industries such as agriculture, fisheries, forestry, and urban bio-waste management.

Key features of the biological feedstock label:

1. Traceability across supply chains:
   The label provides end-to-end traceability of feedstocks, capturing data at each stage of the supply chain. This includes information on sourcing, transportation, transformation processes, and final application. By utilising advanced technologies such as blockchain and IoT-enabled sensors, the label ensures the data is transparent, reliable, and immutable, encouraging trust among stakeholders.
2. Integration of sustainability metrics:
   Sustainability metrics embedded within the label facilitate alignment with circular economy principles and support compliance with sustainability certifications and regulatory frameworks.
3. Real-time data collection and reporting:
   The label supports real-time monitoring through its integration with digital tools and platforms. This allows stakeholders to access up-to-date information about feedstock status and performance, enabling timely decision-making and proactive issue resolution.
4. Dynamic and scalable design:
   The label's framework is built to adapt to evolving regulatory requirements, market demands, and technological advancements. New metrics, certifications, or industry-specific needs can be seamlessly integrated, ensuring the label remains relevant and effective over time.
5. User-centric approach:
   Designed with stakeholders in mind, the biological feedstock label emphasizes intuitive interfaces and seamless access to essential information. This user-centric design ensures that users across the supply chain, from producers and processors to regulators and consumers, can interact with the system easily and efficiently. The label incorporates graphical dashboards, simplified input forms, and guided workflows that minimize complexity and reduce the risk of errors during data entry. By clearly visualizing essential data such as sustainability indicators, traceability

details, and certification statuses, the label simplifies stakeholder engagement. This intuitive presentation ensures that all stakeholders can easily interpret and use the information without needing specialized technical knowledge.

Sectoral adaptability

One of the label's most significant strengths lies in its adaptability to the unique requirements of different bio-based sectors. This adaptability facilitates that the label remains relevant and impactful, regardless of the specific challenges or needs of a given industry. As mentioned before, by tailoring the label design and metrics to suit sector-specific practices and standards, it enables stakeholders to address critical issues such as sustainability, traceability, and resource efficiency. Whether in agriculture, forestry, fisheries, or urban bio-waste management, the label integrates seamlessly into operational workflows, providing actionable insights and promoting transparency across the supply chain.

Below, we present selected examples demonstrating the label's adaptability within BioReCer case studies (WP6), illustrating how specific parameters contribute to addressing sector-specific challenges and advancing circularity goals.

1. Agriculture:
   In agricultural systems, the label tracks parameters such as soil health, pesticide use, water management, and crop yields. For example, in the Central Macedonia case study, pruning residues and straw are tracked from collection to their transformation into bio-based soil enhancers and particleboards. This level of detail supports sustainable farming practices and minimizes environmental impact.
2. Fisheries:
   In fisheries, the label captures data on catch locations, species, bycatch reduction, and waste processing. The Galicia case study highlights its application in tracking fish oil and collagen production, ensuring these by-products are sustainably utilized while complying with EU fisheries regulations.
3. Forestry:
   In forestry, the label monitors sustainable logging practices, biodiversity impact, and the processing of timber by-products. In the Västernorrland case study, it tracks residues such as wood chips and sawdust as they are converted into bioenergy and biochemicals, promoting efficient resource utilization.
4. Urban bio-waste management:

For urban systems, the label supports the monitoring of organic waste streams such as organic fraction of municipal solid waste (OFMSW) and sewage sludge. In case study 4, the label aids in tracking the conversion of these waste streams into biodegradable polymers like PHB, showcasing the circular economy in action.

The biological feedstock label's ability to adapt to the distinct demands of various bio-based sectors demonstrates its transformative potential within the project. By integrating advanced technologies, sustainability metrics, and tailored frameworks, the label not only addresses sector-specific challenges but also fosters innovation and accountability across supply chains. Its practical application in the BioReCer case studies highlights its versatility and effectiveness in driving transparency, promoting circularity, and enhancing resource efficiency. As a key output of WP3, the label exemplifies the commitment to creating actionable solutions that align with the broader goals of sustainability and the circular economy, paving the way for a more resilient and responsible bioeconomy.

1.2.2 Integration with BioReCer system

The biological feedstock label serves as a critical component of the T&T framework developed under WP3. It is designed to provide an end-to-end solution for ensuring traceability, sustainability, and regulatory alignment across bio-based supply chains. By leveraging advanced technologies such as IoT-enabled sensors, centralized blockchain systems, information and communication technology (ICT) tools, and real-time data analytics, the label effectively captures and aggregates critical information at every stage of the supply chain.

The integration of the label with the ICT tool, managed by WP5, is a key enabler of seamless data sharing and interoperability among stakeholders. This connection allows stakeholders—producers, processors, regulators, and consumers—to access accurate and up-to-date information about feedstock status, sustainability metrics, and certification compliance. The interoperability offered by this system bridges gaps between disparate data sources, eliminating storages and fostering a unified approach to supply chain management. By providing a centralized platform for monitoring, the label supports stakeholders in making informed decisions, ensuring alignment with sustainability goals and compliance requirements.

A defining feature of this system is the Electronic Identification Passport (EIP). This digital passport acts as a comprehensive record of feedstock attributes and transformations throughout the supply chain. It captures data such as origin, quality parameters, processing methods, and environmental indicators, offering a transparent and verifiable history for each feedstock batch. The EIP automates the validation of key metrics such as sustainability compliance, CIs, and certification benchmarks. While this reduces human error and enhances operational efficiency, the final verification remains subject to review by auditors, ensuring compliance with regulatory and certification standards. This dual approach builds trust among stakeholders by providing reliable, immutable data with an additional layer of oversight [15].

Moreover, the label's integration within the BioReCer system supports scalability and adaptability. As regulatory requirements and market conditions evolve, the system can incorporate new metrics, standards, and functionalities without disrupting its overall framework. For instance, the ICT tool facilitates the seamless addition of advanced monitoring technologies like hyperspectral imaging or AI-driven data analytics, further enhancing the system's capabilities.

Another critical benefit of this integration is the role it plays in sustainability reporting. Through the ICT tool, stakeholders can generate comprehensive reports that include carbon footprint analysis, resource efficiency metrics, and circularity performance. These reports not only help organizations align with environmental regulations but also strengthen their market position by demonstrating a commitment to transparency and accountability.

In a nutshell, the integration of the biological feedstock label with the BioReCer system exemplifies a robust, technology-driven approach to managing bio-based supply chains. By combining IoT, blockchain, and advanced data management tools, the label supports real-time monitoring, automated validation, and strategic decision-making. Its alignment with WP5's ICT tool ensures a scalable, interoperable, and reliable system that advances the BioReCer project's objectives of sustainability, transparency, and circularity.

1.2.3 Promoting stakeholder trust and sustainability goals

By providing a transparent and reliable record, it bridges gaps between producers, regulators, and consumers. This transparency is critical for enhancing market acceptance of bio-based products. The biological feedstock label, primarily digital and integrated within the BioReCer ICT tool, provides stakeholders, including consumers, with easily accessible information about feedstock origin, sustainability metrics, and certification details. The digital format allows for dynamic and interactive presentation, ensuring verifiable and user-friendly communication of product sustainability information, aligning with consumer expectations.

Furthermore, the label aligns with the European Union's sustainability objectives by embedding CIs and environmental metrics into its framework. These elements enable the measurement of critical aspects such as resource efficiency, waste reduction, and carbon footprint, positioning the label as a key enabler of the circular bioeconomy.

The following sections delve deeper into the designed technical frameworks, methodologies, and tools underpinning the biological feedstock label, showcasing how the BioReCer project has delivered an innovative solution to advance sustainability in bio-based industries.

1.3 Structure of the deliverable

This deliverable is organized into nine sections, each addressing critical components of the biological feedstock label and its development within the BioReCer project. Following the introduction in Section 1, which provided an overview of the label's definition, importance, key features, adaptability, and integration within BioReCer systems, the subsequent sections delve into specific methodologies, frameworks, and outcomes.

Section 2 focuses on the methodology for label development, outlining the data sources and input requirements essential for the label's creation. It discusses the integration of sustainability and CIs into the label's design and highlights the core principles that guided the structure of the label to ensure alignment with industry needs and regulatory standards. Section 3 presents the traceability and reliability framework, detailing the mechanisms for defining units of material, batching protocols, and ensuring granularity in environmental and certification requirements. This section also introduces the concept of the EIP, which enhances traceability and reliability across supply chains.

In section 4, the criteria for the label is explored and it focuses on the reliability metrics and benchmarks that underpin its effectiveness. It also examines how the label supports conformity to certification standards, assesses feedstock quality through performance indicators, and promotes sustainability through transparency. Section 5 then describes the system architecture and implementation of the label, illustrating its integration with the Track and Traceability (T&T) framework. It includes discussions on the tools used for data analysis and reporting and explains the automation processes for label generation and updates. Section 6 introduces the concept of digital product passport (DPP) integration, explaining how the label is embedded into digital passports. This section highlights its interoperability across platforms and discusses the future prospects for enhanced traceability and broader adoption. Finally, Section 7 concludes the deliverable by summarizing the outcomes, highlighting the label's significance, and discussing its implications for advancing sustainability, transparency, and traceability within bio-based industries.

2 Methodology for label development

The methodology employed in WP3 for developing the biological feedstock label builds on the specific objectives of enhancing traceability, sustainability, and stakeholder collaboration within bio-based supply chains. In this context, we focused on translating key findings from earlier project stages into a practical, data-driven framework that addresses the realities of diverse sectors. This effort involved gathering sector-specific requirements, integrating suitable indicators for sustainability and circularity, and aligning technical solutions with user-centric design principles.

To achieve these goals, WP3 led a series of actions aimed at making the label both robust and adaptable. First, relevant data sources were identified through consultations with industry partners, project stakeholders, and regulatory experts, ensuring the label reflects real-world operational and compliance needs. Next, we adapted various sustainability and circularity metrics to fit the label's scope, prioritizing those that are easily measurable, meaningful to stakeholders, and supportive of the project's environmental objectives. Finally, the team structured the label around design principles focused on clarity, scalability, and interoperability, thus creating a framework that can be adopted across sectors such as agriculture, fisheries, forestry, and waste management.

The following sections detail how these actions took shape. Subsection 2.1 explains the data sources and input requirements selected to inform the label. Subsection 2.2 explores how sustainability and CIs were embedded to produce tangible environmental benefits, while Subsection 2.3 discusses the guiding design principles that underpin the label's overall structure.

2.1 Data sources and input requirements

A crucial step in WP3's work on the biological feedstock label involved identifying, collecting, and organizing the data necessary to cover the full spectrum of traceability and sustainability requirements. By collaborating with project partners and sector representatives, we established a data framework that accommodates the complexity of different bio-based supply chains while maintaining enough flexibility to adapt to evolving regulatory and market demands.

Identifying relevant data

WP3 began by mapping the types of information needed to reflect feedstock origin, transformations, and environmental impacts. This process drew on:

- Primary data from producers and processors (e.g., harvest logs, processing records).
- Sensor and IoT data capturing real-time parameters like temperature, moisture, or fish catch details.
- Certification and compliance documents detailing adherence to regulations or certification standards.
- Environmental metrics (e.g., water consumption, GHG emissions) relevant to circularity and sustainability goals.

Setting input requirements

Once the data categories were established, we defined the precision, frequency, and format of inputs required for reliable label generation. These standards were tailored to each sector:

- Agriculture: Emphasis on soil data, pesticide usage, and water management logs.
- Fisheries: Detailed capture data (e.g., catch location, bycatch), along with processing and waste outputs.
- Forestry: Sustainable logging certifications, biodiversity records, and timber conversion tracking.
- Urban bio-waste: Data on organic fractions, contamination levels, and end-use conversion processes (e.g., composting or polymer production).

In parallel, WP3 coordinated with other project work packages to gather relevant datasets and validate the accuracy and timeliness of inputs. These data sources served as the backbone of the label, ensuring it reflects real-world operations and fully addresses the traceability needs of each BioReCer case study. Through this collaborative process, WP3 established a structured, sector-specific approach to data collection and input requirements, setting the stage for the incorporation of sustainability and CIs.

2.2 Integration of sustainability and circularity indicators

In developing the biological feedstock label, WP3 closely collaborated with other work packages—particularly WP2—to embed relevant sustainability and CIs without duplicating efforts. While WP2 focused on identifying and refining these metrics, WP3's role involved determining how the label would assimilate the validated outputs into its data architecture. WP4 further contributed by providing input on traceability, including benchmark results on the traceability of related certification schemes and feedback on the development of the questionnaire. This synergy ensures that the label's traceability functions seamlessly align with the environmental and circular metrics defined elsewhere in the project, creating a coherent framework for stakeholders.

Coordination with WP2

Since WP2 has primary responsibility for defining sustainability (including environmental, economic, and social) and circular metrics, WP3 concentrated on:

- Data integration: Incorporating the indicators provided by WP2 into the label's format, ensuring that each feedstock batch can be tagged with the necessary metrics at different supply chain stages.
- Automation mechanisms: Designing methods (e.g., system triggers, automated calculations, or data validation checks) that allow these metrics to be updated in real-time or at relevant intervals, based on input from sensors, lab analyses, or certification documents.
- Interoperability: Ensuring the label's design supports straightforward data exchange with WP2's assessment tools, so that any updates to metrics can be seamlessly applied without disrupting stakeholders' workflows.

