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DigInTraCE

Methodology of Traceability

D2.1

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A Digital value chain Integration Traceability framework for process industries for Circularity and low Emissions by waste reduction and use of secondary raw materials

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Executive Summary

This deliverable, developed as part of Task 2.1 (Methodologies for digital tracing across value chains), represents the first version (v1) of the "Methodology of Traceability". Its primary objective is to propose a stepwise approach for the conceptual design of blockchain traceability systems for the DigInTraCE demo cases.

In the current version (v1), in chapter 2, key concepts were discussed such as supply chains, value chains, granularity and traceability. A review on Traceability Systems (TSs) was carried out to determine in what extent traditional TSs can assist us in the DigInTraCE demo cases. It was concluded that traditional TSs are prone to tampering due to their centralized nature. For that reason, the research focused on blockchain TSs.

Blockchain-based solutions can overturn the disadvantages of traditional TSs and add additional benefits to the traceability systems. Blockchain technology though, brings also challenges to the table that need to be addressed such as high cost of implementation, scarcity of successful implementation examples to draw upon and ensuring the integrity of input data. A comprehensive and detailed review is presented in chapter 3 where, the enablers and the challenges for BCTSs implementation are presented, the technological aspects are discussed an a preliminary try to connect BCTSs with circular economy is attempted.

In chapter 4, a 12-step approach for the conceptual design of BCTSs for the DigInTraCE demo cases is presented. These steps are identification of the scope, objectives, identification of traceability parameters, mapping of the process, material and information flows across the value chains, evaluation of current traceability status and granularity level, establishment of data collection mechanisms, implementation of data management system, definition of standards and protocols, enabling information sharing, implementation of tracking technologies, establishment of verification and auditing processes and continuous improvement and evaluation. In the current version, the first five steps are introduced and discussed.

The objective of the stepwise approach is to develop a comprehensive conceptual framework for a Blockchain-based traceability system (BCTS) that ensures the accurate tracking of the entire lifecycle of a product, from its initial stages to its final form. In order to accomplish this objective, our approach will involve two key components: firstly, the identification and assessment of the flow, quality, and quantity of information; and secondly, the precise mapping of the value chain. These factors will contribute to assess the current level of granularity and improve it. The high-resolution granularity will facilitate a more comprehensive management of the value chain, leading to its enhancement. This will be achieved by gaining insights into the cause-and-effect relationships within the chain, thereby enabling improvements in its environmental impact, circularity, and overall sustainability.

The proposed framework will aim to address challenges that were identified in chapter 3 and for that reason it focuses on enhancing transparency, ensuring product quality and safety, reducing fraud and evaluating the current sustainability and proposing alternatives to improve it.

The identification of traceability parameters (TPs) will facilitate the construction and implementation of a precise traceability system (TS) for the DigInTraCE demonstration cases. In the process of identifying TPs, it is important

to consider not only conventional parameters, which form the basis of a typical traceability methodology, but also parameters that are designed to promote circularity, LCA assessment, sustainability, and recycling. The parameters deemed significant at this initial stage encompass the raw material's information, transportation mode, frequency and distance, storage conditions, waste and water management, energy resources, monitoring, reporting, labelling, packaging, identifiers (such as RFIDs and barcodes), and record types (including electronic and manual formats).

In order to acquire the necessary TPs for the successful implementation of a precise Traceability System in the demonstration cases, it is imperative to develop a comprehensive mapping of the value chains, as well as the information flow and availability. The integration of these two components will enable the identification of specific instances where information loss transpires, thereby facilitating the development of a more comprehensive BCTS. The implementation of precise process and information flow mapping, coupled with an assessment of the existing traceability and granularity level, will enable us to propose system enhancements. These proposals aim to increase the level of detail in the system, resulting in the development of a more comprehensive and intricate traceability system. This, in turn, is expected to contribute to the improvement of the environmental impact and promote greater circularity and sustainability.

During our investigation, we will utilize indicators such as external trace unit, information update frequency and others, to assess the level of granularity exhibited by the demonstration cases in DigInTraCE. This will enable us to gain a more comprehensive comprehension of the necessary installations and/or measures required to improve the traceability system and attain the intended results.

To acquire the required information for mapping the value chain and the information flow and assessing the level of available information for the DigInTraCE demo cases, we created a questionnaire that attempts to cover these aspects.

As a subsequent course of action, the questionnaire will be dispatched to the pertinent partners of DigInTraCE, specifically those who are actively engaged in the demo cases. Individualized support sessions will be conducted with each participant to provide further clarification on the questionnaire's questions and objectives, as well as assist them in addressing any challenges they may encounter while completing it.

The responses to this questionnaire will facilitate the evaluation of the level of granularity in the demo cases. Consequently, it will enable the development of the initial comprehensive mapping of our traceability systems, encompassing both the procedural and informational aspects. Additionally, we will be able to offer our initial recommendations concerning the installation of sensors, considering our findings related to the identification of points where information loss occurs.

This deliverable will be updated regularly throughout the duration of the project, to depict changes and updates based on the newly acquired information. The subsequent versions of this deliverable will be accessible at the conclusion of the 24th month (v2) and the 48th month (final version).

1. Introduction

1.1. Project intro

The objective of DigInTraCE is to create a transparent and interoperable platform for Decentralised Traceability. This platform will utilise innovative tracking, sensing, and sorting techniques, as well as dynamically updated Digital Product Passport (DPP) schemes to support certification and quality validation. Additionally, it will incorporate AI-based decision-making mechanisms to optimise processes and lifecycles.

The project will also focus on developing technologies for up-cycling, reuse, and upgrading to enhance the use of secondary raw materials. Furthermore, DigInTraCE aims to contribute to standardisation efforts and promote open and easily accessible data. It will also explore business models that create new economic opportunities and provide learning resources for employees, fostering the development of new digital skills and addressing regional social needs.

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The solutions will be developed at Technology Readiness Level 6 (TRL6) by the conclusion of the project and will be showcased in two sectors: a) Pulp & Paper, with a specific focus on composite wood and furniture, as well as wood and Pulp & Paper; and b) Chemicals, with a specific focus on plastic parts for ICT equipment and the automotive market, as well as polymers and textiles [1].

1.2. Purpose of the deliverable

The objective of Deliverable 2.1 (D2.1) is to formulate a comprehensive approach for acquiring data from operational activities and products, as well as the process of discretizing products, services, and business operations. This approach will enable the synchronization of data gathering with the fundamental characteristics of Blockchain technology. The primary characteristics of the product, including its status, sources, composition, manufacturing process (such as quality, carbon footprint, circularity, availability/inventory), and the means by which data regarding these aspects may be obtained, will be identified. Both units of raw material and completed emergent goods (assemblies of raw material) are covered by this definition. The former provides key information for the latter.

A cost and benefit analysis will be undertaken to determine the extent of tracking and tracing, whereby a greater degree of tracking and tracing will necessitate increased investment in hardware and software solutions.

The proposed research aims to create several methodologies for data collecting, including automatic, human prompted, and simulated approaches. Additionally, novel techniques will be explored to effectively integrate the received information for the purpose of process and product modelling, specifically in the context of digital twin development.

The implementation of business operations involves the introduction of a digital representation of a product unit to the Blockchain, utilizing customized learning algorithms tailored to the specific nature of the product and its associated activities. The primary results will encompass the identification and measurement of data, the assessment of its value, and, where appropriate, the use of anonymization techniques guided by Blockchain protocols to provide a precise definition of the Unit of Product [1].

In v1 of D2.1, a first step towards accomplishing the aforementioned purposes of D2.1 has been achieved. The disadvantages of traditional traceability systems (TSs) have been identified but these disadvantages can be overturned by the implementation of blockchain technology. A study on blockchain technology traceability systems (BCTSs) has been carried out, which highlights their advantages compared to traditional TSs. These BCTSs though, come also with challenges that need to be addressed. A stepwise approach (of twelve steps) for the conceptual design of BCTSs for circular value chains is being presented. In the current version, the first five steps have been initiated and discussed. The next steps will be completed in v2 (month 24) and v3 (or FINAL, month 48).

1.3. Intended audience

The intended audience for the first version of the "Methodologies for digital tracing across value chains" include:

Consortium partners: The members of the DigInTraCE project consortium who have a vested interest in understanding the advantages of implementing tracking and tracing frameworks to production lines.

Industry experts, stakeholders and end-users: Individuals or organisations that are affiliated with the wood and plastic industry, as well as other industries such as textiles. They encompass manufacturers, suppliers, distributors, and consumers who have a direct or indirect involvement in the value chain. These entities stand to gain advantages from the innovative solutions created by DigInTraCE.

Research and academic community: Researchers, scientists, and scholars specialising in sustainability, circular economy, innovation management, and related subjects. These individuals are interested in gaining insights into the practical implications and possible effect of the DigInTraCE project.

1.4. Structure of the deliverable and its relation with other work packages/deliverables

The first version of the "Methodologies for digital tracing across value chains" is structured as follows:

- **Definition of key concepts**

  In this section, the key concepts and terms, such as Traceable Resource Units, Critical Traceable Points, etc. will be explained, as they will be used extensively in D2.1.

- **Review on State-of-the-Art (SoA) TSs using blockchains**

  This section will consolidate the major findings from other TSs regarding the technological aspects (especially the blockchain-based systems), the associated challenges, and whether there are existing frameworks even for other supply chains.