Focusing on practical implementation

Rather than redefining or elaborating on the indicators themselves, WP3 focused on integrating them into the biological feedstock label in a way that aligns with WP2's established formats. To streamline data handling, the project leverages the ICT tool (developed under WP5) as the central conduit for gathering both automated sensor/IoT data and manual input from stakeholders. This arrangement guarantees that WP3 does not duplicate data collection efforts, but instead focuses on how best to represent, validate, and document incoming metrics within the label's structure. Practical considerations included:

- Ease of data entry: WP3's label framework receives data directly from the ICT tool, minimizing user effort by pre-formatting data fields to match WP2's metrics. This reduces redundancy and supports efficient data flow.
- Visual clarity: By using dashboards and reports that connect to the ICT tool, the label communicates each indicator's status clearly and transparently, enabling stakeholders to interpret performance insights with minimal training.
- Scalability: Because the ICT tool accommodates varying levels of data granularity—ranging from small producers to large-scale operators—WP3 can integrate both basic and advanced metrics in the label. This flexibility supports broader adoption across different operational sizes.

Enabling stakeholder decision-making

By embedding WP2's sustainability and circularity metrics (D2.3 - Circular indicators) into a user-friendly structure, WP3 aids stakeholders in making informed decisions without having to navigate complex data-collection processes themselves. Producers consult the ICT tool for sustainability scores and traceability data, certifiers can verify conformance through its aggregated reports, and consumers receive concise insights into feedstock origins and transformations.

This method—where WP5's ICT platform aggregates sustainability data and WP3's label structures it—provides a practical digital solution for integrating WP2's indicators into real-world bio-based operations. The biological feedstock label, displayed digitally within the ICT tool, visually presents traceability details and sustainability performance insights in user-friendly dashboards. This digital presentation enables stakeholders to easily interpret and utilise critical data for informed decision-making, enhancing traceability and compliance across bio-based supply chains.

The following subsection explains the key design principles WP3 applied to keep the label adaptable, user-friendly, and ready to meet evolving demands in bio-based industries.

2.3 Design principles for label structure

In developing the biological feedstock label, WP3 adhered to a set of core design principles focused on delivering a solution that is modular, adaptable, and user-friendly. These principles guided every stage of the label's creation, ensuring alignment with BioReCer's broader objectives of reliability, circularity, and practical deployment across various bio-based sectors.

2.3.1 Modular architecture

The label was conceived with a modular architecture, allowing new features or data points to be integrated without disrupting existing structures. This approach is particularly valuable for incorporating sector-specific metrics or emerging regulations:

Sector-specific modules

As previously mentioned, the biological feedstock label integrates sector-specific modules tailored to diverse bio-based industries. For instance, it tracks parameters such as soil composition in agriculture, catch location in fisheries, logging practices in forestry, and waste stream management in urban bio-waste. This modular approach ensures sector-specific requirements are efficiently addressed while maintaining a unified traceability framework.

By designing a modular label architecture, WP3 enabled each sector to attach or detach specialized modules, such as fish stock documentation for fisheries or soil health parameters for agriculture, without compromising the core functionality shared across all bio-based sectors. This modular approach ensures that each industry's unique priorities are captured while maintaining a consistent, overarching framework for traceability and compliance.

Future growth

The modular design of the biological feedstock label positions it to evolve alongside changing industry demands and policy developments. As new sustainability indicators gain prominence or updated regulatory guidelines come into effect—be it revised emissions thresholds, emerging circularity metrics, or stricter biodiversity requirements—additional modules can be integrated without altering the label's underlying framework. This forward-looking approach ensures that the label remains aligned with the latest standards and best practices, preventing the need for time-consuming overhauls. By incorporating fresh data fields and validation rules as needed, the system continues to provide stakeholders with current, credible insights into feedstock performance, reflecting the dynamic nature of bio-based sectors.

2.3.2 Adaptability and scalability

From small-scale producers to large industrial stakeholders, the label's architecture supports scalability to accommodate varied volumes of data and differing operational complexities:

Flexible data input

In tandem with WP5's ICT tool, the label can manage data inputs at varying levels of detail. For smaller operations, simple metrics like basic production quantities or essential traceability parameters may suffice, while larger or more complex organizations can provide extensive datasets capturing nuanced details at multiple points in the supply chain. All such inputs feed into the same label framework, ensuring consistent reporting and a unified approach to traceability. This capacity for variable depth—often referred to as granularity—enables the label to accommodate diverse stakeholders without placing undue burdens on smaller entities. The concept of defining and adjusting 'granularity' will be explored further in Section 3, where we discuss how the label addresses environmental and certification requirements in a scalable manner.

Evolving standards

The biological feedstock label's flexible configuration allows it to remain compatible with shifting regulatory and industry landscapes. As the European Union and other governing bodies update regulations—introducing new emissions thresholds, circularity targets, or biodiversity requirements—the label can be rapidly adapted to accommodate these changes. Likewise, when new certification schemes or industry best practices emerge, relevant data fields and validation rules can be integrated to maintain alignment with market expectations. This adaptability preserves the label's long-term viability, making it easier for stakeholders to demonstrate compliance and preserving the label's credibility in an evolving bio-based economy.

2.3.3 User-focused interfaces

WP3 maintained a user-centric design, facilitating stakeholders can navigate and interpret the label's data effortlessly:

- Intuitive dashboards: Key information is displayed through clear, visual interfaces that reduce technical barriers. These dashboards integrate seamlessly with WP5's ICT tool, providing a one-stop platform for data submission, validation, and reporting.
- Guided workflows: Built-in prompts and context-specific help features minimize errors and training needs, supporting efficient data entry. This is especially beneficial for stakeholders with limited technical resources or knowledge.

2.3.4 Data security and quality assurance

From the earliest design stages, WP3 integrated robust security measures and quality checks into the label's structure, even though a dedicated section later in this deliverable addresses security and compliance in greater depth. By employing centralized blockchain components, the label records feedstock information in a manner that resists tampering or unauthorized alterations. This approach, combined with role-based access protocols, allows only approved users to view or modify specific data fields, preserving data integrity throughout the supply chain.

To further strengthen reliability, WP3 implemented automated validations that cross-reference submitted data against authoritative sources, such as recognized certification databases or relevant regulatory lists. These automated checks help flag inconsistencies, such as incorrect product codes or out-of-range emissions figures, reducing the need for manual oversight. As a result, stakeholders can trust that the label's data is both accurate and protected from unauthorized modifications, aligning with the BioReCer project's overarching mission to bring up transparency and accountability in bio-based industries.

2.3.5 Seamless interoperability

In a multi-partner environment like BioReCer, where supply chains vary significantly in complexity and scope, interoperability emerges as a vital component of the label's design. To address this need, WP3 defined label fields in formats aligned with recognized industry protocols, established certification frameworks, and the data structures used by WP2, WP4 and WP5. By adhering to these standardized formats, the label can accommodate diverse data inputs—from agricultural yields and fishing catch details to urban waste management logs—without creating inconsistencies or communication barriers.

Beyond standardized definitions, the label's architecture facilitates harmonized data exchange between different systems, most notably WP5's ICT tool. This confirms that all stakeholders—producers, processors, regulators, and certifiers—work within a cohesive framework that minimizes duplicate tasks. As a result, critical information flows smoothly from data capture to final reporting, supporting more efficient operations and a higher degree of transparency throughout bio-based supply chains.

2.3.6 Continuous feedback and iteration

WP3 adopted an iterative approach to label design, actively seeking input from project partners and case study participants:

- Pilot testing: Early pilot phases in the four case studies provided real-world feedback on interface usability, data clarity, and adaptability.
- Incremental improvements: Recommendations from these pilots shaped refinements to the label's structure, ensuring that design choices reflect actual operational needs rather than theoretical assumptions.

By integrating these design principles, WP3 created a versatile label framework that supports the specialized needs of diverse bio-based sectors. This thoughtful structure underpins the label's capability to deliver accurate, actionable insights while maintaining clarity, security, and interoperability. The result is a tool that meets WP3 objectives for transparent, efficient, and sustainable management of biological feedstocks, laying a solid foundation for the traceability and reliability framework discussed in the next section.

3 Traceability and reliability framework

A robust traceability and reliability framework is essential for ensuring that the biological feedstock label consistently delivers accurate, verifiable, and meaningful information throughout the bio-based supply chain. Whereas D3.1 outlined the conceptual rationale for T&T within BioReCer this section highlights how WP3 has put those principles into practice for the biological feedstock label. The focus is on translating theoretical T&T insights into tangible mechanisms: defining discrete batch protocols, refining data granularity, and deploying an EIP that documents each feedstock's journey. By adapting the foundational framework to real-world conditions, WP3 offered a robust approach that not only supports compliance but also developed transparency and consistent data quality throughout the bio-based supply chain. This chapter thus moves beyond theory to reveal how traceability and reliability become operational drivers of the BioReCer label's overall effectiveness.

3.1 Unit of material and batching protocols

An effective labelling system begins with establishing clear definitions for feedstock units and the corresponding batching protocols. WP3 developed a practical approach to identify and group feedstocks in a way that aligns with both traceability objectives and real-world operations. This subsection outlines how the unit of material was defined, how batches are formed, and why these protocols are vital for maintaining consistent, verifiable records across diverse bio-based supply chains.

3.1.1 Defining the unit of material

Pinpointing the smallest viable segment of feedstock—known as the *unit of material*—is a foundational step in establishing robust traceability protocols. This concept refers to the minimal quantity that can stand on its own for identification, data logging, and reporting. Deciding how granular this unit should involve balancing sector-specific needs, resource availability, and the practical constraints of field operations [16].

In agriculture, for instance, the unit of material frequently takes the form of a harvest lot tied to a particular field or section of land. This lot might correspond to a single day's harvest or be delimited by crop variety. By standardizing this level of detail, the label can track geographic origin, harvest date, and potential environmental factors (e.g., weather patterns) that shape the lot's quality.

Within fisheries, the unit of material might be defined as a 'catch segment' from a single voyage, net haul, or even a day's worth of landings at sea. In some specialized contexts—

such as high-value or endangered species—the unit could extend down to the individual fish. Data attributes like capture location, species composition, and handling conditions become integral for each unit, enabling more detailed assessments of stock levels, bycatch reduction initiatives, and compliance with fishing quotas. This level of granularity is especially valuable for fisheries aiming to document traceability at a refined scale, such as tracking individual catches of premium species or verifying adherence to strict regulation.

In the forestry sector, a 'logging batch' associated with a specific felling site or cutting season often serves as the defining unit. This includes essential data like tree species, compartment identification (e.g., subplots within a forest concession), and certifications tied to the area (e.g., FSC or PEFC labels). Building on insights from the Swedish case study in BioReCer, logging batches can also encompass residual streams such as branches, roots, and tips (GROT), bark, sawdust, and fibre sludge. These materials play a significant role in sustainability efforts, as they are valorised into bio-based products like pellets, biofuels, and advanced biomaterials. The biological feedstock label aligns with these practices by attaching critical traceability data to each logging batch, supporting both sustainability certification and the efficient use of by-products.

In urban bio-waste management, the smallest traceable segment typically revolves around a 'collection batch' tied to a specific municipal route, waste reception facility, or processing unit. This unit encompasses diverse streams such as the Organic Fraction of Municipal Solid Waste (OFMSW) and sewage sludge, each with unique attributes. For OFMSW, key data points include collection time, source location, weight, contamination levels, and organic content. For sewage sludge, metrics such as nutrient composition, moisture content, and origin at the treatment plant are critical.

This refinement reflects the complexities of urban bio-waste streams and aligns with the BioReCer case studies in Lombardy, which emphasize resource recovery through biorefineries. By incorporating such granularity, the biological feedstock label can provide robust traceability and support sustainability goals within the urban bio-waste context.

By framing units of material in this manner, the biological feedstock label consistently attaches vital contextual data—such as geographic origin, timestamps, or compliance certificates—to each batch. The result is a clear, reproducible record of where and how materials are sourced, empowering stakeholders to trace feedstock movements across complex supply chains. This approach also lays the groundwork for more accurate sustainability metrics and compliance checks, since the label can isolate specific portions of feedstock that meet or deviate from industry standards.

3.1.2 Batching protocols

Batching protocols are vital in traceability and reliability across the supply chain, enabling stakeholders to manage the dynamic flow of biological feedstocks effectively. Once the base unit of material is defined, WP3 developed detailed batching protocols tailored to the unique challenges of bio-based industries. These protocols establish a standardized approach to managing the merging, splitting, and reconciliation of feedstock batches as they progress through various stages of production and processing [17].

Batch creation

Batch creation refers to the process of aggregating smaller units of feedstock into larger, standardized batches based on specific criteria such as origin, quality, certification status, or intended end-use. The aim is to facilitate efficient management, simplify logistics, and maintain consistent traceability and accountability throughout the supply chain. During batch creation, careful attention is given to ensuring that each aggregated batch meets established quality standards and compliance requirements.

For example, we are indicating two case studies:

- Agriculture: Multiple harvest lots from the same farm or field might be combined into a batch for storage or transport, ensuring consistency in attributes like pesticide use and soil conditions.
- Forestry: Smaller logging batches from the same tract of sustainably managed forest could be pooled into a single batch for further processing, maintaining alignment with certification standards such as FSC or PEFC. This process not only simplifies logistics but also preserves critical traceability data, allowing stakeholders to verify the provenance and quality of the material even after merging.

Batch splitting

Batch splitting involves dividing a single consolidated batch into multiple smaller units to accommodate various product lines, processing pathways, destinations, or distinct use cases. This division ensures precise allocation of materials based on specific requirements or purposes while retaining full traceability and transparency across all split batches.

For instance:

- Fisheries: A catch segment might be split into different processing streams based on intended end products. For example, part of the biomass could be allocated to collagen production, while another portion is directed toward fish oil extraction or other secondary products. Each sub-batch retains essential traceability data, such as catch location, species type, and processing conditions. This ensures that the transformation of the raw catch into high-value products like collagen is fully documented, aligning with sustainability and certification requirements as emphasized in the WP3 framework.

- Urban bio-waste: A batch of collected OFMSW could be split into streams for composting, anaerobic digestion, or biopolymer production, with contamination levels and processing routes recorded for each stream. By defining clear rules for splitting, the protocols ensure that traceability and accountability are maintained even when feedstocks are diversified.

Re-batching and reconciliation

Re-batching and reconciliation involve adjusting and updating batch identifiers and associated data when feedstocks undergo transformations such as blending, refining, or secondary processing. These processes are essential to accurately reflect the new state of the material while preserving comprehensive traceability and accountability throughout subsequent supply chain stages [18].

Examples include:

- Agriculture: Re-batching might occur when raw grains are milled into flour, with the new batch capturing details of the milling process while linking back to the original harvest lot.
- Forestry: Sawdust and bark from different logging batches might be combined to produce pellets or biofuels. The reconciliation process ensures that all input batches are documented in the final product's traceability record. Such mechanisms are vital for maintaining data integrity, particularly in sectors where materials are frequently transformed or combined.

Alignment with stakeholder needs

WP3's batching protocols (creation, splitting and re-batching), detailed in this section, were developed in collaboration with project partners and stakeholders to address practical challenges such as:

- Regulatory compliance: Ensuring batches align with certification requirements and environmental standards.
- Logistics and storage: Adapting protocols to account for storage constraints, transportation schedules, and market demands.
- Dynamic data capture: Utilising the BioReCer ICT tool to automate batch tracking and reduce manual data entry.

These comprehensive batching protocols create a robust framework for managing the lifecycle of biological feedstocks, supporting the traceability and reliability objectives of the BioReCer project.

3.1.3 Aligning with operational realities

WP3 carefully designed batching protocols to align with practical challenges and operational realities faced by stakeholders across bio-based supply chains. These protocols are implemented in coordination with the ICT tool, which collects real-time data, ensuring accurate tracking and traceability. By continuously integrating feedback from project partners and stakeholders, WP3 will update the batching protocols to remain responsive and adaptable. The approach guarantees that logistical constraints, seasonal variations, and regulatory requirements are seamlessly integrated into the label's framework.

Seasonality

The biological nature of feedstocks introduces fluctuations in volume, quality, and composition due to seasonal factors. For instance:

- Fisheries: Seasonal fishing quotas and variations in species availability directly affect the size and composition of catch segments. Batching protocols are designed to account for these fluctuations, ensuring that smaller, seasonal batches can still be reliably tracked and combined when appropriate.
- Agriculture: Harvest cycles influence the timing and size of batches, particularly for crops with narrow harvesting windows. WP3's protocols allow for dynamic updates to batch identifiers based on seasonal variations, facilitating traceability despite changes in production volume.

By incorporating seasonality, the system is able to supports flexibility while preserving the consistency of traceability data in the future.

Storage limitations

Biological feedstocks often require specific storage conditions to maintain quality and prevent spoilage [19]. This introduces challenges such as managing:

- Stock rotation: Ensuring that older batches are used or processed first to minimize waste. Batching protocols integrate timestamps and expiration dates to support this practice.
- Capacity constraints: Limited storage space in processing facilities can necessitate re-batching or consolidating smaller batches. Protocols are designed to track these

changes, maintaining that traceability is preserved even as batches are combined or split during storage transitions.

For example, in fisheries, storage facilities might require re-batching when handling frozen fish segments or biomass destined for collagen or fish oil production. This confirms that product quality and traceability are preserved while accommodating logistical realities.
By aligning batching protocols with operational realities, WP3 confirmed that the biological feedstock label remained both functional and adaptable. This practical approach supports stakeholders in overcoming logistical challenges while preserving the integrity of traceability data. These considerations strengthen the label's value as a tool for managing biological resources sustainably and transparently within diverse bio-based supply chains.

3.1.4 Benefits for reliability and traceability

By applying standardized batching protocols:

- Consistent identification: Each batch is assigned a stable identifier, preventing confusion and data fragmentation across stages.
- Detailed tracking: Stakeholders (and consumers) can drill down into a batch's history, from raw resource to finished product, capturing essential changes in volume, quality, and location along the way.
- Seamless validation: Automated checks, supported by WP5's ICT tool, verify batch data against predefined criteria (e.g., origin records, certification standards), bolstering confidence in the label's reliability.

These protocols, combined with the label's data architecture, create a foundational layer for precise and transparent supply chain documentation. The following sections explore how WP3 tailored data granularity to manage environmental and certification requirements and how the EIP further strengthens the label's reliability and functionality.

3.2 Granularity for certification requirements

Granularity refers to the level of detail captured in the traceability framework for bio-based feedstocks. WP3 designed the biological feedstock label to provide flexible and scalable levels of granularity, enabling precise tracking while supporting the diverse environmental and certification requirements across sectors. This section outlines the principles of granularity, its integration into the labelling framework, and its role in meeting regulatory and sustainability objectives.

3.2.1 Defining Granularity in Traceability

Granularity determines how detailed the information recorded about each feedstock unit must be to meet stakeholder needs. A more granular system captures finer details, such as specific environmental metrics or process-specific data, whereas a less granular system aggregates broader categories of information [20]. WP3 tailored the granularity of the biological feedstock label to ensure it satisfies:

- Regulatory standards: Capturing data at a level detailed enough to comply with EU regulations, such as the General Food Law (EU 178/2002) or specific directives like the EU Fishery Product Labelling Regulation [21].
- Certification schemes: Providing the depth of information needed for schemes such as FSC for forestry, ISCC PLUS for sustainability,
- Sustainability metrics: Documenting key parameters such as carbon emissions, resource efficiency, and CIs, as defined in collaboration with WP2 (D2.3, Circular indicators)

3.2.2 Granularity across sectors

Each bio-based sector has distinct operational, regulatory, and sustainability requirements that shape the level of granularity needed for effective traceability. The degree of detail captured in the tracking process varies depending on the sector's complexity, product transformation stages, and compliance needs. A well-structured granularity framework enables stakeholders to access precise data on resource flows, environmental impacts, and certification adherence, facilitating transparency and informed decision-making.

Table 1: summarizes key attributes relevant for granularity across different sectors, illustrating how traceability requirements align with sector-specific priorities, including feedstock origin, processing details, and sustainability metrics. By structuring data collection based on these parameters, the biological feedstock label supports accurate tracking, regulatory compliance, and circularity assessment in diverse bio-based industries.

3.2.3 Balancing granularity with practicality

While achieving high granularity in traceability enhances the accuracy and reliability of the biological feedstock label, it also introduces challenges, particularly for smaller stakeholders with limited resources [22]. Excessive data requirements can increase administrative burdens, discourage participation, and complicate the adoption of the labelling system. WP3 anticipated and addressed these challenges by developing a tiered granularity model, which balances the need for detailed traceability with the practical constraints of diverse supply chain participants.

Table 1: Granularity attributes for traceability across bio-based sectors

Sector	Granularity attributes	
Agriculture	Harvest details	Crop type, variety, yield per hectare, exact harvest date and time
	Farm specifics	Geographic location (GPS coordinates), farm management practices, soil health indicators, pesticide and fertilizer application records
	Handling and storage	Transportation method, storage conditions (temperature, humidity), storage duration, warehouse details
Fisheries	Catch details	Species, catch weight, catch location coordinates, fishing gear type, vessel ID and crew certification
	Sustainability metrics	Bycatch data, discard rates, fishing method sustainability certification (MSC)
	Post-catch handling	Processing method (fresh, frozen, processed), processing conditions, transportation and cold-chain management details
Forestry	Logging details	Geographic location, precise logging site coordinates, harvesting date and method (selective cutting, clear-cutting), machinery used
	Forest management	Certification status (FSC, PEFC), biodiversity indicators, reforestation plans, tree species and age classes
	Residue recovery	Residue recovery: Volume and type of residues (chips, sawdust), residue processing details, final product destination
Urban bio-waste	Collection specifics	Collection time and date, source type (residential, commercial, industrial), contamination analysis (type and level), geographic collection zones
	Waste processing	Detailed pathway (anaerobic digestion, composting, incineration), processing facility specifics, energy or bio-product output details
	Product valorisation	Type and volume of derived products (biopolymers, fertilizers), certifications, and alignment with circular economy guidelines

The Basic granularity model caters to smaller producers or less complex supply chains by focusing on capturing only essential data. For instance, small-scale agricultural operations or fisheries with limited output might only need to record key parameters such as batch origin, basic certification information, and processing type. This simplified approach ensures that these stakeholders can participate in the traceability system without being overwhelmed by complex data entry or management processes. By reducing the entry barriers, the label promotes inclusivity while still maintaining its core functionality.

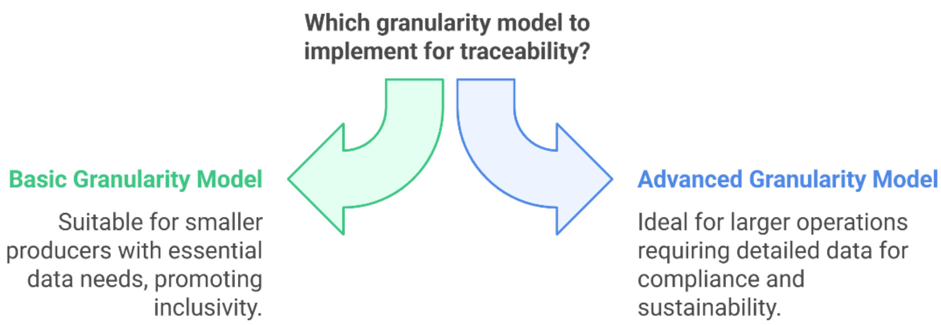

Figure 1: Basic and advanced granularity models

On the other hand, the Advanced granularity model is designed for larger or more complex operations that require detailed data to meet regulatory, certification, and sustainability standards (Figure 1). For example, industrial-scale forestry or urban bio-waste facilities might integrate data on multi-stage transformations, environmental performance metrics, and processing efficiencies. This advanced tier allows for the capture of comprehensive information, including detailed tracking of by-products, energy usage, or emissions. Such granularity supports in-depth sustainability assessments and compliance with stringent certification schemes.

The flexibility of this tiered model ensures that the label adapts to the scale and complexity of each operation, making it accessible and practical for all stakeholders. Smaller entities can adopt the system with minimal disruption, while larger players can leverage advanced granularity to demonstrate leadership in sustainability and compliance. By balancing these tiers, WP3 has created a labelling framework that is not only robust but also scalable and user-friendly, ensuring widespread adoption across bio-based sectors.

3.2.4 Technical integration of granularity

To achieve seamless integration of granularity into the biological feedstock label, WP3 collaborated with WP5 to leverage the ICT tool. This digital platform, designed to facilitate data collection, management, and exchange, plays a pivotal role in ensuring that the varying levels of granularity required across sectors are implemented effectively.

Dynamic data fields

One of features of the data collection system is its ability to adjust data capture requirements dynamically. This flexibility allows the system to cater to sector-specific needs, accommodating diverse bio-based industries such as agriculture, fisheries, forestry, and urban bio-waste management. For example:

- In agriculture, the tool can capture simple batch identifiers for small-scale farms or more complex metrics such as harvest lot specifics and post-harvest handling for larger operations.
- In fisheries, the system adjusts to record additional data points for high-value processing, such as biomass destined for collagen production, without overwhelming smaller fishery operators with unnecessary requirements. This adaptability ensures that stakeholders at all levels, from small producers to large industrial players, can engage with the system effectively while meeting regulatory or market demands.

Automated validation

WP3 has established a comprehensive automated validation mechanism, detailed in D3.2, designed to confirm the accuracy and reliability of data provided by ICT tool. This validation involves cryptographic hashing (SHA-256) for data authenticity, integrity checks to ensure compliance with predefined certification criteria, and data format standards. Once data passes these validation steps, it is securely and immutably recorded onto the blockchain, ensuring full traceability and transparency. This systematic approach significantly enhances data integrity and supports trustworthy decision-making across bio-based value chains.

Real-time updates

As feedstocks progress through the supply chain, granularity must be maintained even as batches are split, merged, or transformed during processing. Key examples include:

- Batch splitting: When a single batch of OFMSW is divided into multiple streams for composting and anaerobic digestion, the tool records the transformation and updates traceability data for each sub-batch.
- Re-batching: When residues like sawdust from multiple forestry operations are combined to produce bioenergy pellets, the system reconciles the original data from all input batches into the final product's traceability record.
- Evolving metrics: Real-time updates also enable the tool to incorporate new data points or changes in regulatory requirements as they arise, ensuring that the label stays relevant and compliant.