- **A stepwise approach for the conceptual design of TSs for circular value chains**

  This section focuses on the structured way to (a) design conceptually a TS, and (b) identify traceability parameters (including but not limited to circularity/sustainability, etc

- **Concluding remarks and next steps ahead**

  In this section, conclusions will be presented, and the suggested next steps will be delineated.

D2.1 will be directly linked with:

- **D2.4**

  D2.4 aims to harmonise the requirements produced in T2.3 with the traceability framework and the schemes developed in T2.1, T2.2 to produce the technical specifications and the architecture for the Decentralized Traceability platform of DigInTraCE and the modules to be developed in WP3.

- **D4.1**

  Linked to T2.1, T2.3 two live traceability methods will be used to feed DPP: i) technologies from T3.1, T3.3 along with existing plant (e.g., SCADA), Logistics and Operator instigated input (HMI) systems, to collect the necessary information about the unit of product. ii) in cases that these techniques are not possible, the deployment of bespoke event-based process simulation to generate Simulation-based Traceability will be proposed.

- **D6.4**

  T6.4 will use the generated data of WPs 2,3,4 to demonstrate their importance, sufficiency, and adequateness to both assess and optimise circularity of value chains.

- **WP7**

  Furthermore, D2.1 is relevant to WP7 "Guidance, Training, Cooperation, Exploitation and communication" in terms of identifying and studying the best practices and developing replication guidelines and methodology with technical and practical information to replicate a successful case.

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2. Definition of key concepts

2.1. Supply Chain (SC)

A supply chain is a chain structure (Figure 1) consisting of several interconnected nodes, including suppliers, manufacturers, and consumers. Due to the phenomenon of globalisation, the various parts of a supply chain are often dispersed across different geographical locations, resulting in a complex and convoluted network structure [2]. Due to the inherent complexity of the structure, several stages are susceptible to multiple possible risks of failure [3]. Within a supply chain, several partners engage in distinct value-added activities with the objective of generating value for customers [3][4].

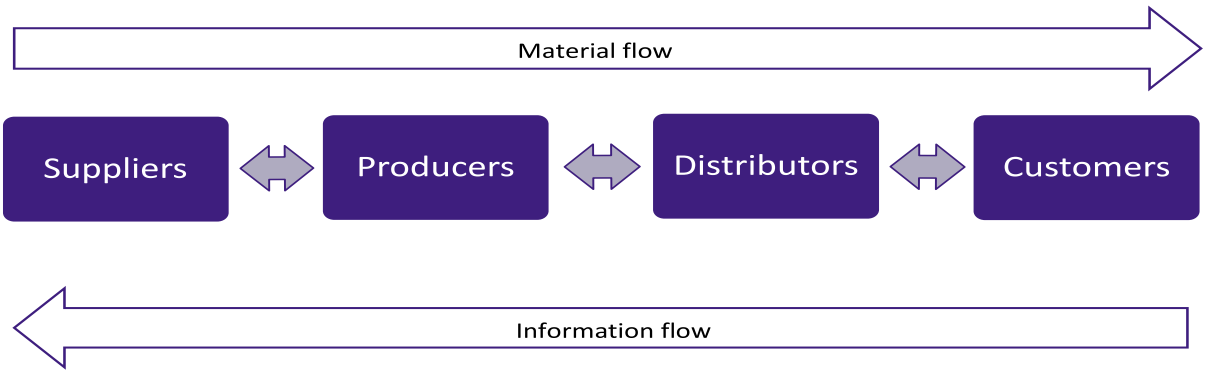

Figure 1. Supply chain [2] .

2.2. Value chain

The term "value chain" (Figure 2) was introduced by Michael Porter in 1985 [5] to describe the interconnected actions undertaken by an organisation that influence its competitive advantage [6]. The value chain is comprised of five major activities and four support activities. Primary activities are those that are directly involved in the production or provision of a certain product or service. These activities are inbound logistics, operations, outbound logistics, marketing and sales and service. The execution of these core activities is made possible by the presence of ancillary activities, commonly referred to as support activities. The support activities are firm infrastructure, human resource management, technology development and procurement [6].

Value chain and supply chain facilitate the provision of high-quality items to customers at an affordable price [7].

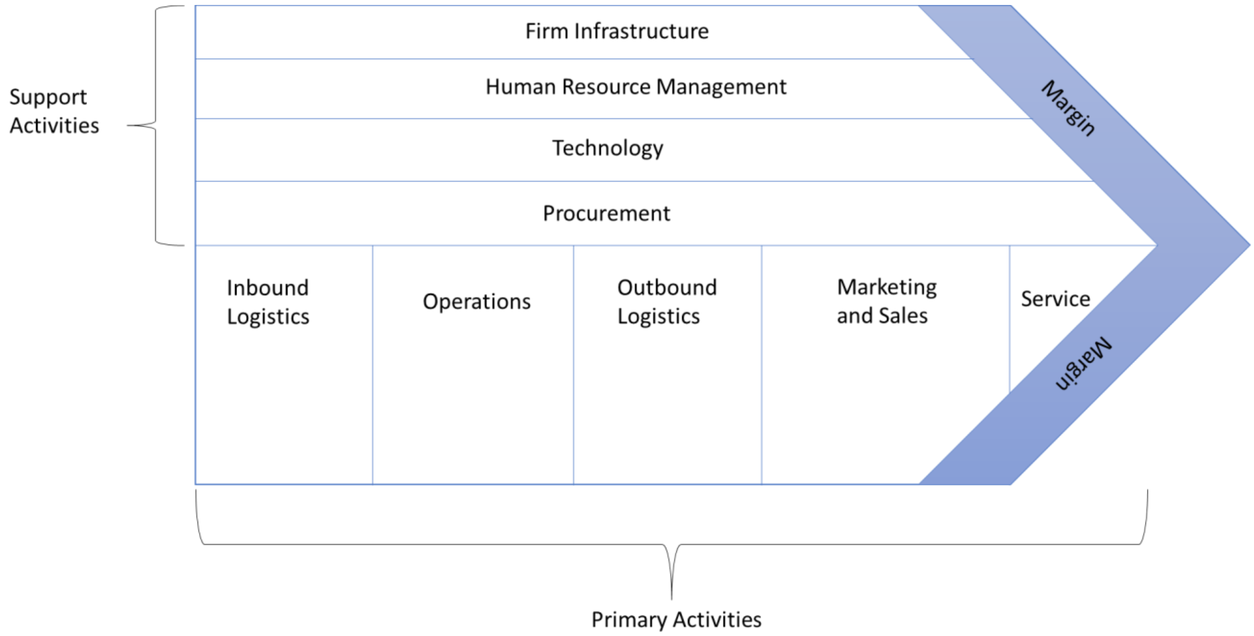

Figure 2. Value chain introduced by Porter [5].

2.3. Supply chain and value chain from a traceability perspective

Although value chain and supply chain are not the same, in terms of traceability they are interconnected. When traceability systems are implemented, they are implemented in the supply chain. Accurate traceability of the supply chain can benefit the value chain by highlighting the areas that need improvement and thus boost the competitiveness of the company, improve its environmental footprint and enhance its transparency.

2.4. Granularity

Granularity pertains to the size of the units under evaluation, encompassing both large and small dimensions [8]. In supply chains, production processes etc., there can be many levels of granularity. For instance, low level of granularity is considered a quality assessment of the entire factory output where a high level of granularity is considered a quality assessment of each individual product that is produced by the factory. According to Santana et al. [9], only a few studies considered various levels of granularity or the distinct characteristics of the entities that need to be monitored across the supply chain or manufacturing process. This implies that granularity might be complex and might have not been studied in a great extent.

2.5. Traceability

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Traceability is defined as the "ability to trace the history, application or location of an *object*" in BS EN ISO 9000:2015 [10]. Considering the aforementioned definition, traceability in DigInTraCE should contain information about the raw materials, their processing, transportation, storage, origin of the finished product and other things that will be identified in time through the demo cases.

Traceability may be understood from two distinct perspectives: chain traceability and internal traceability [11]. Chain traceability refers to the capacity to track and trace the whole history of a product, encompassing the acquisition of raw materials and parts, the machining process, distribution, and sales. This traceability may be conducted in both forward and backward directions. Manufacturers have the capability to engage in forward tracing, enabling them to monitor the destinations to which their products have been transported. Conversely, enterprises and consumers situated downstream could engage in backward tracing, allowing them to ascertain the origins from which the items in their possession have originated. This feature offers manufacturers the advantage of simplified cause investigation and product recall in the event of unforeseen issues with their goods. Consumers may utilise this benchmark to choose items with high reliability, hence alleviating concerns related to issues such as mislabelling [11].

Internal traceability refers to the systematic monitoring and tracking of the movement of components or products within a confined and well-defined region of a larger supply chain. This area can encompass a single firm or facility, therefore facilitating the effective management and control of the internal flow of goods [11].

Some key concepts of traceability (that will also be used later in D2.1) are:

- <u>Traceable Resource Units (TRUs)</u>

A Traceable Resource Unit (TRU) refers to a grouping of one or more Objects (goods) that lack the ability to be independently tracked beyond their current state [12]. TRUs should not be confused with Trade Units (TUs) and Logistic Units (LUs). Trade Unit represents an amount of material (e.g., a pen) that is sold by one trading partner to another trading partner [13]. Logistic Units are trade units that are organized into groups for the purpose of storage or transportation, such as being placed on a pallet [14]. According to Olsen [13], any traceable item can be a TRU, however they are usually trade, logistic, or production units (i.e., lots or batches).