Interoperability with other systems

The granularity framework within T&T application is designed to support seamless interoperability with external systems, including certification bodies, regulatory agencies, and partner organizations. Standardized data formats and communication protocols ensure that granular data can be easily shared, verified, and integrated with other platforms, reducing redundancy and improving efficiency.

3.2.5 Supporting certification and sustainability Goals

By empowering the biological feedstock label to capture detailed and accurate data, granularity ensures alignment with diverse regulatory and certification standards, significantly reducing the risk of non-compliance. For example, certifications such as FSC for forestry or EU Organic Certification for agriculture rely on precise documentation of origin, processing methods, and compliance with sustainability criteria. Through granular traceability, stakeholders can easily meet these requirements, avoiding delays and penalties while streamlining the certification process.

Moreover, the availability of transparent and detailed information needs trust among key stakeholders, including regulators, consumers, and certification bodies. Regulators gain confidence in the integrity of reported data, while certification bodies benefit from simplified auditing and validation processes. For consumers, granular traceability reinforces the credibility of sustainability claims, making it easier to understand how products align with ethical and environmental standards. This transparency not only promotes stakeholder engagement but also strengthens the market position of bio-based products.

Granularity also provides critical insights into sustainability performance, empowering stakeholders to measure and report on key indicators. By capturing specific data points, such as resource utilization, by-product recovery, and batch-level emissions, the biological feedstock label supports stakeholders in aligning with the circular economy goals. For instance, forestry residues tracked with granular data can demonstrate compliance with circularity targets by showing how side streams like bark or sawdust are valorised into bioproducts. Similarly, agricultural batches documented at the farm level can provide insights into carbon footprint reduction efforts and soil health improvements.

Through its contribution to certification, stakeholder trust, and sustainability insights, granularity serves as a cornerstone of WP3's mission to advance transparency, traceability, and environmental accountability across bio-based industries.

By implementing a flexible and scalable granularity model, WP3 has ensured that the biological feedstock label meets the rigorous environmental and certification requirements of bio-based industries. This approach not only enhances traceability but also aligns with the overarching goals of transparency, sustainability, and compliance within the BioReCer project.

3.3 Electronic identification passport generation

The EIP developed under WP3, providing a digital record that ensures traceability, reliability, and alignment with certification and regulatory standards. The EIP serves as a unique identifier for each batch of biological feedstock, capturing critical data throughout its lifecycle, from production to transformation and distribution. This section outlines the methodology for generating and managing EIPs, their integration into the BioReCer framework, and their role in enabling transparency and accountability across diverse bio-based supply chains.

3.3.1 Purpose and design of the EIP

The EIP is designed to function as a dynamic and comprehensive digital passport, consolidating data points essential for verifying the provenance, quality, and sustainability of feedstocks. It includes:

- Batch identification: A unique code that links the EIP to a specific batch, ensuring that the feedstock can be tracked across all supply chain stages.
- Core attributes: Key data such as geographic origin, harvest or collection date, processing methods, and certifications are explicitly linked to each batch identification code, allowing immediate traceability and verification across the supply chain.
- Lifecycle data: The EIP captures updates at every stage of the feedstock's lifecycle, ensuring a detailed and continuous record of its journey through the supply chain.

This includes critical transformations such as 'batching', where multiple smaller units are consolidated; 'splitting', where a single batch is divided into smaller sub-batches for different applications; and 'merging', where residues or by-products from multiple sources are combined into a new batch. Each update is logged in real-time and includes key attributes such as the location, date, and method of transformation. This comprehensive tracking enables stakeholders to maintain a transparent and verifiable record of feedstock movements and transformations, supporting both regulatory compliance and market demands for traceability and accountability.

The EIP structure was developed with flexibility in mind, allowing it to accommodate sector-specific requirements and evolving regulatory or market needs. For instance, fisheries related EIPs might include data on catch location, species composition, and by-product generation, while urban bio-waste EIPs might emphasize contamination levels and processing methods.

3.3.2 EIP generation methodology

WP3 adopted a systematic and scientifically grounded approach to generating EIPs, exploiting advanced technologies, stakeholder collaboration, and automated validation processes. This methodology ensures that the EIPs provide a robust, secure, and transparent record of feedstock data, supporting BioReCer's traceability and sustainability objectives. The process is broken down into three key stages: data capture, EIP generation, and lifecycle tracking.

Data capture

The generation of an EIP begins with the collection of critical feedstock data from diverse sources, ensuring a comprehensive and reliable dataset. To achieve this, WP3 utilized the following methods:

- IoT-enabled devices: Sensors and IoT systems capture real-time data on key attributes such as temperature, moisture, and location during harvesting, transport, and storage. This is particularly relevant for sensitive materials like OFMSW or perishable fisheries by-products, where real-time monitoring ensures quality preservation and regulatory compliance.
- Manual entries: For smaller producers or scenarios where IoT infrastructure is not yet in place, data is entered manually via user-friendly interfaces in the ICT tool. This includes information such as batch origin, processing steps.

- Existing certification records: Data from certification schemes can be integrated into the system to validate compliance and reduce redundancy in reporting.

The captured data is transmitted securely to the ICT tool, where it undergoes initial validation to ensure accuracy, completeness, and alignment with regulatory and certification requirements.

EIP Generation

Once the feedstock data has been validated, WP3's methodology encodes it into a unique EIP This process involves:

- Batch-specific identifiers: A globally unique identifier (e.g., a hashed code) is assigned to each batch, confirming traceability across the supply chain without duplication or overlap.
- Attribute encoding: The EIP includes essential attributes such as geographic origin, batch size, processing details, and associated certifications. Additional data fields can be dynamically added based on sector-specific needs or regulatory updates.
- Blockchain storage: The EIP is stored on a centralized blockchain platform managed by WP3. Blockchain technology guarantees the immutability of records, meaning that once data is entered, it cannot be altered or deleted without a transparent record of changes. This ensures that stakeholders can trust the integrity of the data throughout the feedstock's lifecycle.

The generation process also incorporates role-based access controls (RBAC), ensuring that only authorized users, such as producers or regulators, can input or retrieve specific data.

Lifecycle tracking

As the feedstock progresses through the supply chain, the EIP is updated in real time to reflect every transformation or handling event. WP3 has developed protocols to ensure that these updates are systematic, secure, and transparent:

- Processing steps: The EIP records details of each stage, such as milling in agriculture, palletisation in forestry, or collagen extraction in fisheries. This level of detail facilitates that stakeholders can trace the exact history of the material.
- Batch splitting and merging: When a batch is divided into smaller units (e.g., splitting OFMSW into biopolymer production and composting streams) or merged with other batches (e.g., combining sawdust from multiple forestry operations), the EIP captures these events and links them to the original source batches.

- Blockchain transactions: Each update to the EIP is logged as a new transaction in the blockchain, creating an unbroken, verifiable history of the feedstock's journey. This transactional history ensures accountability and facilitates audits by regulators and certification bodies.

Scientific and operational significance

The systematic approach to EIP generation confirms that the methodology is scientifically sound and operationally feasible. By combining advanced technologies such as IoT and blockchain with stakeholder inputs and validation processes, WP3 has developed a robust system that:

- Enhances traceability and compliance by maintaining an accurate, tamper-proof record of feedstock data.
- Simplifies audits and reporting for regulators and certification bodies by providing a single, reliable source of truth.
- Reduces the risk of errors and inefficiencies through automated validation and real-time updates.

This methodology aligns with BioReCer's broader goals of advancing sustainability, transparency, and circular economy principles and addresses the practical needs of stakeholders across bio-based sectors.

3.3.3 Role of the EIP in traceability and certification

The EIP designed to centralize and consolidate all batch-related information into a secure, verifiable, and dynamic digital record. By serving as a single source of truth, the EIP strengthens transparency, reliability, and accountability across the supply chain. Its role is critical in facilitating traceability, compliance, and supporting sustainability goals. Below shows on how the EIP benefits stakeholders and supports certification objectives.

Verify compliance

The EIP provides certification bodies and regulators with instant, secure access to critical data required for verifying compliance with relevant standards. For example, in fisheries catch location, species type, and handling conditions are embedded in the EIP, enabling compliance with EU Fishery Product Labelling and sustainability guidelines.

By offering a comprehensive and tamper-proof record, the EIP reduces the risk of non-compliance and strengthens trust between stakeholders, certification bodies, and consumers.

Monitor sustainability

By embedding T&T data, environmental and CIs, the EIP provides stakeholders with a transparent view of the feedstock's lifecycle impact. For instance, in circularity metrics, indicators related to by-product utilization, waste reduction, and resource efficiency are integrated into the EIP, highlighting contributions to circular economy objectives.

Sustainability trends

Over time, the EIP's records allow stakeholders to identify patterns and trends in sustainability performance, enabling continuous improvement. This integration supports not only regulatory compliance but also voluntary sustainability initiatives, enhancing the marketability of bio-based products.

Streamline audits

Audits, essential for certification, often bring administrative and logistical challenges. The EIP simplifies this by consolidating all relevant data into a single platform, reducing time and resources required for preparation. It enhances accuracy by eliminating manual data consolidation, minimizing errors, and ensuring audit readiness with real-time updates and automated validation. This streamlined process reduces disruptions for producers and processors while maintaining full compliance, fostering trust across the supply chain.

Supporting stakeholder engagement

The EIP enhances stakeholder confidence by providing a transparent and reliable mechanism for verifying sustainability and compliance claims. This develops stronger collaboration across the supply chain, as all parties—producers, processors, regulators, and consumers—can access the data they need to make informed decisions.
For example:

- Producers can use the EIP to demonstrate the integrity of their operations, strengthening relationships with buyers and certification bodies.
- Processors gain a clear and reliable record of feedstock origins and transformations, supporting their own sustainability and traceability goals.
- Consumers are empowered with verified information about the ethical and environmental attributes of the products they purchase, building trust in bio-based products.

By consolidating traceability and certification-related data into a single, secure platform, the EIP enhances compliance, supports sustainability monitoring, and streamlines audits.

This capability strengthens the overall traceability framework and aligns with the project mission to promote transparency, accountability, and sustainability within bio-based supply chains. The EIP is a transformative tool that empowers stakeholders, drives market confidence, and sets new standards for managing biological feedstocks in a circular and sustainable economy.

3.3.4 Technical integration with the ICT tool

The ICT tool plays a central role in integrating the EIP into the broader traceability system. Once fully implemented, it will enable the passport to remain a dynamic and reliable source of information. A key objective of this integration is to support real-time updates throughout the feedstock's lifecycle. Planned features include the automatic recording of changes, such as batch transformations, splitting, or merging, to maintain accuracy and relevance. Future developments aim to introduce user-friendly, role-specific interfaces that will allow producers, processors, and regulators to access the specific data they need without being overwhelmed by unnecessary details. This streamlined interaction is intended to enhance data sharing, traceability, and compliance across the supply chain.

4 Label criteria

The biological feedstock label within the BioReCer framework is designed to provide a transparent, reliable, and verifiable record of biological resources used across various bio-based industries. To achieve this, WP3 has established a robust set of label criteria that define the essential characteristics required for traceability, certification, and sustainability compliance. Labelling establishes market confidence, encourages regulatory compliance, and promotes environmental responsibility, among other things.

The development of the label criteria was guided by several key objectives:

- Establishing reliability metrics to maintain data accuracy and prevent inconsistencies in supply chain reporting.
- Verifying conformity with certification standards, allowing seamless verification of compliance with sustainability frameworks.
- Defining performance indicators for assessing the quality and suitability of feedstocks at different stages of processing.
- Enhancing transparency and accessibility, enabling stakeholders to make informed decisions based on real-time, verifiable data.

This section explores the specific benchmarks and assessment frameworks used in the labelling process. By outlining these criteria, WP3 has developed a comprehensive labelling framework that supports the BioReCer project's broader objectives of sustainability, traceability, and market acceptance. The following sections delve into the details of each component, demonstrating how the label functions as an essential tool for certifying bio-based resources.

4.1 Reliability metrics and benchmarks

Reliability ensures that all recorded information remains accurate, traceable, and consistent across different supply chain stages. WP3 developed a set of reliability metrics and benchmarks to validate data quality, prevent inconsistencies, and support robust traceability in alignment with certification and regulatory requirements. These metrics provide stakeholders with confidence that the label can be trusted as a verifiable source of truth within the BioReCer ecosystem.

Defining reliability in the labelling framework

Reliability in the context of the label refers to the consistency, accuracy, and verifiability of data collected at each stage of the supply chain. To ensure that the label meets these criteria, WP3 established three core reliability pillars:

- Data accuracy: Ensuring that information recorded in the EIP reflects the real attributes of the feedstock, such as batch origin, transformation processes, and certification status.
- Traceability consistency: Maintaining uniform recording methods across all supply chain actors, preventing discrepancies between production, processing, and certification data.
- Verification benchmarks: Cross-referencing recorded data with recognized certification standard and its compliance requirements and regulatory databases

Key reliability Metrics

The key quantitative and qualitative metrics identified to assess the reliability of recorded data within the labelling system includes the following:

- Batch identification accuracy: Measuring the percentage of correctly assigned batch IDs without duplication or misclassification. For example, a fisheries processing facility receives fish biomass from multiple vessels. Each batch is assigned a unique identifier linked to its catch location, vessel name, and processing date. If two different batches from different vessels are mistakenly assigned the same batch ID, the system flags the duplication. A high batch identification accuracy means that each fish oil or collagen production batch retains its distinct identifier, preventing traceability errors.
- Data integrity score: A validation score based on automated and manual cross-checks against certification standards and regulatory databases. For instance, A batch of fish biomass certified under certification under the Fishery Product Labelling Regulation is logged in the EIP. The T&T application cross-checks the certification ID with an official database. If the certificate is expired or invalid, the system assigns a lower integrity score, requiring to provide a valid certificate and apply corrective actions as required. With this score, we ensure that fish by-products processed into collagen have verifiable origins and meet sustainability criteria.
- Traceability completeness index: Evaluating how consistently data is recorded across different supply chain stages, confirming no missing records in processing and transformation stages. For example, batch of tuna heads and bones intended

for collagen production is tracked from catch to final product. If all supply chain actors (fishing vessel, cold storage, processing plant) correctly record their transactions, the completeness index remains 100%. However, if the cold storage operator fails to log temperature data, a missing entry reduces the index. This index confirms that each fish batch's history is fully documented, minimizing gaps that could compromise sustainability claims or food safety.

- Anomaly detection rate: Identifying inconsistencies in feedstock classification, processing declarations, or certification claims through automated verification tools. For instance, a batch of fish by-products is recorded as being sourced from a vessel operating in a specific zone, but GPS data from the vessel shows fishing occurred outside the certified area. The T&T application detects this discrepancy and flags it for review. This metric prevents mislabelling of products.
- Audit pass rate: The percentage of batch that successfully pass compliance with the certification standard requirements during the audits without requiring corrective actions. For example, a processing facility undergoes an audit to verify that its fish oil production from by-products follows traceability and sustainability requirements of a certain certification standard. If all recorded data during the audit matches supply chain records, the batch passes without issue. However, if missing records (e.g., processing temperature logs) are found, corrective actions are required, lowering the pass rate. It is however to note that validity of certification standards may vary and may require to carry out audit annually either onsite or remote.

These metrics allow WP3 to continuously monitor and improve the reliability of the label, therefore, stakeholders can rely on it as an authoritative source of supply chain information.

Benchmarking against industry standards

To maintain credibility and ensure compliance with existing certification standards, WP3 aligned the reliability metrics of the biological feedstock label with established industry standards. These benchmarks provide a foundation for regulatory adherence, sustainability validation, and market acceptance.

Under WP4, a comparative analysis between the environmental and traceability assessment framework (developed by WP2 & WP3) and existing bio-based certification systems was conducted. This included a gap analysis between different globally applicable voluntary certification schemes for the different sectors within the scope of the project. Some of the certification standard assessed are the Roundtable on Sustainable Biomaterials (RSB), Forest Stewardship Council (FSC), Programme for the Endorsement of

Forest Certification (PEFC) and Global G.A.P Aquaculture while ISCC PLUS remained a key reference. The outcomes of this tasks will be provided in the deliverable D4.3 under WP4.

Each feedstock type follows a sector-specific benchmark, ensuring that the biological feedstock label remains compliant with its respective industry requirements. By including these certification standards, WP3 provided a traceability framework that is both globally recognized and practical for real-world applications. Thus, these efforts reinforce BioReCer's commitment to strengthening traceability, transparency, and regulatory compliance, ensuring that bio-based supply chains meet the highest standards of reliability.

4.2 Conformity to certification standards

The biological feedstock label developed under WP3 is designed to align with the project's framework that is developed on the basis of established certification standards and regulatory requirements. This guarantees bio-based feedstocks meet industry-recognized sustainability and traceability standards, ensuring that each batch of biological feedstock can be verified against relevant industry standards. This conformity strengthens market credibility, regulatory compliance, and consumer confidence, allowing stakeholders to demonstrate adherence to best practices in sustainable sourcing, processing, and environmental responsibility.

Structuring the label for certification compliance

To facilitate conformity with certification standards, WP3 implemented a multi-tiered approach in the labelling system:

- Certification data fields: The label structure includes dedicated sections allowing producers and processors to upload their certificates or input information or weblink of the valid existing certification records.
- Automated cross-validation: The T&T application verifies entered data against official databases of certification standard, ensuring accuracy and preventing fraudulent claims.
- Audit-ready documentation: The label securely records all certification-related attributes in a tamper-proof format, simplifying third-party certification audits. It preserves key details of valid certificates alongside the necessary documentation required by certification bodies, facilitating efficient compliance verification and audit processes.

- Role-specific access: Certification bodies and certification standards can retrieve relevant data from the label to confirm compliance without requiring direct involvement from producers at every verification stage.

By structuring the label to document and verify certification records, WP3 has developed a traceability solution that not only aligns with regulatory expectations but also simplifies certification workflows for stakeholders. This approach strengthens traceability across bio-based supply chains while reducing administrative burdens for producers seeking certification.

4.3 Performance indicators for feedstock quality

The biological feedstock label developed under WP3 incorporates performance indicators to assess the quality of feedstocks across different bio-based sectors. These indicators provide a standardized approach to evaluating feedstock characteristics, communicating that materials used in processing meet traceability, and market expectations. By integrating measurable performance criteria, the label supports quality assurance, sustainability monitoring, and regulatory compliance, helping stakeholders make informed decisions throughout the supply chain.

WP3 established these performance indicators to:

- Maintain consistency in feedstock classification and traceability.
- Support certification standards and regulatory frameworks by aligning with recognized quality benchmarks.
- Enhance the reliability of bio-based feedstocks for further processing and valorization.
- Facilitate sustainability assessment, ensuring that the feedstocks contribute to circular economy objectives.

The following sections outline the key performance indicators applied to different feedstock categories and their role in maintaining quality standards.

4.3.1 Defining performance indicators for feedstock quality

Performance indicators are sector-specific and depend on the type of biological material being processed.WP3 developed a framework that integrates quantifiable and verifiable criteria, enabling stakeholders to assess the suitability of feedstocks for further processing while supporting alignment with certification and sustainability goals. These indicators fall into the following categories:

- Physical and chemical properties – Defining material quality based on moisture content, purity levels, or contaminant presence.
- Traceability and documentation accuracy – Maintaining accurate data on feedstock attributes such as records of production data, geographic origin, and batch details.
- Processing suitability – Evaluating whether the feedstock meets the specifications for its intended application (e.g., composting, collagen extraction).
- Sustainability and circularity metrics – Capturing attributes that align with circular economy goals, such as by-product recovery rates or waste minimization.

By structuring the label to incorporate these indicators, WP3 enhanced the transparency and reliability of feedstock data, allowing for more precise quality control across bio-based supply chains.

4.3.2 Integration of performance indicators into the label

To ensure that feedstock quality is assessed consistently, WP3 structured the 'biological feedstock label' to accommodate performance indicators at different stages of the supply chain. These indicators are embedded into the label through a multi-layered approach, ensuring they remain accessible, verifiable, and relevant for stakeholders across various bio-based sectors.

- Sector-specific data fields – The label includes predefined fields for performance indicators tailored to different feedstock types, such as biomass composition in fisheries, moisture content in agriculture, and residue recovery rates in forestry.
- Integration with certification requirements – Performance indicators are mapped to certification benchmarks and verify that feedstocks meet sectoral quality standards before the label is issued.
- Transformation tracking – Performance data remains linked to feedstocks throughout batching, processing, and transformation, maintaining continuity in traceability and quality verification.
- Stakeholder validation – Producers and processors can review and validate performance indicators before submitting data for certification, minimizing discrepancies and improving audit efficiency.

This structured integration of performance indicators into the label enhances quality assurance, supports certification compliance, and facilitates data-driven decision-making for stakeholders. By embedding these indicators directly into the BioReCer traceability system, WP3 provided a reliable framework for monitoring and improving feedstock quality across bio-based supply chains.

4.4 Promotion of sustainability through transparency

Transparency is a fundamental principle which supports sustainability objectives by confirming that all stakeholders—producers, processors, regulators, and consumers—have access to verifiable, traceable, and meaningful data on feedstock origins, processing methods, and environmental impact. By embedding transparency into the labelling framework, WP3 strengthened trust in bio-based supply chains while reinforcing compliance with circular economy principles and sustainability regulations.

Through traceability, open data access, and verifiable sustainability metrics, the label promotes responsible resource management, informed decision-making, and regulatory compliance. This section outlines how WP3 has structured the label to enhance sustainability transparency across different sectors.

4.4.1 Embedding sustainability and circularity metrics in the label

To effectively promote sustainability, WP3 designed the biological feedstock label to capture and display key sustainability and CIs throughout the supply chain. This approach certifies that stakeholders have access to critical data on environmental impact, resource efficiency, and compliance with EU sustainability policies.

For example, one of the elements integrated into the label is resource efficiency data, which documents material utilization rates, by-product recovery efficiency, and waste minimization efforts. By tracking how resources are used and repurposed, the label helps identify opportunities for optimizing material flows and reducing waste, supporting the principles of circularity. Another crucial aspect is valorization pathways, which record how feedstocks are transformed into high-value bio-based products. By embedding these pathways into the labelling framework, WP3 ensures that feedstocks contribute to circular economy goals, emphasizing sustainable material recovery and reuse.

Additionally, the label integrates data relevant to sustainability certifications by linking each feedstock batch to environmental standards and certification schemes. While WP3 does not perform sustainability assessments, it provides calculated CIs that contribute to evaluating the material recovery and efficiency of bio-based feedstocks. The traceability system ensures that relevant circularity data is accessible through the BioReCer ICT tool, supporting informed decision-making across bio-based supply chains. By embedding these quantifiable circularity metrics, WP3 enhances transparency and traceability, allowing stakeholders to assess the contribution of bio-based feedstocks to circular economy goals while relying on established sustainability frameworks for full sustainability assessment.

4.4.2 Enhancing stakeholder trust through transparency

A core function of the biological feedstock label is to develop trust among stakeholders by providing a clear, auditable, and secure record of sustainability performance. The label is primarily digital and accessible through the ICT tool, allowing stakeholders to retrieve verified traceability data linked to each batch of feedstock. While the main implementation is digital, it can also be represented through QR codes or embedded tracking identifiers for on-site verification. This approach keeps sustainability information accessible at different points along the supply chain, supporting informed decision-making based on reliable, verifiable data.

By confirming that sustainability data is traceable and verifiable, the label strengthens confidence across the bio-based value chain, enabling different actors to make informed decisions based on reliable information.

For producers and processors, the label serves as a credible demonstration of sustainable practices, helping them showcase their adherence to responsible sourcing, efficient resource use, and regulatory requirements. This transparency simplifies certification processes and allows businesses to differentiate themselves in sustainability-driven markets. Certification bodies and regulators benefit from the label's ability to streamline verification processes, reducing the reliance on manual documentation checks and facilitating compliance assessments more efficiently. With traceability data digitally structured, certifications can be validated faster, ensuring that only verified bio-based feedstocks enter sustainable markets.

From a consumer and market perspective, transparency in sustainability reporting strengthens confidence in bio-based products and materials. The label provides accessible, standardized data that allows buyers, investors, and policymakers to assess the environmental and ethical integrity of feedstocks. By integrating role-specific access, the label ensures that each stakeholder group can retrieve the necessary sustainability data while maintaining data security and business confidentiality. This structured approach to transparency reinforces trust in sustainable supply chains, making sustainability claims more credible, data-driven, and resistant to misinformation.

4.4.3 Ensuring data integrity and open access

To further promote sustainability, WP3 incorporated mechanisms that enhance the accessibility, accuracy, and security of sustainability-related data. This includes:

- Immutable record-keeping – Data recorded in the label is protected through cauterised blockchain integration (D3.1), guaranteeing that sustainability claims cannot be tampered with or falsified.

- Standardized sustainability reporting – Aligning data structures with EU regulatory frameworks, allowing seamless integration with external certification and compliance bodies.
- Interoperability with ICT Tool – Enabling automated updates and real-time verification of sustainability metrics through WP5's data-sharing infrastructure.

These features provide a transparent and reliable system that reinforces sustainability commitments and reduces the risks of greenwashing in bio-based supply chains.

By embedding sustainability indicators, enhancing data transparency, and providing secure access to critical information, the BioReCer biological feedstock label serves as a key enabler of responsible resource management. WP3's focus on traceability and open access to sustainability data ensured that bio-based feedstocks align with EU circular economy objectives, creating a labelling framework that is both scientifically rigorous and practical for real-world applications.

This transparency-first approach strengthens credibility, regulatory alignment, and stakeholder confidence, making sustainability a quantifiable and verifiable component of bio-based supply chains.

5 System architecture and implementation

The biological feedstock label developed under WP3 is designed to be seamlessly integrated into WP3's T&T system, providing a structured, secure, and dynamic approach to managing feedstock traceability. To achieve this, WP3 developed a scalable system architecture that supports real-time data updates, certification verification, and automated reporting, ensuring that stakeholders can access reliable information while minimizing manual intervention.

This section outlines the technical foundation and implementation strategy for integrating the label within BioReCer's digital infrastructure. It describes how the label connects with T&T systems, the tools used for data analysis and reporting, and the automation mechanisms that facilitate efficient label generation and updates.