- <u>Critical Transformation Point (CTP)</u>

A Critical Transformation Point (CTP) is a point where the potential for information loss arises as a result of potential identification loss and deficiencies in accurately recording transformations [15].

2.6. Traceability Systems (TS)

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Based on Olsen et al. [16], a broad definition of the components that create a traceability system (TS) comprise a mechanism that identifies TRUs, records their attributes and documents transformations throughout the supply chain. To ascertain the TRUs, it is imperative to determine the code type and structure. Decisions must be taken about granularity and code uniqueness, and an approach must be devised to establish an association between the identifier and the TRU [16]. Types of simple transformations that can be documented (as presented in [16]) are: *one input TRU to one output TRU*, where only one TRU is used to obtain a new TRU, *many TRUs to one TRU*, where many TRUs are used to obtain a single TRU (can me considered as merging) and *one TRU to many TRUs*, where one TRU is used to obtain many new TRUs (can be considered as splitting). There is also the transformation of *many TRUs to many TRUs*. The transformations can be seen in Figure 3.

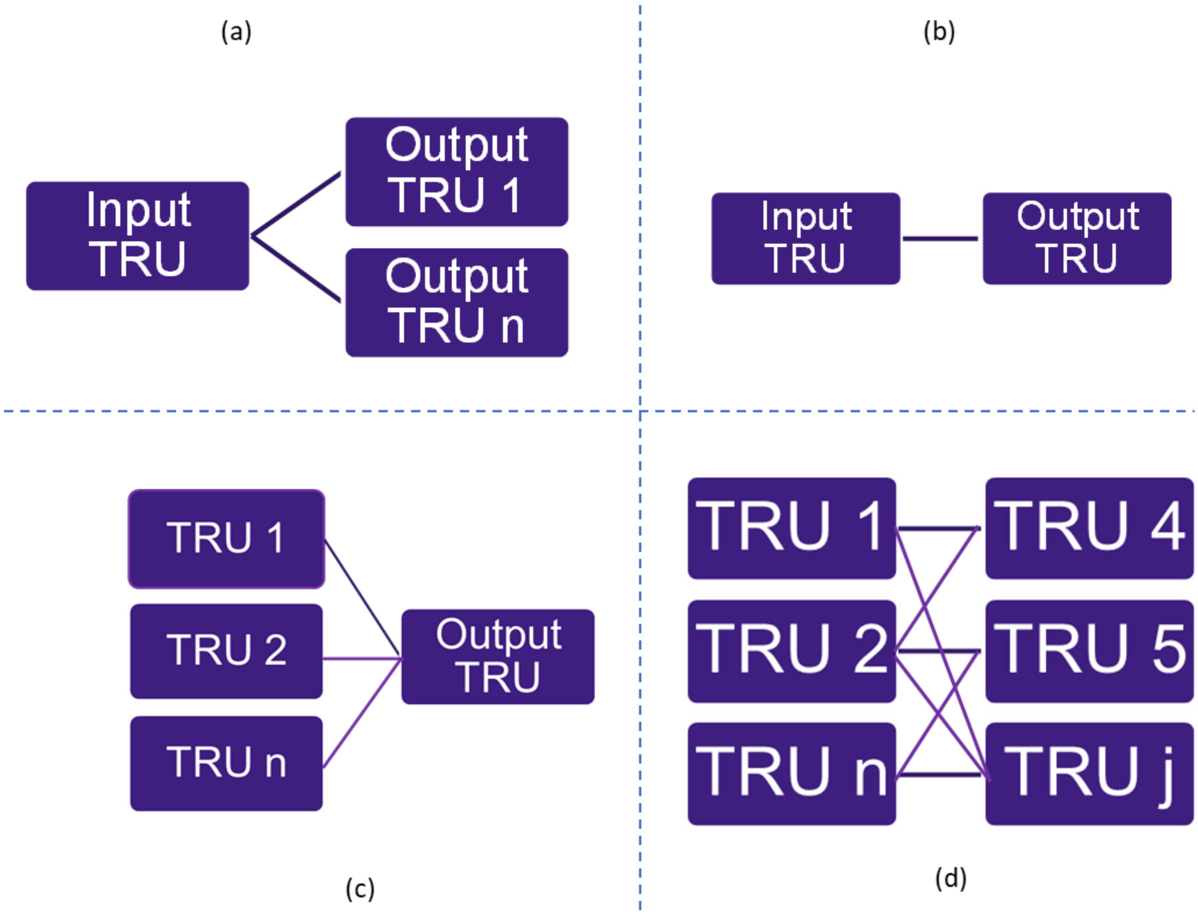

Figure 3. (a) One to many TRUs (splitting), (b) One to one TRU, (c) Many to one TRU (merging), (d) Many to many TRUs

The use of traceability systems inside supply chains is crucial in guaranteeing the attainment of high product quality. Therefore, there is a growing consumer preoccupation with the issue of product traceability [2]. Meanwhile, pertinent organisations have the potential to enhance their management and decision-making capabilities by implementing an effective traceability system. For instance, in the case of a food safety incident, it is crucial for members of the food supply chain to promptly identify the origin of the issue and initiate a recall of the pertinent items through the implementation of an effective traceability system. This proactive approach plays a significant role in safeguarding public health [2].

At present, traditional traceability systems may be categorised into three distinct types: enterprise-built systems, third-party platforms, and government-built systems [2]. In contrast to the other two categories, the enterprise self-built option necessitates a greater investment and presents additional challenges in terms of operation and maintenance management. Third-party systems often exhibit a lack of relevance and often do not possess the necessary level of authority to be deemed trustworthy by both companies and consumers.

The government's created systems primarily serve the purpose of overseeing agricultural goods, although they exhibit limited adaptability for other applications [2]. The three categories are founded upon a system of centralised information management and are susceptible to the subsequent vulnerabilities in practical implementation (as described in [2]):

One potential concern is the susceptibility to data manipulation. The information pertaining to traceability is held within a centralised system. In instances where the recorded information contradicts the interests of the company, it is probable that the enterprise will engage in the manipulation of the product's information. Furthermore, the efficacy of data protection in a central database, even under the supervision of the government or a third party, is contingent upon the reliability of the institutions involved and remains susceptible to potential network breaches.

The phenomenon of information asymmetry arises when various types of information produced during the functioning of supply chains are stored in separate systems of each individual node, leading to the issue of information silos. In order to ensure the comprehensiveness of supply chain data, more human and material resources are required for the purpose of data integration. The association between traceability information and difficulty is evident, as the traceability process is intricate and susceptible to frequent disruptions.

Challenges in ascertaining the accountable entity arise, due to the intricate framework of the prevailing traceability system. Determining the origin of the issue and precisely attributing responsibility to the relevant department pose difficulties when quality concerns emerge.

2.7. Blockchain (BC)

According to Demestichas et al. [17], the concept of "blockchain" as it is known today can be traced back to the foundational work conducted by Stuart Haber and W. Scott Stornetta in 1991. In their article titled "How to Time-Stamp a Digital Document" [18], they laid the groundwork for what would

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later become known as the blockchain. Subsequently, in 2008, Satoshi Nakamoto's influential paper [19] not only introduced bitcoin as a cryptocurrency but also introduced the first implementation of a blockchain database.

As stated by Song et al. [20], blockchain may be defined as a mechanism for maintaining records. The system retains data pertaining to transaction records that are distributed across all computers inside its network using a peer-to-peer mechanism. A block is a data structure that contains both data and two hash values: one representing the hash of the preceding block, and the other representing its own hash. The term "hash" refers to the cryptographic representation of a certain quantity of data within a block. The connection between the hash value of the current block and the hash value of the preceding block elucidates the significance of the cryptographically linked sequence of blocks formed by these hash values [17]. Due to the decentralised nature of blockchain technology, wherein transaction records are kept by several nodes, the potential for tampering with these data is effectively eradicated. The property known as immutability is widely recognised as one of the key features of blockchain technology that several industrial applications want to use [20].

Blockchain can be classified into three categories based on its level of public accessibility. The first category is *public*, or permissionless, blockchain, which allows any participant in the network to have the ability to read, write, or audit the blockchain. The second category is *private*, or permissioned, blockchain, where only a single entity has complete control over the blockchain. The third category is *consortium*, or federated, blockchain, where the rights to read, write, or audit the blockchain are shared among the members of the consortium. The use of public blockchain is sometimes deemed impractical because to its inherent drawbacks, including its high cost and slowness [20].

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3. Review on State-of-the-Art (SoA) Blockchain Traceability Systems (BCTS)

As mentioned before, traditional supply chain traceability comes with many vulnerabilities due to the centralized information management. The integration of blockchain technology has been widely used across many supply chains with the aim of establishing traceability and subsequently enhancing transparency. Blockchain traceability solutions have gained significant recognition in several supply chains, including but not limited to the food and agricultural, pharmaceutical, textile, wood, consumer electronics, and automotive industries [21].