By structuring the label's system architecture to accommodate evolving regulatory, certification, and industry requirements, WP3 has established a robust, transparent, and adaptable labelling framework that enhances traceability across bio-based supply chains. The following sections provide a detailed breakdown of how these elements have been implemented within BioReCer.

5.1 Integration with the track and traceability framework

The biological feedstock label is embedded within T&T framework, enabling real-time tracking, certification validation, and automated data management across bio-based supply chains. Unlike the broader traceability principles outlined in previous deliverables, this section focuses on the technical and functional integration of the label within T&T system, ensuring that data flows seamlessly from feedstock production to final processing. The integration of the label into the T&T system enhances data reliability, regulatory compliance, and certification verification, preventing inconsistencies that could arise from manual record-keeping. By structuring label data to interact directly with ICT tool, WP3 ensured that stakeholders can retrieve, update, and validate feedstock traceability information in an automated and structured manner.

5.1.1 Aligning the label with T&T System

To facilitate full interoperability, WP3 structured the biological feedstock label within T&T system based on three key principles:

- Standardized data framework: The label follows a structured format that aligns with T&T system protocols, ensuring that all recorded attributes (e.g., certification status, batch transformations) match predefined traceability fields used across BioReCer. For example, in the fisheries sector, the label captures catch location, vessel ID, species composition, and processing details. If a batch of fish by-products is destined for collagen extraction, the EIP (not the label itself) is updated to reflect handling conditions and processing transformations, ensuring that stakeholders can verify sustainability claims and compliance with certification standards.

- Automated lifecycle tracking: Batch modifications, such as splitting, merging, or processing updates, are automatically recorded in the T&T system and reflected in the EIP, ensuring synchronized traceability records. For instance, in the fisheries sector, a batch of fish by-products may be split into two processing streams: one for collagen extraction and another for fish oil production. When this split occurs, the EIP (not the label) is updated in real-time to log processing details such as processing date, facility location, and sustainability certification status. This ensures that each batch retains its full traceability history while maintaining the static nature of the issued label.
- Blockchain-backed security: The T&T system logs every update to prevent data tampering and ensure auditability, reinforcing compliance with regulatory and sustainability standards.

This structured approach prevents data fragmentation and guarantees that the label remains a static identifier, while the EIP and T&T system handle dynamic updates, maintaining a complete and transparent traceability history across different sectors.

5.1.2 Enhancing certification and regulatory compliance

One of the primary functions of integrating the label within the T&T framework is to streamline compliance verification for regulators and certification bodies. Through this integration, the label directly interacts with certification standards, allowing for:

- Automated certification cross-validation: The system cross-checks feedstock data with certification repositories, validating compliance with relevant standards.
- Real-time certification status tracking: Certification status updates—such as renewal, expiration, or non-compliance—are recorded in the T&T system and reflected in the EIP, ensuring stakeholders can monitor compliance. While the issued label remains static, any certification changes are linked to the batch's traceability records, allowing for verification in audits and compliance checks.
- Simplified audit access: Certification bodies can retrieve label compliance reports and sustainability metrics without requiring manual data collection from producers.

By embedding these certification verification features, WP3 minimizes administrative workload and on the other side stakeholders maintain continuous compliance with certification and regulatory frameworks.

5.1.3 Interoperability with the ICT tool

The ICT tool, managed by WP5, serves as a data collection and visualization platform, providing stakeholders with access to WP3's biological feedstock label and its associated traceability records. While the ICT tool does not process or modify data on behalf of WP3, it functions as a gateway for stakeholders to submit, retrieve, and view relevant traceability and certification information.

This integration ensures that:

- Stakeholder data submission and retrieval: Producers, processors, and regulators can enter, and access data related to feedstock traceability, certification, and sustainability metrics via the ICT tool, ensuring structured data collection without interfering with WP3's traceability system.
- Visualization of label and EIP data: The ICT tool provides graphical dashboards and structured reports that allow stakeholders to interpret feedstock traceability data without altering WP3's records.
- Access to WP3's traceability system: Stakeholders interact with WP3's data framework through the ICT tool, enabling them to verify certification status, track sustainability indicators, and review batch history, while WP3 remains responsible for the traceability and labelling framework itself.

The integration of the biological feedstock label into WP3 T&T framework confirms structured traceability, stakeholder access to data, and reliable compliance tracking. While WP3 independently manages traceability, certification cross-verification, and data validation, the BioReCer ICT tool provides a platform for stakeholders to submit, retrieve, and visualize relevant information. By structuring the label to be accessible through the ICT tool, WP3 enhances regulatory trust, sustainability monitoring, and transparency, ensuring that stakeholders can interact with feedstock traceability data while WP3 maintains full control over labelling and compliance processes.

5.2 Tools for data analysis and reporting

To support stakeholder decision-making, certification validation, and sustainability tracking, WP3 designed the biological feedstock label to be compatible with data analysis and reporting tools. These tools facilitate data-driven insights, allowing producers, processors, regulators, and certification bodies to assess traceability performance, compliance levels, and environmental contributions.

While WP3 is responsible for the T&T framework, the ICT tool serves as the data access and visualization platform, assist stakeholders can retrieve and interpret feedstock data without modifying the labelling system itself. This section outlines the analytical and reporting capabilities used to assess and communicate traceability information across the supply chain.

5.2.1 Analytical capabilities for traceability and certification

WP3 utilizes data analysis tools to extract meaningful insights from the labelling system. This helps stakeholders to evaluate traceability performance and compliance trends. These capabilities include (Figure 2):

- Traceability performance metrics: Analysing batch movements, processing history, and certification status to identify inconsistencies or missing records.
    - For example, in the fisheries sector, a batch of anchovy by-products is recorded for collagen extraction. However, when cross-referencing the batch movement logs, the processing facility records show a discrepancy in weight—the recorded incoming batch was 5% lower than the amount reported at the landing site. This triggers a traceability alert, prompting further investigation to verify whether the missing quantity was lost during transportation, misreported, or diverted to another processing stream. By detecting such inconsistencies, the system helps prevent data mismatches, unauthorized diversions, or potential fraud, ensuring that the traceability records accurately reflect real-world batch movements.
- Certification compliance tracking: Assessing whether feedstock batches maintain compliance with certification schemes over time, with alerts for expired, revoked, or missing certificates. For instance, a batch of sardine by-products is registered for processing into fish oil and collagen extraction. During a routine compliance check, the system detects that one of the batch's certificates expired two weeks before processing but was not renewed by the supplier. This triggers an automated alert, notifying both the processor and relevant stakeholder that the batch no longer meets compliance with the certification schemes. As a result, the batch is flagged for further review, preventing it from being marketed as a sustainably sourced product until the certificate is renewed or an alternative verification process is completed.

- Batch-level sustainability trends: Measuring valorization rates, resource efficiency, and circularity metrics, supporting EU sustainability reporting requirements. In collaboration with WP2, WP3 integrates traceability data with sustainability and circularity assessments by recording how a batch of fish by-products is valorized into collagen and fish oil production. WP3's labelling system captures batch transformations, while WP2 calculates and analyses the efficiency of resource utilization—such as the percentage of biomass converted into valuable products and the reduction of processing waste. If WP2 calculations identifies inefficiencies in by-product recovery, stakeholders can use this insight to optimize resource use, ensuring that sustainability targets are met and accurately reported under EU Circular Economy guidelines.

These analytical tools allow WP3 to continuously refine the traceability framework, ensuring that the biological feedstock label remains aligned with evolving regulatory and industry standards.

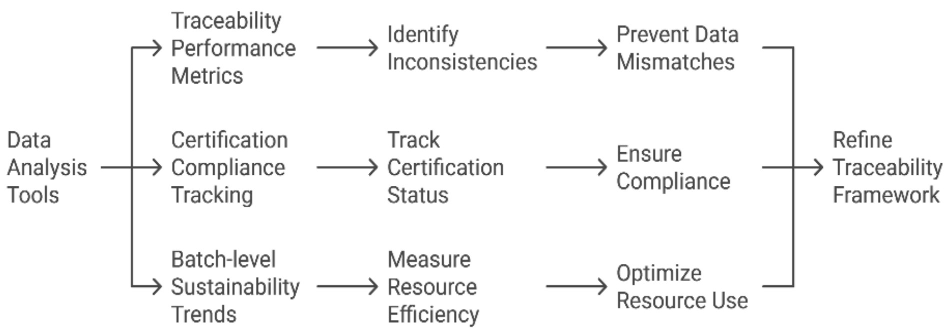

Figure 2: WP3 analytical capabilities for traceability and certification

5.2.2 Reporting framework for stakeholders

To enhance transparency and decision-making, WP3 structured the label data to be accessible through customizable reporting formats, ensuring that different stakeholders can retrieve and interpret relevant traceability insights. These include:

- Producers and processors: Reports on batch traceability, processing history, and certification status, allowing them to monitor compliance with traceability requirements.
- Certification bodies: Reports that consolidate sustainability compliance data along the supply chain, and certification details based on existing audit results. This tool

simplifies access to structured sustainability data but does not replace the audit process or its reports.

- Consumers: Summarized traceability reports supporting sustainability claims and bio-based product verification.

The ICT tool provides an interactive visualization interface where stakeholders can access historical traceability reports, and CIs, ensuring that key data remains accessible and actionable. The tool allows users to retrieve batch traceability details, processing history, and certification status, offering transparency across the bio-based supply chain. Below is an example of a batch traceability report available to producers and processors, summarizing essential compliance and circularity metrics. This batch overview presents a streamlined and stakeholder-friendly version of the full traceability record stored within the T&T system.

BioReCer batch traceability report

📌 **Generated by: BioReCer** Track & Traceability System
📌 **Date:** 12 February 2025
📌 **Generated for:** Galicia marine bioprocessing plant (Fish collagen and oil processor)
📌 **Batch ID:** FISH-RAW-2025-004

1. Batch overview

- **Feedstock type:** Sardine and anchovy by-products (Heads, Bones, and Skin)
- **Source Location:** Galicia, Spain
- **Catch method:** Purse seine
- **Landing Site:** Vigo port, Spain
- **Initial Batch Weight:** 2,500 kg
- **Receiving facility:** Galicia marine bioprocessing plant
- **Processing start date:** 9 Jan 2025
- **Processing completion date:** 10 Jan 2025

2. Processing history and transformation records

📌 **Pre-processing inspection:**

✓ Passed quality check (Contaminant-free, Moisture content: 8%)

📌 **Batch splitting details:**

- 1,500 kg → Collagen extraction (Batch ID: FISH-COLLAGEN-2025-004A)

- 1,000 kg → Fish oil refining (Batch ID: FISH-OIL-2025-004B)

📌 **Processing facility logs:**
✓ **Hydrolysis for collagen extraction:** Enzyme-based, 55°C, 6-hour process
✓ **Oil separation process:** Low-temperature centrifugation, 2-Stage filtration
✓ **End products yield:**

- **Collagen peptides:** 750 kg (50% Yield)
- **Refined fish oil:** 800 kg (80% Yield)
- **Residual waste (Non-valorized):** 250 kg (10% Loss)

📌 **Waste handling record:**

- **Valorization rate:** 90% of total batch utilized
- **Disposal method for residual waste:** Sent for biogas production (Confirmed by WP2 Circularity data)

📌 **Batch authentication (HSI-based verification):**
✓ **Stored HSI spectrum:** Spectral fingerprint of collagen/oil batch captured during processing and stored in the EIP for future authentication. Future HSI scans can be compared with stored spectral data to verify batch integrity and detect potential adulteration or mislabelling.

3. Certification and compliance status

📌 **Certification compliance check for feedstock:**

- ☑ Marine stewardship council (MSC) – Certificate Valid until: 30 June 2025

📌 Certification compliance check for processing facility:

- ✖ ISCC PLUS certification – Certificate expired on 31 December 2024 (Corrective action: Renew certificate)

📌 Automated alert:
⚠ ISCC PLUS Certificate not valid – Processor must contact the certification body and undergo certification process before claiming the processed product as ISCC PLUS certified.

📌 **Traceability verification:**
✓ All processing stages logged and synchronized with T&T system
✓ Batch movements cross-checked with landing records and processing logs
X Missing data related to certificate validity

4. Circularity indicators

- By-Product Recovery Rate: 90% (Fish bones and skins successfully valorized into collagen and fish oil).
- Resource Efficiency Score: 85% (Minimal processing waste, energy-efficient extraction methods used).
- Carbon Footprint Per Kg of Product: 1.2 kg CO_2e (Reduction achieved through optimized processing).

5. Stakeholder actions & next steps

- **For processors:** Submit ISCC PLUS certificate to complete full compliance.
- **For certification bodies:** Documents and reports available for verification during the audits
- **For consumers:** Information on feedstock compliant with MSC certification. The feedstock batch is fully traceable and has a 90% valorization rate. However, the product is yet to be verified as sustainable while compliance with ISCC PLUS needs to be renewed.

📌 **Report access:** BioReCer ICT Tool → Compliance reports section
📌 **Next report update scheduled:** May 2025

5.2.3 Providing data reliability and audit-readiness

To maintain data integrity and reliability, WP3 structured the reporting system to ensure that all traceability records, compliance documentation, and sustainability assessments remain accurate, transparent, and secure. One of the key mechanisms supporting this objective is the audit log system, which maintains an immutable record of all modifications related to feedstock traceability and certification history. By preventing unauthorized alterations, this approach ensures that compliance records remain tamper-proof and verifiable, strengthening regulatory confidence in the biological feedstock label.