For instance, in the food and agricultural supply chains, it can be seen (from [21]) that, the main reasons that blockchain-based traceability solutions are applied is to: ensure food safety and quality [22]–[24] and improve customer experience [25][26]. In the wood industry, a blockchain-based traceability application has been developed (as stated in [21]), to prevent products of illegal origin [27]. Finally, in the pharmaceutical industry, the main reason for blockchain-based traceability solutions is to prevent counterfeiting and substandard medicines [28]–[32]. As it can be concluded, blockchain-based traceability solutions add to the supply chain transparency, guard the safety of the customers and improves their experience.

In those solutions though, challenges arise that need to be addressed. These challenges along with the enablers of blockchain technology will be addressed in 3.1. Finally, the technological aspects of BCTSs will be discussed in 3.2 and a try to find a connection between BCTSs and circular economy will be made in 3.3.

3.1. Enablers and Challenges for BCTS implementation

In [33], Kamble et al. present thirteen enablers for blockchain technology implementation in agricultural supply chains. Although the focus of the paper lies on agricultural supply chains, can be concluded that these enablers could be applied to any supply chain as they have to do with the blockchain technology in general. What differentiates each supply chain though, is the importance of these enablers (e.g., in agriculture supply chains, some enablers might be more important that the enablers that are considered important in the wood supply chains etc.). These enablers are (as presented in [33], Table 1):

1. <u>*Anonymity and privacy*</u>: BT implements a cryptographic private key mechanism that guarantees the privacy and anonymity of data.

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2. *Auditability*: The utilisation of blockchain technology ensures the absence of errors in the recorded data and enhances its visibility across the supply chain, hence facilitating the process of auditing and improving overall efficiency.
3. *Decentralized database*: The data is not centrally kept on a singular server, but rather it is scattered across several nodes.
4. *Immutability*: The integrity of the transaction data is preserved, as it is immutable and resistant to alteration, modification, or tampering.
5. *Improved risk management*: Instantaneous settlement of trade is now feasible, alleviating concerns over payment failures or delays in trade settlement for the parties involved.
6. *Provenance*: A distinct digital token is allocated to the product at every transaction point across the supply chain.
7. *Reduced transaction costs*: In contrast to conventional supply chains, the elimination of intermediaries results in reduced transaction costs.
8. *Reduced settlement lead times*: The reduction in the number of intermediaries and the elimination of the need for external agency verification might result in a decrease in lead time.
9. *Secured database*: The data contained within a blockchain is inherently resistant to tampering and manipulation.
10. *Shared database*: Relevant parties are granted access to the data.
11. *Smart contracts*: Electronic contracts that include agreed-upon terms and conditions between the involved parties.
12. *Traceability*: The data's provenance facilitates the traceability of the product by giving information on the original source of the end-product.
13. *Transparency*: The data is readily accessible to relevant stakeholders in real-time, and transactions are executed based on a consensus method.

Most of the aforementioned enablers agree also with the enablers that are presented by Yousefi et al. in [34] and Dutta et al. in [35]. In [34]

According to Kamble et al. [33] though, while the use of blockchain technology is anticipated to provide several advantages to traditional supply chains, organizations must also confront some challenges that need to be addressed. Kamble et al. categorize these challenges into three categories: technological, environmental and organizational. In the following paragraphs, these challenges will be presented based on the work of Kamble et al. [33] and the sources they used in their work.

Regarding the technological side (as presented in [33]), an important concern is that BT solutions may be still hacked by a practice known as selfish mining. Also, another concern is the significant expenses associated with implementation, the substantial computer power demands, and the environmental implications resulting from the substantial energy use [33]. Furthermore, the transactions recorded on the blockchain are inherently immutable. Nevertheless, this approach does not facilitate the implementation of any necessary corrections in the database in cases when errors occur during the process of data input [36]. In addition, the goal of attaining an appropriate combination of interoperable and compatible systems may provide challenges. Finally, the transition from centralized ledger systems, such as Enterprise Resource Planning (ERP), to decentralized systems and the question of data ownership require a comprehensive rationale that outlines the potential large extra advantages that Blockchain Technology (BT) might provide.

Regarding the environmental side (as presented in [33]), the task of integrating blockchain technology across the supply chain network, involving the collaboration of all supply chain and trading partners, poses significant challenges. Furthermore, it is imperative to adhere to the legal and regulatory framework established by the government. Several nations have yet to establish regulatory rules regarding this matter. The value provided by BT may be limited due to potential regulatory and legal constraints imposed by the government, notwithstanding the ability of modern BT design to circumvent government meddling.

Regarding the EU, the European Commission highlights the importance of legal certainty and clear regulatory regime concerning blockchain-based applications. For that reason, the Commission has put forth a proposal for a pilot regime that would allow market infrastructures to experiment with trading and settling transactions involving financial instruments in the form of crypto-assets. The pilot regime facilitates the granting of exemptions from established regulations, enabling regulators and companies to experiment with novel solutions utilizing blockchain technology [37].

Regarding the organizational side (as presented in [33]), successful organizations often exhibit resistance when it comes to making changes to their current income structures [38]. In addition, the use of blockchain technology, which seeks to eliminate middlemen throughout the supply chain, has encountered opposition from established intermediaries and other collaborative entities [39]. Furthermore, there might be a reluctance from current supply chain partners to instantly communicate important data on a shared, decentralized database. Finally, there is a noticeable deficiency in technical proficiency and awareness of BT. In order to acquire proficiency in the field of blockchain technology, it is necessary to cultivate a comprehensive understanding of several key dimensions, such as the application scope, counterparties, process, data, technology, people, regulation, performance, and security.

As a conclusion, Kamble et al. support that Blockchain technology is now in its early developmental phase, and it faces a multitude of obstacles across several domains, including technological, regulatory, infrastructural, and institutional. These challenges must be addressed and solved in order for blockchain technology to progress towards its mature stage. The use of blockchain technology has the ability to greatly enhance Agricultural SC operations, provided that favorable strategies and policies are implemented to strengthen the supporting factors.

According to Zhang et al. [2], there are four primary obstacles that arise when attempting to implement blockchain technology for the purpose of enhancing supply chain traceability. These challenges include scalability, cost implications, excessive transparency, and regulatory considerations.

Therefore, certain domains may be examined and enhanced; specifically, there are discernible avenues for future research.

Scalability is achieved in a decentralised blockchain system by the equitable distribution of rights and duties among its nodes. These nodes, which possess maintenance capabilities, collaborate in the collective maintenance of data blocks throughout the whole network. As a result, transaction data is saved and checked in its whole in order to fulfil security standards. Nevertheless, this architecture implies that the performance of the system is constrained by the maximum capacity of a single node. Hence, the system's throughput is typically suboptimal for the supply chain, which encompasses a significant amount of data. Using mainstream blockchains as a case study, it can be observed that Bitcoin has a maximum throughput of around seven transactions per second, with an approximate confirmation time of one hour for committed transactions to be included in the blockchain. On the other hand, Ethereum exhibits a processing capacity of approximately 15 transactions per second. The potential enhancement of performance may be achieved by developing a consensus algorithm that specifically aligns with the unique attributes of the supply chain, as opposed to adopting the conventional PoW, PBFT, and other generic algorithms. Furthermore, using a multi-chain architecture might potentially serve as an alternate approach to enhance scalability [2].

Regarding the ***cost implications***, the execution of operations by a smart contract and the occurrence of transactions on the Ethereum platform incur gas costs, which may be uneconomical for a system that heavily relies on data. Furthermore, a significant number of managers exhibit a lack of awareness regarding the inherent value of blockchain technology. Their apprehension stems from the potential decrease in returns that may arise due to the excessive operational and transactional expenses associated with its implementation. Hence, it is recommended that future research endeavours prioritise the development of a more cost-effective and low-risk approach [2].

Concerning ***excessive transparency***, the potential compromise of privacy may arise from the immutability and perpetual visibility of data on the blockchain. Therefore, it is imperative to develop suitable access restrictions in order to address the concerns of the relevant parties [2].

Regarding ***regulations***, at present, the existing rules pertaining to blockchain are deficient, and the use of blockchain technology needs appropriate oversight. In addition, it is important for the design of the supply chain traceability plan to consider the involvement of regulators. If faulty items are identified, it is imperative for regulators to promptly identify the accountable entity and initiate a recall process [2].

The analysis reveals that existing supply chain traceability solutions based on blockchain predominantly concentrate on the design of storage mechanisms. Consequently, blockchain technology primarily serves as a means of storage within the supply chain. In contrast to the multifaceted roles of blockchain in the financial sector, such as facilitating bookkeeping, transaction authorisation, and rights confirmation, the supply chain domain now employs just the rudimentary storage function of blockchain. This limited utilisation is indicative of an imperfect and underdeveloped use in this context. The primary significance of blockchain lies in its ability to facilitate the digitization of assets. In the context of supply chain management, it is imperative to see information as valuable data assets. By doing so, it becomes possible to build reciprocal relationships that validate ownership rights and grant authorised access. This approach enables the realisation of the full potential of blockchain technology [2].

Based on Song et al. [20], some additional difficulties are:

- establishing a connection between the physical realm and the digital domain. Considerable financial resources are required to establish connections between non-digitized and physical entities using several communication technologies, including RFID, NFC, and IoT.
- The cultural assimilation of decentralised networks. In order to effectively persuade stakeholders who are unfamiliar with and hesitant towards the new model of democratised processing, it is crucial to overcome the cultural barrier.
- The Perception and Trust of the General Public.