Additionally, WP3 implemented custom reporting filters (with aliasing WP5 and ICT tool) that enable stakeholder-specific insights tailored to the needs of regulators, producers, and certifiers. Through these filters, each stakeholder can generate reports specific to their verification requirements, whether it be compliance checks, certification tracking, or sustainability performance evaluations. This level of customization enhances efficiency in compliance monitoring, reducing administrative burdens and making the reporting system adaptable to various industry and regulatory needs.

By structuring reporting tools around traceability verification, compliance tracking, and sustainability assessment, WP3 supports the provision of reliable, structured, and regulatory-aligned data for bio-based supply chains. This approach enhances audit readiness, facilitates transparent reporting, and reinforces the role of the label in supporting sustainable and legally compliant bio-based supply chains.

5.3 Automation of label generation and updates

The automation of label generation and updates assist in enhancing the efficiency, accuracy, and consistency of traceability within the BioReCer framework. WP3 developed an automated labelling system to ensure that each batch of biological feedstock is assigned a standardized label, containing validated traceability, certification, and sustainability information. By reducing manual input errors and improving processing speed, this automation streamlines compliance monitoring, enhances audit readiness, and minimizes administrative workload for stakeholders.

While the biological feedstock label remains static once issued, WP3 structured the labelling system to integrate real-time certification updates and sustainability tracking through the EIP and the T&T system. This helps stakeholders to access updated compliance data without modifying the originally issued label, preserving traceability integrity while keeping records dynamic and auditable.

5.3.1 The Role of automation in label generation

To maintain a consistent and structured label creation process, WP3 implemented an automated system that generates labels only when predefined traceability and certification conditions are met. This system guarantees that a label is only generated when all required traceability, certification, and sustainability conditions are met, preventing incomplete or non-compliant feedstocks from entering certified supply chains. If conditions are not met, the batch is flagged for review, and stakeholders must address missing data, renew certifications, or provide sustainability documentation before revalidation and label issuance.

Key aspects of this automation include:

- Data-driven label assignment: Once a batch enters the BioReCer T&T system, the system automatically verifies traceability records, batch origin, processing history, and certification status before issuing a label.
- Sector-specific label customization: The system confirms that each label reflects the specific requirements of different feedstock types, such as fisheries, forestry, agriculture, and urban bio-waste.
- Stakeholder accessibility: Producers, processors, and policy makers can retrieve certification status, batch history, and CIs without modifying the static label, simplifying verification and compliance checks.

For example, a batch of fish by-products destined for collagen extraction automatically receives a label only after the T&T system confirms catch documentation, processing facility compliance, and sustainability certification validation. This automated process eliminates human errors, ensures standardized labelling across all supply chains, and enhances the efficiency of compliance monitoring.

Steps taken when conditions are not met

1. Automatic rejection and flagging for review

If the system detects missing traceability records, expired certification, or incomplete sustainability data, the batch is flagged for manual review before a label can be issued. For instance, if a batch of anchovy by-products is missing a catch location or date, the system prevents label generation and notifies the processor to provide the missing data.

2. Notification to stakeholders

The T&T system generates an automated alert to the processor, producer, or relevant certification body, detailing the reason why the batch failed compliance checks.
For instance, a batch of wood residues lacks a valid certification. The processor receives an alert indicating that documentation must be updated before processing can continue.

3. Corrective actions and resubmission

The stakeholder responsible for the batch (e.g., processor, certifier) must correct the issue—this could involve adding missing traceability records, renewing an expired certification, or providing sustainability documentation.

4. Revalidation and label issuance

Once the missing data is submitted and verified, the system automatically rechecks compliance. If all conditions are met, the label is generated and attached to the batch. If issues persist, the batch remains blocked from certification until compliance is achieved.
Figure 3 illustrates the compliance check and labelling process when conditions are not met.

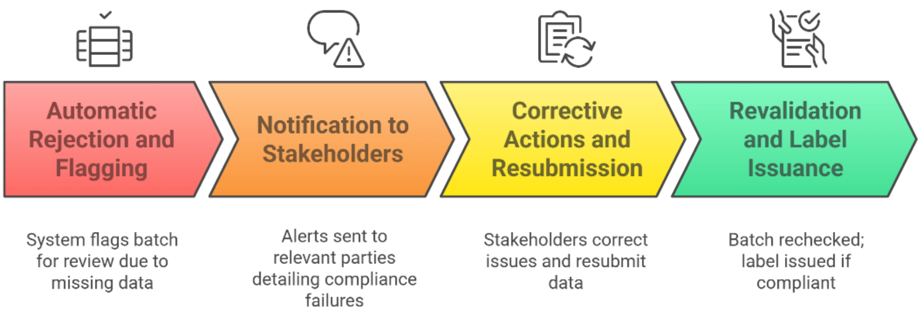

Figure 3: Compliance check and labelling process

5.3.2 Automating label updates without modifying static data

While the issued biological feedstock label remains unchanged, WP3 structured the system to allow real-time updates in certification status, sustainability metrics, and traceability logs via the EIP and T&T system. These updates provide dynamic compliance tracking without requiring modifications to the originally assigned label.

Key features of this approach include:

- Certification status tracking: If a batch's certification is renewed, revoked, or updated, the change is automatically recorded in the EIP, ensuring that stakeholders always access the latest compliance information.
- Sustainability and circularity indicator updates: WP2's CIs are linked to the batch's traceability system, ensuring that new sustainability and circularity findings are accessible without modifying the label. It means that the label remains unchanged, but stakeholders can access the latest sustainability evaluations by retrieving the updated data from the EIP and traceability system.
- Traceability log updates: Every batch movement, processing transformation, or supply chain event is automatically recorded in the T&T system, stakeholders can track the entire history of the feedstock, even after the label has been issued. These records provide real-time verification of processing activities, enhancing transparency and regulatory compliance.

As an example, a batch of wood residues used for biofuel production retains its issued label, while an update in FSC certification status is dynamically recorded in the EIP and T&T system, allowing certification bodies and buyers to verify the current compliance status. This approach preserves the integrity of issued labels while keeping certification and sustainability tracking fully dynamic, ensuring that stakeholders always access the most recent compliance data.

5.3.3 System integration for label automation

To support automated label generation and updates, WP3 structured the system to align with:

- BioReCer's T&T protocols – Ensuring labels are only issued when predefined compliance benchmarks are met.
- ICT Tool for data access – While WP3 manages the labelling process, the ICT tool serves as the stakeholder interface, allowing data retrieval and visualization without altering labelling records.

- Blockchain-backed logging for auditability – Every label generation and update process is logged in the T&T application and assure tamper-proof audit records for certification bodies and regulators.

This structured integration certifies that labelling automation remains secure, transparent, and fully compliant with BioReCer's sustainability objectives.

5.3.4 Compliance and quality control in automated labelling

WP3 integrated automated compliance verification into the labelling system to maintain data integrity and prevent fraudulent labelling. Before a label is generated, the system performs:

- Automated cross-checks: Meeting certification benchmarks for batch traceability, processing records, and sustainability data.
- Error detection and alerts: If missing information is detected (e.g., incomplete processing logs, certification inconsistencies), the system flags the batch for manual review before label issuance.

For example, if a batch of organic waste converted into biopolymers lacks a validated valorization rate, the system prevents label generation until the required sustainability data is submitted. By automating these quality control measures, WP3 ensures that only verified and fully compliant feedstock batches receive a label, reinforcing the credibility of traceability framework.

6 Digital product passport integration

The DPP serves as an advanced traceability mechanism designed to enhance transparency, regulatory compliance, and circular economy tracking within bio-based supply chains. In BioRecer, WP3 structured the biological feedstock label to interconnect with the DPP framework, therefore, all stakeholders can access structured, verifiable data on feedstock origins, transformations, and sustainability credentials.

Unlike the EIP, which tracks batch-level processing data, the DPP is applied at the final product level, providing market-facing sustainability and compliance data that remains accessible throughout the product's lifecycle.

The integration of the DPP with the T&T system enables:

- Enhanced traceability – The DPP links processed feedstock batches to structured traceability records, ensuring a complete digital footprint across sourcing, production, transformation, and distribution.
- Regulatory compliance alignment – It facilitates compliance with EU rules, and sector-specific frameworks (e.g., EU Fishery Product Labelling Regulation,).
- Stakeholder access and verification – Through the BioReCer ICT tool, role-specific access enables regulators, producers, and consumers to verify DPP-linked traceability data, reducing risks related to fraud, greenwashing, and mislabelling.

By integrating the biological feedstock label within the DPP, WP3 structured a framework that facilitates traceability and links bio-based products to relevant sustainability records. This approach enhances transparency, supports regulatory compliance, and strengthens market trust by providing verifiable data for informed decision-making across industries.

6.1 Embedding labels into the digital passport

The integration of the biological feedstock label into the DPP enhances traceability, certification compliance, and sustainability transparency across bio-based industries. As mentioned in previous sections, WP3 structured the label to be seamlessly embedded within the DPP framework, that indicates each feedstock batch carries a verifiable, immutable, and standardized sustainability record accessible throughout its lifecycle.

Unlike the EIP, which records batch-level transformations and processing history, the DPP consolidates final product-level sustainability credentials, certifying that certification, traceability, sustainability metrics, and CIs remain attached to the bio-based product beyond initial processing and into distribution and market stages.

6.1.1 Structural Integration of the label in DPP

To establish a structured and automated connection between the biological feedstock label and the DPP, WP3 implemented the following mechanisms:

- Static data embedding: The label's fixed attributes (e.g., feedstock type, origin, certification status, and processing standards) are encoded within the DPP, allowing regulatory bodies and market actors to verify compliance.
- Interoperability with the T&T system: The DPP maintains a dynamic link to the T&T system, enabling stakeholders to access batch-level processing records while keeping the originally issued label intact.
- Automated data synchronization: Although the label itself remains static, updates related to certification renewals, circularity assessments, and sustainability scores are reflected in the DPP. This feature supports real-time compliance tracking without altering the label's core information.

6.1.2 Data interoperability between label, EIP, and DPP

The biological feedstock label, EIP, and DPP operate in a tiered system, where each serves a specific function:

- Biological feedstock label: The primary static identifier, carrying essential traceability, sustainability, and certification data for the batch.
- Electronic identification passport: A batch-level, traceability-focused record, logging processing transformations, handling conditions, and sustainability assessments throughout the batch's lifecycle.
- Digital product passport: A final product-level document, consolidating verified sustainability and traceability credentials to remain accessible in the supply chain, consumer markets, and regulatory checks.

To maintain this structured approach, WP3 designed the T&T system to allow direct interaction between the EIP and DPP, without modifying the label itself. This ensures that any updates in certification status, environmental impact assessments, or regulatory compliance are reflected in the DPP while preserving the original label attributes.

In Table 2, the comparison between the EIP, DPP, and the biological feedstock label highlights their distinct roles in traceability, compliance, and certification within bio-based supply chains, demonstrating how each component supports different aspects of sustainability, regulatory alignment, and market transparency.

Table 2: Comparison of EIP, DPP, and biological feedstock label

Feature	EIP	DPP	Biological feedstock label
Scope	Batch-level (Raw materials and intermediate feedstocks)	Final product-level (Market-ready)	Certification and traceability identifier
Use Case	Internal traceability of batches during production and processing	External product-level compliance and transparency for consumers and regulators	Static label confirming compliance and traceability
Data Type	Batch ID, sourcing, processing, splitting/merging, HSI spectrum, certification status, sustainability data	Product ID, sustainability metrics, recyclability, regulatory compliance, consumer-facing data	Unique identifier showing compliance with certification schemes
Update Type	Dynamic – Updates throughout the batch lifecycle (e.g., processing changes, new certifications)	Mostly Static – Final product passport remains unchanged after issuance, except for regulatory updates	Static – Issued once, does not change
Who Uses It?	Internal stakeholders (processors, auditors, quality control teams)	External stakeholders (policy makers, auditors, businesses, consumers, retailers)	Auditors, policy makers, producers, consumers
Storage	T&T System & Blockchain – Secure storage with real-time updates	Regulatory & Industry Platforms – DPP databases linked to compliance repositories	Physical Label & Certification Database – Applied to product packaging and stored in digital repositories
Interaction with Other Components	Feeds traceability data into the DPP, ensuring all transformations and compliance updates are recorded	Uses EIP data to verify final product compliance, displaying relevant sustainability scores and certification statuses	Final label is generated based on EIP and DPP data, confirming regulatory alignment and consumer trust
Example in Fisheries	Logs batch details for fish collagen & oil production (e.g., catch ID, processing steps, HSI fingerprint, certification updates)	Shows end-product details for a collagen supplement, including sustainability scores, recyclability, and regulatory compliance	Label on collagen peptide product, confirming it is MSC-certified & EU Organic, with a QR code linking to the DPP

6.1.3 Stakeholder use cases and benefits

The integration of the biological feedstock label within the DPP ecosystem creates a structured and accessible framework for diverse stakeholders, enhancing traceability, regulatory compliance, and sustainability transparency. By linking batch-level records to final product documentation, the system strengthens supply chain accountability and market confidence.