In [35], Dutta et al. conduct a comprehensive review on the applications, challenges and research opportunities on the application of BT in supply chains operations. They distinguish many challenges that arise. These challenges are (as presented in [35], Table 6):

- The absence of comprehension of the advantages and intricacies associated with the subject matter.
- The user possesses a restricted understanding of the intricate nature of the technology in question.

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- As the technology is still in its early stages, there is a scarcity of successful implementation examples to draw upon.
- There exists a prevailing belief that conventional information and database systems are sufficient for resolving most issues, leading to a lack of perceived necessity for blockchain.
- Ensuring the integrity of input data poses a formidable challenge.
- Garnering the cooperation of all parties to facilitate information sharing presents a significant hurdle.
- The management and use of vast quantities of data pose a significant challenge.
- Numerous initiatives are currently underway in isolated contexts, with diverse blockchain systems being actively developed.
- The imperative need of standardisation and the need for seamless interoperability cannot be overstated. Failure to achieve these objectives would result in increased complexity and difficulty, rather than the intended simplification.
- The implementation of technological changes and adoption throughout an entire organisation incurs significant costs and requires a substantial amount of time.
- It is imperative to guarantee the privacy and security of models and data, given the nascent and susceptible nature of the technology.
- The presence of regulatory ambiguity might give rise to several undesirable complexities.
- There is a possibility of a significant impact on the entire organisation in the event of system failure.
- The use of blockchain technology should be done judiciously, taking into consideration the economic factors associated with deployment, including cost and risk.
- The adoption of blockchain technology represents a substantial transformation across all facets of an established firm.
- The engagement of several stakeholders is a significant challenge in addressing deeply ingrained mindsets, cultural norms, and work techniques that have been established over a long period of time.
- Different stakeholders may have divergent objectives.
- The potential elimination of intermediaries at different levels may lead to the emergence of divisions.
- The adoption of a concept is hindered by uncertainty and a lack of awareness.
- There exists a notion among certain circles that the introduction of blockchain technology has the potential to result in job losses.

As it can be concluded, although each supply chain has a different area of focus, the main enablers and challenges are almost the same for each supply chain. The only difference is the importance of each enabler in each supply chain and the same applies also for the challenges, though not in the same manner. The challenges can be considered more universal and do not have to do with the type of the supply chain as they are closely related to the blockchain-based solutions.

3.2. Technological aspects of BCTSs

Regarding the technological aspects of BCTSs, these are distinguished in two categories: the blockchain technological aspects and the traceability technological aspects.

Blockchain technological aspects

The fundamental components of blockchain technology encompass cryptography, consensus mechanisms, and smart contracts [2].

- **Cryptography**: A detailed explanation of cryptography on blockchains is given by Demestichas et al. in [17]. A block is a data structure that contains information within it, along with a preceding block's hash value and its own hash value. The term "hash" refers to the cryptographic representation of a certain quantity of data within a block. The relationship between the hash of the current block and the hash of the preceding block elucidates the significance of the cryptographically interconnected sequence of blocks via these hashes. The property known as the "fingerprint" serves as the distinctive identifier for each block and is a fundamental aspect of the blockchain design. The SHA256 hash algorithm, invented by the National Security Agency (NSA), is widely utilised for cryptographic application on many digital data sources. The utilisation of a hashing method is justified due to the impracticality of employing reverse engineering techniques. Therefore, the significance of employing the SHA256 method is in the fact that any endeavour to decrypt it is not feasibly achievable, owing to its intrinsic attributes (hashing functions are irreversible) [17].
- **Consensus mechanisms:** A consensus algorithm serves two primary functions: firstly, it guarantees that the subsequent block in a blockchain represents the singular and definitive version of reality, and secondly, it prevents powerful adversaries from disrupting the system and successfully forking the chain [40]. There are many consensus mechanisms with the two major being: proof of work (PoW) and proof of stake (PoS). Their description and differences are presented in detail in [41].

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- The proof of work (PoW) consensus mechanism, first used by Bitcoin, stands as the original cryptographic method for achieving consensus in a decentralised manner. The term "proof of work" is attributed to the substantial computational resources used by the network. Proof-of-work blockchains are safeguarded and authenticated by the participation of virtual miners located globally, who engage in a competitive race to successfully solve a mathematical puzzle and get the title of being the first to do so. The individual who emerges as the victor is granted the privilege of updating the blockchain with the most recent validated transactions, and in return, receives a fixed quantity of cryptocurrency as a reward from the network [41].

  The utilisation of proof of work has notable benefits, particularly in the context of a straightforward yet immensely valuable digital currency such as Bitcoin. The maintenance of a secure decentralised blockchain is achieved by a well-established and resilient approach. As the value of a cryptocurrency rises, it serves as a catalyst for attracting additional miners to participate in the network, therefore augmenting its computational capacity and fortifying its overall security. Due to the substantial computational resources required, it becomes unfeasible for any individual or collective entity to tamper with the blockchain of a significant cryptocurrency [41].

  However, because of its energy-intensive nature, it may not be able to scale to handle the enormous volume of transactions that blockchains that are compatible with smart contracts, like Ethereum, are capable of producing. Various solutions have been devised, with one particularly prominent one being referred to as proof of stake [41].

- In a proof of stake system, the act of staking fulfils a comparable role to the mining process in proof of work. It involves the selection of a network participant to include the most recent set of transactions into the blockchain, therefore receiving a certain amount of cryptocurrency as compensation.

  The specific particulars may differ among projects, but in a broad sense, proof of stake blockchains utilise a network of individuals known as "validators" who offer their own cryptocurrency as a kind of collateral, referred to as "staking," in order to increase their likelihood of being selected to verify new transactions, update the blockchain, and get a payment. The selection of a winner inside the network is determined by considering two factors: the quantity of cryptocurrency held by

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each validator in the pool and the duration for which they have maintained their holdings. This approach effectively rewards members who have made significant investments. After the winner has successfully verified the most recent block of transactions, further validators have the ability to confirm the accuracy of the block. Once a sufficient number of attestations has been reached, the network proceeds to update the blockchain. The native cryptocurrency is given by the network to participating validators in proportion to their stake, resulting in a payout for each validator [41].

One significant distinction between the two consensus processes is in their respective energy consumption levels. Proof-of-stake blockchains provide the advantage of reduced resource consumption compared to traditional proof-of-work blockchains. This is due to the elimination of the need for miners to expend resources on redundant activities, such as competing to solve the same problem [41].

- **Smart contracts:** Smart contracts refer to computer programmes that are recorded on a blockchain and are designed to execute automatically whenever specific pre-established criteria are fulfilled. A network of computers carries out operations after specific requirements have been satisfied and validated. These activities may encompass the disbursement of monies to the relevant entities, the registration of a motor vehicle, the transmission of notifications, or the issuance of a ticket. The blockchain is updated upon the successful completion of a transaction. This implies that the transaction is immutable, and access to the results is restricted solely to authorised parties [42].

Traceability technological aspects

Automatic identification technology, including barcodes, 2D barcodes, radio frequency identification (RFID), and Internet of Things (IoT) data capture and processing technologies, possess the capability to record and process diverse forms of information pertaining to product visibility throughout the entire supply chain. These technologies facilitate the tracking and tracing of products [43].

- Barcodes

  Barcodes are data represented in an optically readable format for machines. Barcodes are simple, more economical and provide exact traceability. Their disadvantages are that: reading them requires a direct visual connection between the reader and the text being read, the labels are rendered illegible in case they are damaged, the scanner has the capability to read one item at a time and, they do not have sensing capabilities, thus collection of environmental information is not possible [44].

- Radio Frequency Identification (RFID)

  Radio Frequency Identification (RFID) is a technological system that employs radio waves for the purpose of automatically identifying various objects. The process of identification involves the use of a microchip, which is affixed to an antenna, with the purpose of storing a serial number and maybe additional information. The aforementioned assemblage is commonly referred to as an RFID tag. The presence of an antenna facilitates the transmission of identifying information from the chip to a reader. The process involves the conversion of radio waves that are reflected from the RFID tag into digital data, which may then be transmitted to an enterprise information system [45]. Some advantages of RFID technology are as follows: there is no need of a direct visual connection in the act of reading, can read and write tags, has increased data rate and memory, it implements the concept of reversible tags and, it has the possibility to concurrently read several tags [44]. Some disadvantages contain (a) the lack of cooperation among the devices, (b) cost and, (c) limited capability for environmental sensing [44].

- IoT technologies

  Within the framework of the Internet of Things (IoT), a considerable multitude of objects in our immediate surroundings are interconnected with the network in various ways. The difficulty of seamlessly integrating information and communication devices into our surroundings is effectively addressed by technological advancements like Radio Frequency Identification (RFID) and sensor network technology. The model consists of services that may be classified as commodities and will be distributed in a way that is analogous to the distribution of conventional commodities [46][47]. Some examples of data capture IoT devices are sensors, microcontrollers, antennas etc.

3.3. BCTSs and circular economy (CE)

According to Santana et al. [9], the adoption of a circular economy has been increasingly prominent among policymakers, scholars, and practitioners due to its potential to facilitate the effective utilisation of resources and dissociate economic growth from environmental consequences. In the same paper [9], Santana et al. conclude that the establishment of a connection between traceability and the circular economy remains inconclusive based on existing published research and practical evidence showcasing the impact of traceability model and system development.

As can be observed, CE is not given enough attention throughout the implementation of TSs. Consequently, D2.1 will attempt to collect pertinent data from the project's demo cases in an effort to establish a link between BCTS and CE so that the latter may be incorporated into the DigInTraCE framework.

4. A stepwise approach for the conceptual design of BCTSs for circular value chains

The proposed stepwise approach consists of the following steps:

1. **Identification of the scope of the TS**
2. **Objectives of the TS**

   Clearly define the objectives of the traceability system. Common objectives include enhancing transparency, ensuring product quality and safety, complying with regulations, reducing fraud, and improving sustainability.
3. **Identification of Traceability Parameters**

   Determine the specific information that needs to be tracked and recorded at each stage of the value chain. In this section the focus is not only on typical T&T perspective (origins of materials, etc.), but tries to facilitate LCA assessments, the assessment of circularity indicators, etc.

   - ***Capture Sustainability Metrics***

     Traceability in circular value chains often includes sustainability metrics, such as carbon emissions, water usage, and energy consumption. Collection of data on these metrics throughout the value chain will be achieved by gathering information from the DigInTraCE consortium via questionnaire (see Anex I).
   - ***Recycling and Recovery Processes***

     Collection of data on recyclability and recovery processes will be achieved by gathering information from the DigInTraCE consortium via questionnaire (see Anex I).
4. **Mapping of the process, material, and information flows a cross the value chains**

   This section will highlight the main parts of the protocol for the mapping process (which parts it covers, what kind of questions will be asked, etc.)
5. **Evaluation of current traceability status**

   The evaluation will help us define the degree of granularity, and will allow for moving to the next steps, i.e., establishing data collection mechanisms.
6. **Establishment of Data Collection Mechanisms**

   Define the methods and technologies for collecting relevant data at different stages of the value chain. This could involve manual data entry, barcodes, RFID tags, sensors, blockchain, or other advanced technologies.

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7. **Implementation of Data Management System**

   Develop a centralized data management system to store, process, and analyse the collected information. This system should ensure data integrity, security, and accessibility for authorized stakeholders.

8. **Definition of Standards and Protocols**

   Establish standardized formats, protocols, and data exchange mechanisms to ensure interoperability and compatibility between different participants in the value chain. This enables seamless data sharing and traceability across the entire chain.

9. **Enabling Information Sharing**

   Foster collaboration and cooperation among stakeholders to facilitate the sharing of traceability data. Encourage suppliers, manufacturers, distributors, and retailers to contribute and access relevant information to maintain a comprehensive traceability record.

10. **Implementation of Tracking Technologies**

    Introduce tracking technologies such as barcodes, QR codes, or RFID tags to enable the physical identification and tracing of products along the value chain. These technologies should integrate with the data management system to provide accurate and real-time traceability.

11. **Establishment of Verification and Auditing Processes**

    Develop mechanisms to verify and audit the accuracy and reliability of the traceability data. This may involve periodic inspections, third-party audits, or certification processes to ensure compliance with standards and regulations.

12. **Continuous Improvement and Evaluation**

    Regularly assess the effectiveness of the traceability system and gather feedback from stakeholders. Identify areas for improvement, address challenges, and update the system to adapt to evolving needs and technologies.

In the current version (v1), the steps that will be covered are step 1 to step 5. The remaining steps will be covered in the following versions.

4.1. Identification of the Scope

The scope of the stepwise approach is to conceptualise a BCTS that will provide an accurate traceability of the end-product from start to finish. To achieve that, we will focus on two things: a) identify the information flow, quality and quantity and b) accurately map the value chain. These aspects will enhance the granularity and high-resolution granularity will allow for a more robust control of the

value chain and will assist in its improvement as it will allow us to understand the causal relationships of the chain and thus improve its environmental footprint, its circularity and its sustainability.
The traceable products in our case will be pulp and paper, wooden furniture, etc. The higher the granularity, the more capable we will be to trace the end-product back to its origins and at the same time trace its environmental footprint. Manufacturing processes, transportation routes, storing and handling will be examined to map the value chain. Internal traceability, reporting, raw materials passports will be examined to map the information flow and assess the quality and quantity of the available information. The combination of these two, will allow us to detect the parts that information loss occurs and take actions to rectify them, thus improving the resolution of granularity in the DigInTraCE demo cases, which will improve the environmental footprint and enhance circularity and sustainability.

4.2. Objectives

As it can be seen from 3.1 (Enablers and Challenges for BCTS implementation), there are many challenges that need to be addressed during the implementation of blockchain traceability systems. For that reason, the proposed methodology will focus on the following objectives:

Enhance Transparency*:* By creating an accurate mapping of the value chain, each step of the process will be described and recorded in a transparent way. The blockchain technology will also aid to that as it provides transparency through readily accessible data for relevant stakeholders in real-time, and transactions that are executed based on a consensus method.

Ensure product quality and safety*:* The mapping will take into consideration all the protocols that are in place and all the requirements and regulations that appeal to the product quality and safety.

Reduce fraud: By implementing blockchain-based solutions for traceability along with accurate mapping, the fraud risk will be minimised. The blockchain technology will add the decentralized characteristic along with the immutability, to ensure that fraud cannot be committed (e.g., tampering). Accurate mapping will aid from the perspective that accuracy of information leaves no room for tampering or fraudulent activity (as detailed information for each process is logged).

Evaluate and propose alternatives for improving sustainability: After detailed mapping of the value chain is finished, conclusions and recommendations about manufacturing or logistic changes can be made, in order to improve sustainability.

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4.3. Identification of Traceability Parameters (TPs)

Identification of Traceability Parameters (TPs) will help us build and implement an accurate TS to the DigInTraCE demo cases that will adhere and abide to the objectives mentioned in 3.2.

During the identification of TPs, not only typical parameters are to be considered (that would constitute a typical traceability methodology) but also parameters that aim to facilitate circularity, LCA assessment, sustainability and recycling will be taken into consideration. The parameters that have been identified as important at this (preliminary) stage are information of the raw material, transportation mode, frequency and distance, storage conditions, waste and water management, energy resources, monitoring, reporting, labelling, packaging, identifiers (e.g. RFIDs, barcodes etc.) and record types (e.g. electronically, manual etc.) We need to emphasize here that, the identification of TPs is a dynamic process, meaning that it will be updated and adjusted throughout the whole duration of DigInTraCE. Based on the needs, new TPs might be identified that were not available before (e.g there were no records kept about them etc.). For that reason, in the next two versions of D2.1 (on month 24 and month 48) this chapter will be updated accordingly.

In our approach, we have divided the whole value chain in parts, in order to identify more accurately the parameters that may or may not be relevant to traceability and thus, to the aim of this deliverable. For the first part, we need to focus on the aspects of the raw material (e.g., its origins, its type etc.). The details of the raw material are vital TPs, as they create a strong "ID" for the end product (e.g., recycled wood used to make furniture etc.). Besides origin of the raw material and its type though, its sustainability and any certification that might accompany it are also important. This information facilitates the implementation of circularity, sustainability and other environmental indicators, as mentioned before. Furthermore, it enhances transparency and builds trust between the consumer and the company.

The next part where important traceability parameters can be found is the transportation of the raw materials and the transportation of the end products. Transportation mode, distance and frequency, alongside packaging and handling, are TPs that affect the environmental footprint of the product but also have a managerial impact as they provide insight on the logistics functionalities of the company and their efficiency. Adjustments on the processes based on these parameters can add value, save time and make the end products more environmentally friendly and sustainable.

In the same manner, the storage of raw materials but also the storage of end-products contain TPs that contribute in the same manner as the TPs of transportation. For instance, during the storage process (where materials are unpacked to be stored) there might be a storage waste stream, that can negatively impact the environment footprint. Furthermore, packaging of the materials during the storage process is an important TP as it contains information about the product's environmental footprint, sustainability but also its quality and safety.