For regulators and certification bodies, the DPP provides real-time access to compliance records for key regulations, such as the EU Fishery Product Labelling Regulation and certification standards. Through the ICT tool, authorities can retrieve batch records, review sustainability indicators, and track certification statuses without relying on extensive manual audits. This approach reduces administrative workload while reinforcing oversight mechanisms.

Producers and processors benefit from the ability to connect feedstock batches with final product documentation, maintaining sustainability metrics, traceability logs, and regulatory compliance throughout the product lifecycle. By integrating with the DPP, businesses can demonstrate alignment with sustainability goals, respond efficiently to audits, and retain records that reflect sourcing and processing practices from raw materials to market-ready products.

For consumers and market players, the DPP acts as a transparent and verifiable source of sustainability information. Buyers can retrieve detailed product data, including origin, processing history, and certification status, helping them make informed purchasing decisions. This transparency reduces the risk of greenwashing and mislabelling, strengthening trust in bio-based products and encouraging the adoption of sustainable feedstocks across various industries.

Through this structured integration, WP3 enhanced regulatory trust, supply chain visibility, and consumer awareness, reinforcing the principles of the circular economy and responsible production.

6.2 Facilitating interoperability across platforms

The biological feedstock label within the WP3 T&T system must interact seamlessly with multiple platforms, ensuring that traceability, certification, and sustainability data remain structured, transferable, and verifiable across regulatory, industrial, and consumer-facing systems. Given the growing adoption of DPPs and cross-sector sustainability certifications, achieving robust interoperability is essential for ensuring that biological feedstocks can be digitally tracked throughout their lifecycle without data fragmentation or loss of compliance information.

Unlike previous static traceability methods, WP3 integrated real-time, multi-platform interoperability, allowing stakeholders to:

1. Retrieve and verify compliance records dynamically (e.g., certification renewals, sustainability metrics).

2. Verify that biological feedstock labels remain immutable yet linked to evolving environmental impact data.
3. Connect with external regulatory, certification, and market systems without manual intervention.

This section explores how the BioReCer T&T system facilitated interoperability between biological feedstock labels, EIPs, and DPPs, assist that traceability and certification updates remain consistent across platforms.

6.2.1 Interoperability between the biological feedstock label, EIP, and DPP

The WP3 framework structured interoperability across three key components:

1. Biological feedstock label (Static identifier):
   - A fixed, verifiable identity assigned at the batch level.
   - Contains core traceability, sustainability, and regulatory compliance data.
   - Must remain immutable while integrating with evolving compliance records.
2. EIP:
   - A dynamic, blockchain-backed digital record that tracks batch transformations, certifications, and sustainability assessments throughout the supply chain.
   - Confirms that regulatory updates, re-batching, and processing changes are accurately logged and verifiable.
3. DPP:
   - Consolidates final product-level sustainability credentials.
   - Provides market actors, regulators, and consumers with structured, verifiable sustainability and compliance information.
   - Must be linked dynamically to EIP updates while preserving the static biological feedstock label as a reference.

These three layers interact seamlessly through the ICT tool, which certify that traceability, certification, and sustainability records remain aligned across supply chain stages.

6.2.2 Standardized data formats for seamless exchange

One of the primary challenges to achieving interoperability in bio-based industries is the lack of uniform data structures, which can create inconsistencies in traceability, sustainability, and certification processes. To address this, the WP3 , with the support of WP2 and WP4 partners, framework integrated globally recognized standards, ensuring that data can be exchanged efficiently across platforms. GS1-compliant batch tracking has been adopted to standardize supply chain traceability, providing a consistent approach for tracking materials from origin to end-use. In the food sector, particularly in fisheries and agriculture, ISO 22005 is implemented to align traceability practices with regulatory requirements, ensuring transparency and compliance across supply chains. Additionally, the framework is structured to fit within the EU Digital Product Passport system, allowing sustainability claims to be systematically recorded and accessed for greater product transparency. To support sustainability verification, the WP3 framework incorporated internationally recognized certification schemes enabling seamless compliance with sustainability benchmarks. Furthermore, CIs, developed under WP2, are embedded into the traceability system to provide real-time environmental performance data, ensuring that sustainability metrics are accurately measured and reported. By aligning with these globally recognized frameworks, BioReCer enhances the interoperability of biological feedstock labels, facilitating seamless integration with regulatory databases, certification systems, and market traceability platforms, ultimately contributing to a more transparent and efficient bio-based economy.

6.2.3 Blockchain-backed interoperability for secure certification tracking

The BioReCer T&T framework integrates blockchain technology to enhance cross-platform interoperability, ensuring secure, transparent, and verifiable certification tracking. As detailed in D3.1 (Theoretical Framework for T&T) and D3.2 (Cloud-Based T&T System), blockchain strengthens traceability by providing:

- Immutable traceability records, preventing unauthorized modifications or retroactive alterations.
- Cross-system data validation, allowing certification bodies to verify compliance independently.
- Automated certification tracking, where smart contracts facilitate compliance updates in the EIP and DPP without requiring manual intervention.

Unlike traditional centralized traceability models, which rely solely on static databases managed by a single entity, WP3's blockchain-backed system enhances data security, transparency, and accessibility. Although WP3 employed a centralized blockchain, it significantly improves upon conventional centralized repositories by ensuring that:

- Once data is recorded, it remains immutable, preventing tampering or unauthorized edits.
- Multiple stakeholders (certifiers, regulators, producers) can independently verify compliance records, reducing reliance on a single authority.

- Automated compliance updates through smart contracts streamline certification validation, eliminating manual processing delays.

By integrating blockchain as the backbone for certification tracking, the T&T framework enabled secure, automated, and verifiable data exchange across supply chain actors, regulatory agencies, and sustainability frameworks and facilitated that biological feedstock labels, EIPs, and DPPs remained trusted and interoperable across digital platforms.

6.2.4 API-driven integration with external platforms

To minimize operational disruptions and enable real-time data synchronization, the T&T framework is built on an API-driven architecture, ensuring:

1. Automated data exchange → Enabling seamless interactions between producers, processors, certification bodies, and regulators.
2. Interoperability with ERP & sustainability platforms → Allowing companies to maintain compliance without modifying internal systems.
3. Real-time compliance monitoring → Confirming certification and CIs remain accurate across platforms.

By implementing API-based data sharing, the ICT tool ensured that biological feedstock labels remained linked to evolving compliance records without requiring redundant data entry or manual verification.

In summary, WP3 framework has created a comprehensive digital infrastructure that enables seamless traceability, certification tracking, and sustainability reporting across diverse platforms. Through standardized data formats, blockchain-backed validation, and API-driven interoperability, the biological feedstock data remains secure, verifiable, and accessible. This integrated approach aligns fully with regulatory requirements, industry standards, and consumer-facing traceability ecosystems, fostering trust, compliance, and transparency throughout the bio-based supply chain.

6.3 Future prospects for enhanced traceability

As bio-based industries evolve to meet growing sustainability and regulatory demands, enhancing traceability systems will become increasingly critical for ensuring compliance, transparency, and stakeholder trust. The BioReCer T&T framework, built on interoperable digital infrastructure, standardized certification tracking, and blockchain-backed data security, provides a solid foundation for future advancements in traceability across biological feedstocks. Moving forward, several key innovations and refinements will shape the next phase of traceability within BIORECER, ensuring greater efficiency, automation, and integration across supply chains.

Expanding the role of DPPs in bio-based supply chains

WP3 has already structured its framework to align with the EU DPP initiative, ensuring that traceability, sustainability, and certification data from batch-level tracking (EIP) seamlessly transition into product-level transparency (DPPs). While this integration is already in place, further enhancements will focus on removing remaining manual validation steps and increasing automation to streamline the process.

Currently, when a batch of certified bio-based material undergoes processing, its traceability data is recorded in the EIP, covering aspects such as batch origin, processing details, and certification status. After successful transfer to the DPP, the final validation step—where certifiers or manufacturers review and confirm sustainability indicators before making them publicly available— will still require manual verification.

Future enhancements will further automate this process by:

1. Implementing AI-driven validation - to confirm that sustainability metrics (e.g., carbon footprint, CIs) are automatically verified and correctly linked to the final product without human intervention.
2. Using smart contracts - to trigger instant certification updates, so that if a certificate is renewed or updated in the EIP, it will automatically reflect in the DPP in real time, eliminating the need for manual confirmation.
3. Expanding machine-readable DPPs - ensuring that regulators, certifiers, and consumers can instantly verify sustainability claims through fully digitalized and integrated platforms without requiring additional verification steps.

By fully automating these linkages, they will enable BioReCer to assure that DPPs remain a reliable and seamless tool for all stakeholders in bio-based supply chains by fully automating these linkages.

Artificial intelligence and machine learning for predictive traceability analytics

Future advancements in traceability will leverage artificial intelligence (AI) and machine learning (ML) to enhance data accuracy, fraud detection, and supply chain optimization. These technologies will enable:

- Predictive analytics for sustainability compliance, identifying potential risks (e.g., non-compliant batches, certification lapses) before they occur.
- Automated anomaly detection, flagging inconsistencies in batch records, processing data, and certification updates.

- Optimized resource allocation, using data-driven insights to enhance supply chain efficiency and reduce waste in bio-based industries.

By integrating AI-driven analytics into the WP3 T&T system, stakeholders will gain real-time insights into traceability patterns, and they can assure that compliance and sustainability tracking remain proactive rather than reactive.

WP3 team members, with extensive expertise in supply chain optimization, can play a crucial role in supporting BioReCer stakeholders by developing advanced AI models to:

1. Minimize energy consumption and operational costs in bio-based supply chains.
2. Optimize logistics and material flows to reduce carbon footprint while maintaining efficiency.
3. Enhance profitability by using AI-driven simulations to identify cost-effective and sustainable sourcing, production, and distribution strategies.

As AI capabilities within the BioReCer framework continue to evolve, WP3 can offer custom AI-driven solutions to stakeholders, ensuring that sustainability goals align with economic efficiency and business profitability.

Strengthening cross-sector traceability through enhanced interoperability

Cross-sector interoperability will be essential as traceability requirements extend beyond bio-based supply chains. Future enhancements will focus on:

- Seamless data integration with emerging regulatory frameworks such as EU Green Deal policies, and global carbon footprint reporting standards.
- Interoperability with financial sustainability assessments, enabling traceability data to support ESG (Environmental, Social, and Governance) compliance reporting for investors and market regulators.
- Expanding certification interoperability, ensuring that biological feedstock labels remain recognized across international sustainability frameworks and EU Taxonomy classifications.

WP3's traceability framework will remain scalable, adaptable, and relevant across multiple industries by aligning it with broader digital sustainability ecosystems.

Looking ahead, BioReCer’s T&T framework is well-positioned to scale, adapt, and integrate emerging digital innovations in traceability and sustainability tracking. Through advancements in AI analytics, blockchain scalability, IoT-driven monitoring, and cross-sector interoperability, the next generation of BioReCer traceability solutions will offer greater efficiency, transparency, and regulatory alignment.

7 Conclusion

In D3.3, we developed the BioReCer biological feedstock label, establishing a structured framework for traceability, certification compliance, and sustainability assessment in bio-based supply chains. This deliverable defined the label's key attributes, integration with the WP3 T&T system, and its role in regulatory alignment and stakeholder engagement.

WP3 designed the biological feedstock label to provide a static yet verifiable identifier for biological feedstocks while incorporating dynamic traceability components such as the EIP and DPP. These elements facilitated real-time sustainability tracking and certification validation, ensuring that each batch of biological material was linked to its environmental performance and regulatory compliance data.

A core achievement of this deliverable was harmonizing traceability mechanisms with existing certification standards to enable seamless integration with regulatory databases, digital compliance tools, and sustainability frameworks. By implementing standardized data structures and blockchain-backed verification, WP3 improved the reliability, security, and transparency of certification records, supporting regulatory audits and market confidence.

WP3 also developed an API-driven architecture that facilitated real-time data exchange between producers, certification bodies, and regulatory authorities. This approach minimized manual verification efforts while enabling automated compliance reporting, strengthening stakeholder engagement and supply chain efficiency.

Furthermore, through four case studies across different bio-based industries (fisheries, forestry, agriculture, and urban bio-waste management), WP3 validated the label's effectiveness in promoting circularity, sustainability metrics, and stakeholder adoption. These studies demonstrated how the label contributed to waste valorization, secondary material utilization, and carbon footprint reduction.

By completing this deliverable, we established a robust, scalable, and regulatory-aligned framework for biological feedstock traceability. Moving forward, the BioReCer biological feedstock label is positioned to enhance transparency, improve compliance monitoring, and support the transition towards a more sustainable bio-based economy.

8 List of Abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
BioReCer	Biological Resources Certification Schemes
CIs	Circularity Indicators
CO2e	Carbon Dioxide Equivalent
DPP	Digital Product Passport
EIP	Electronic Identification Passport
ERP	Enterprise Resource Planning
EU	European Union
FSC	Forest Stewardship Council
GHG	Greenhouse Gas
GROT	Grenar och Toppar
ICT	Information and Communication Technology
ISCC	International Sustainability and Carbon Certification
ISO	International Organization for Standardization
ML	Machine Learning
MSC	Marine Stewardship Council
OFMSW	Organic Fraction of Municipal Solid Waste
PEFC	Programme for the Endorsement of Forest Certification
T&T	Track and Traceability

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