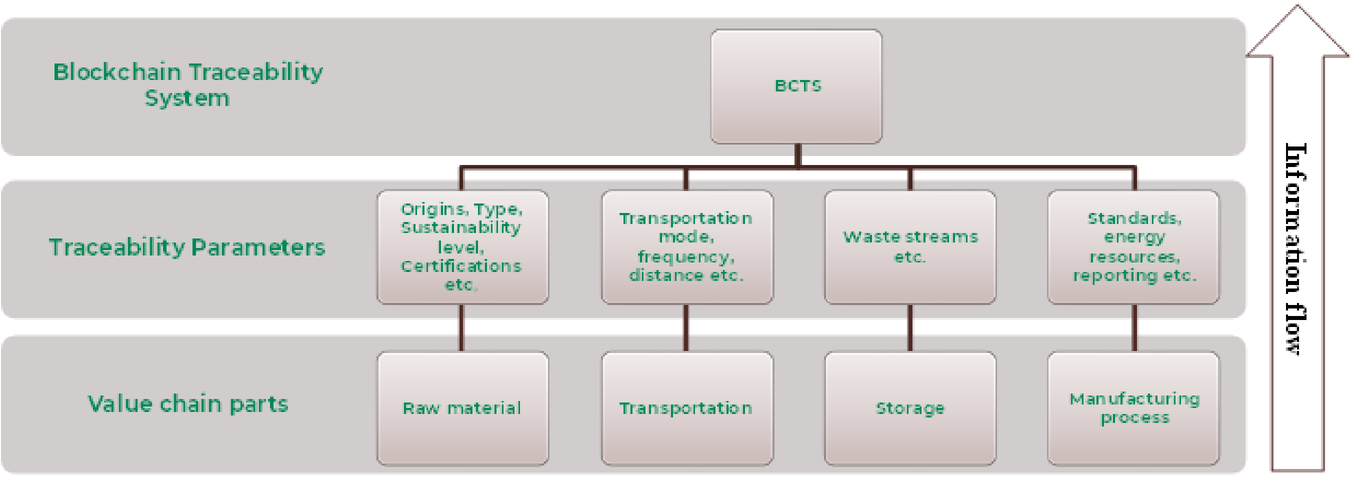

Figure 4. Traceability Parameters (TPs)

At the manufacturing part, there are many TPs to be identified. These TPs range from standards and certifications to energy resources, waste management and detailed reporting. These TPs enhance transparency (by detailed information being reported in a hard-to-tamper platform), improve the product's quality and safety (by following standards during the manufacturing process and acquiring certifications) and improve the product's environmental footprint and sustainability. The aforementioned TPs along with the areas that contribute can be seen in Figure 4.

4.4. Mapping of the process, material, and information flows across the value chains

To obtain the TPs that are needed to implement an accurate Traceability System to the demo cases, a detailed mapping of the value chains and the information flow and availability needs to be created. These two, when combined, will allow us to identify the points where loss of information occurs and thus create a more detailed BCTS. To do so, we have based our approach on the paper "Reference method for analysing material flow, information flow and information loss in food supply chains" published by Olsen et al. [14]. The reason for choosing this paper as our guide is that it is highly relevant to DigInTraCE demo cases, it exhibits a comprehensive methodological structure for process mapping and the methodology is designed to include generic, adaptable, and extendable characteristics, rendering it readily applicable in many supply chain contexts. Accurate mapping of the processes and the information flows along with evaluation of the current status of traceability and granularity level (which will be presented in 4.5) will allow us to suggest ways of improving the system (e.g., propose installation of traceability tools in specific points where there is loss of information etc.). These proposals will enhance the system's granularity and thus, a more robust and detailed tracebility system will be created which will lead to improved environmental footprint and enhanced circularity and sustainability.

Steps for mapping the value chain

1. Firstly, **communication** needs to be established with the studied case partners in order to explain to them clearly the aim, the objectives and the possible benefits of the mapping. Mapping is a process that requires resources (allocation of expert to answer questions etc.), so clear and structured explanation of the benefits that the mapping will provide is of the essence.
2. Before the gathering of information, some ground **rules** need to be established to facilitate the process of mapping. Privacy concerns, access to data, focus on a single or multiple product types need to be discussed before mapping begins, to achieve a focused, robust and smooth mapping.
3. The key aspect of this approach for process mapping is the **categorization** of questions into several forms, where each form corresponds to a specific duration or transformation pertaining to the component or product [14]. The questionnaire is divided into seven forms from which: five focus on the transformations of materials (e.g. merging) and duration of processes (e.g. transporting) and two focus on raw material information and the current internal traceability that is in place.

   There are five types of questions and the answers to the questions of each type will be interpreted together (as in [14]). These types are:

   - Material flow questions where we will examine the type of the materials, their transportation routes, frequency etc. in order to create the overall material flow.
   - Questions about keys, where we will examine existing identifiers, where they are used etc. This will help us identify the type of the existing identifiers and will help us decide if more identifiers are needed to processes that do not currently have.
   - Questions regarding parameters, how they are recorded etc. These will help us understand the information that is currently gathered and can be used for mapping.

    - Questions about transformations, what is the link between inputs and outputs, how the products are transformed etc. These will help us as we will be able to highlight CTPs.
    - Safety questions, such as storage protocols, process certifications etc. These will help us map legislative aspects that are followed or, need to be followed.
4. After the questionnaires have been answered by the experts, the process of **mapping** begins. The gathered data are used to understand and map the causal relationship between processes and materials and capture the transformations. In this stage, it is important to highlight all the Critical Transformation Points (CTP) efficiently, to minimise the risk of information loss and thus the accuracy of the mapping.
5. After the mapping is completed, we will be able to proceed with the **installation of additional traceability tools** based on the needs that will rise (e.g., important information might be missing due to not keeping records of a process or transportation records are kept manually and this leads to missing entries etc.). Of course, this needs to be discussed with each case separately and, a comprehensive presentation of the evidence that support the installation of additional features to the chain need to be presented to the case owners, so they can decide based on the benefits and the drawbacks (e.g., cost my be disproportional to the benefit).

Structure of the questionnaire

To acquire the required information to map the chain, a questionnaire will be circulated to the consortium partners that are involved in the DigInTraCE demo cases. The questionnaire is divided into seven categories and each category focuses on a different area of the value chain. These categories are: **Raw Material composition**, **Transportation of Materials**, **Storage and Handling**, **Manufacturing process**, **Post-production**, **Transportation of end-product** and **Internal Traceability**.

- Raw Material composition

  In this category, the questions revolve around Primary raw materials (e.g. their type, sustainability etc.), Secondary or Recycled materials and Corporate sustainability (e.g. certifications provided during the acquisition of these materials etc.).
- Transportation of Materials

  In this category, the transportation mode, distance and frequency are examined. Furthermore, packaging and handling of these materials during transportation will be investigated.
- Storage and Handling

In this category, storage and handling are examined (e.g. equipment, protocols etc.). Unpacking and handling, storage conditions and packaging waste management are the main areas of focus.

- Manufacturing process

  In this category, manufacturing processes will be studied (e.g., manufacturing and assembly steps, standards, management practices etc.). The questions revolve around water management, energy sources, waste generation and management, monitoring, reporting and transparency and occupational health and safety (H&S).

- Post-production

  In this category, we will examine the storage after manufacturing, the labeling, the packaging of the end products and any potential end-of-life management that takes place.

- Transportation of end-product

  In this category, the transportation of the end-product to the vendors/customers will be examined.

- Internal Traceability

  This category focuses on different stages and aspects such as: collection of raw materials (e.g., trade units (TU), logistic units (LU) etc.), application of ingredients and raw materials (e.g., what parameters are recorded and how), information gathered during production (e.g., batch handling etc.), information gathered at the end of production and the transportation of finished goods (e.g. parameters linked to shipping etc.).

The detailed questionnaire can be found in Annex III.

4.5. Evaluation of current traceability status and granularity level

Qian et al. [48] conducted a review on studies that evaluate Traceability Systems (Table 1, [48]). Some key evaluation indicators that are taken into consideration when it comes to evaluating TSs are precision, breadth, depth and granularity.

The level of certainty with which the tracing system can identify the movement or properties of a specific product is reflected in precision. The quantity of data that the traceability system keeps track of is referred to as its breadth. How far back or forward a traceability system tracks is known as its depth. The scale of traceable units is determined by granularity, where higher granularity is associated with finer scales. [48].

In the same paper [48], Qian et al. propose a framework for quantitative evaluation of granularity.

They introduce an index suite with two layers namely the factor layer and the subfactor layer. The factor layer consists of Precision, Breadth and Depth and the subfactor layer consists of seven indicators that are: external trace unit, internal flow unit, identifiable unit (IU) conversion, information collection content, information update frequency, forward tracking distance, and backward tracing distance. According to Bollen et al. [49], the unit of a product that needs to be uniquely identifiable in every system where it can be traced is called identifiable unit (IU). This index suite can be seen in Figure 5.

Most of the traceability precision evaluation is comprised of internal flow units and external trace units. An external trace unit between supply chain nodes is thought of as a unique whole.

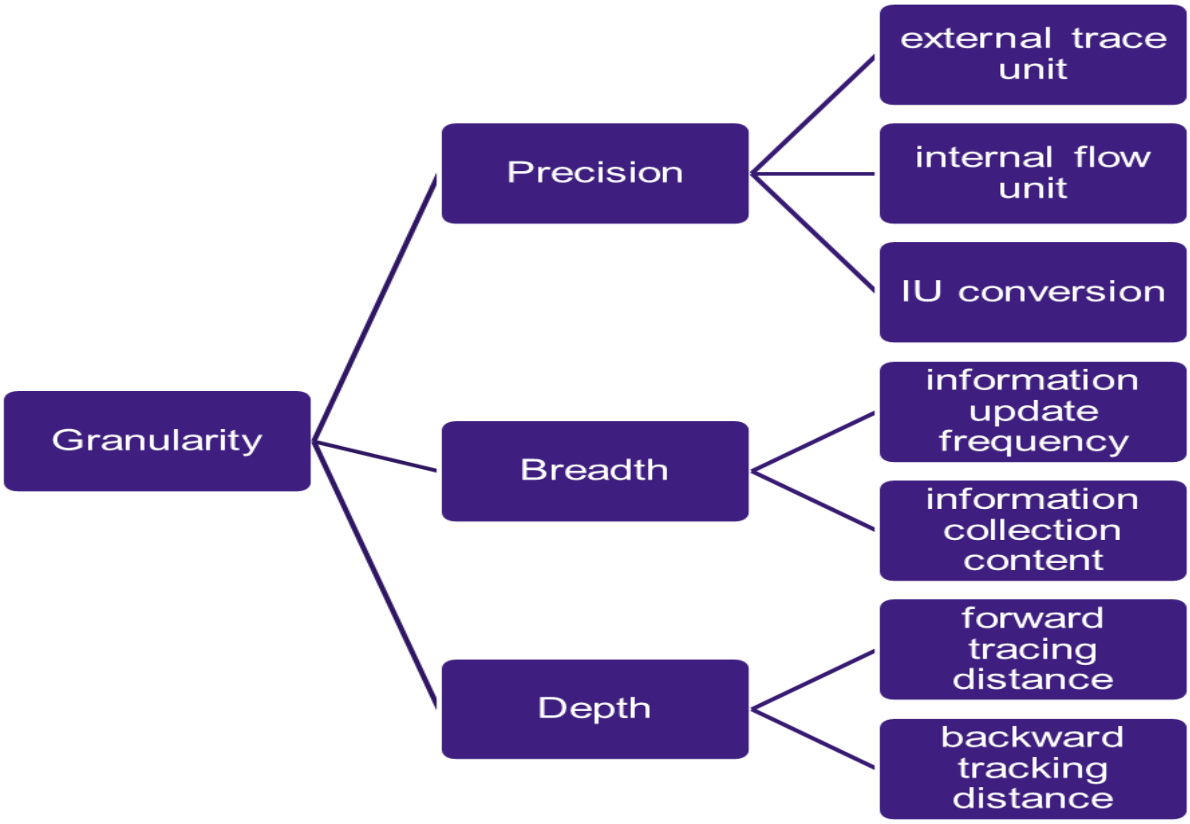

Figure 5. Index suite for traceability/granularity [48]

The tracing precision decreases with increasing external trace unit size. There are three tiers of external trace units: single product, single batch, and mixed batches. The smallest external trace unit is a single product. A single batch is a collection of goods that may be tracked together using a common code. Mixed batches are taken into consideration when the batches come from different companies or sources [48].

For flow tracking purposes, product management may be split up into several components inside an internal business system. The internal flow unit has three levels of definition: single product, single batch, and mixed batch, just like the exterior trace unit.

There are some scenes of Identifiable Unit (IU) conversion in between supply chain nodes. There are numerous transformations that can occur, as was stated in 2.6 (e.g., one to one etc.) For one-to-one,

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precise traceability can be used. Identification correspondence and information association can accurately realise the one-to-many relationship found in split batch cells. Precise traceability is challenging for many-to-one, which is present in aggregated batch cells due to mixed batches [48].

The frequency of information updates varies greatly amongst different enterprises and supply chains. Thanks to the quick advancement of information and communication technology, a transmission network, portable equipment, and a variety of sensors can be used to gather data on the spot and in real time. As a result, the frequency of information updates rises and is accompanied by higher system implementation and operating expenses [48].

The information collection content for Traceability Systems encompasses various aspects such as product basic information, forward source information, backward direction information, processing information, and other relevant details [48].

Forward and backward tracing distance refers to the distance that a product can be tracked or traced. The number of layers traced is an important indicator for measuring traceability depth [48].

These indicators have weights that allow us to assess the level of traceability granularity of the studied system. The weights differ from case to case and need to be established for each demo case separately. In the course of our investigation, we will be using these indicators (Table 1) to evaluate the granularity of the demo cases in DigInTraCE. This will allow us to get a better understanding of the installations that might be needed and/or the actions that need to be taken to enhance the traceability system and achieve the desired outcomes.

Table 1. Indicators for evaluation of granularity

Indicators	Description
External trace unit	mixed batches, single products, and single batches
Internal flow unit	single product, single batch, and mixed batch (for flow tracking purposes)
IU conversion	One to one, many to one etc.
Information update frequency	The rate with which information is acquired
Information collection content	product basic information, forward source information, backward direction information, processing information, and other relevant details
Forward tracing distance	distance that a product can be tracked or traced (forward)
Backward tracing distance	distance that a product can be tracked or traced (backward)

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5. Concluding remarks and next steps ahead

The primary purpose of this deliverable is to propose a step-by-step methodology for the conceptual design of blockchain traceability systems applicable to the DigInTraCE demo cases.

In the current version, key ideas were discussed including granularity, supply chains, value chains, and traceability. A study on Traceability Systems, also known as TSs, was carried out in order to ascertain the degree to which conventional TSs are capable of assisting us with the DigInTraCE demo cases. The fact that traditional TSs are not decentralised led to the discovery that they are susceptible to being tampered. Because of this, the research concentrated on TSs that use blockchain technology.

Blockchain-based solutions have the potential to eliminate the drawbacks of conventional TSs while also adding new advantages to the tracking and monitoring of products. The use of blockchain technology does, however, present some difficulties that must be overcome before it can be put into practise. These difficulties include the high cost of implementation, the dearth of examples of successful blockchain implementations from which to draw, and the need to guarantee the data's integrity. A thorough and in-depth review about the enablers and the challenges for BCTSs implementation, the technological aspects, and the connection of BCTSs with circular economy is presented in chapter 3. It can be concluded that, although blockchain technology can assist to build an advanced TS, there are still drawbacks that need to be addressed. Furthermore, a clear connection between BCTSs and circular economy is yet to be established.

A 12-step methodology is presented for the conceptual design of BCTSs for the DigInTraCE demo cases. These steps include the identification of the scope and objectives, the identification of traceability parameters, the mapping of the process, material, and information flows across value chains, the evaluation of the current traceability status and granularity level, the establishment of data collection mechanisms, the implementation of a data management system, the definition of standards and protocols, the enabling of information sharing, the implementation of tracking technologies, the establishment of verification and auditing procedures, and the establishment of a verification and auditing framework. The first five steps are presented and talked about in the current version. The next steps will be presented in the future versions of the deliverable.

The objective of the stepwise approach is to develop a comprehensive conceptual framework for a Blockchain traceability system (BCTS), which ensures the accurate tracking of the entirety of a product's lifecycle, beginning with its earliest stages and ending with its final form. This will be accomplished by following a specific set of steps. Our strategy will consist of the following two primary elements in order to achieve this objective: firstly, the determination and evaluation of the flow, quality, and quantity of information; and secondly, the accurate mapping of the value chain. These elements will work together to help us realise our goal. The current level of granularity will be evaluated, and then improved, thanks to the contribution of these factors. Granularity with a high resolution will make it easier to engage in all-encompassing management of the value chain, which will ultimately result in the chain's improvement. This will be accomplished by gaining insights into the cause-and-effect relationships that exist within the chain, which will enable improvements to be made regarding the environmental impact, circularity, and overall sustainability of the chain.

The framework that is being proposed will seek to address the challenges that were identified in the literature, and as a result, it will place an emphasis on increasing transparency, ensuring product quality and safety, reducing fraud, and evaluating the current level of sustainability and proposing alternative ways to improve it.

The construction and implementation of an accurate traceability system (TS) for the DigInTraCE demonstration cases will be facilitated by the identification of traceability parameters (TPs). In the process of identifying TPs, it is important to consider not only conventional parameters, which form the basis of a typical traceability methodology, but also parameters that are designed to promote circularity, LCA assessment, sustainability, and recycling. The information regarding the raw material, the mode, frequency, and distance of transportation, the conditions of storage, the management of waste and water, the energy resources, monitoring, reporting, labelling, and packaging, identifiers (such as RFIDs and barcodes), and record types (including electronic and manual formats) are all considered to be significant parameters at this early stage.

It is imperative to develop a comprehensive mapping of the value chains, as well as the information flow and availability, in order to acquire the necessary TPs for the successful implementation of a precise TS in the demo cases. As a result of the integration of these two components, it will be possible to identify specific instances in which information is lost, which will make it easier to develop a BCTS that is more comprehensive. It will be possible for us to suggest improvements to the system if we first implement accurate process and information flow mapping and then conduct an analysis of the level of granularity and traceability that is currently in place. These proposals aim to increase the level of detail that is currently present in the system, which will ultimately result in the development of a traceability system that is more extensive and complex. Because of this, it is anticipated that the environmental impact will improve, and greater circularity and sustainability will be promoted as a result.

Throughout the course of our inquiry, we will evaluate the level of granularity exhibited by the demo cases in DigInTraCE by using a variety of indicators, some of which include the external trace unit and the information update frequency, amongst others. This will make it possible for us to gain a more comprehensive understanding of the essential installations and/or measures that are required to improve the TS and achieve the results that are desired.

We developed a questionnaire that tries to cover all of these areas in order to collect the data necessary for mapping the information flow and the value chain as well as determining the extent to which information is available for the DigInTraCE demonstration cases.

Following this course of action, the questionnaire will be sent out to the relevant DigInTraCE partners, more specifically to those who are actively involved in the demo cases. Each participant will have individualised support sessions in order to provide further clarification on the questionnaire's questions and objectives, as well as to assist them in addressing any challenges they may encounter while completing the questionnaire. These sessions will also be conducted in order to help them address any challenges they may encounter while completing the questionnaire.

The responses that partners provide to this questionnaire will make it easier to evaluate the level of granularity that is present in the demo cases. As a direct result of this, we will be able to develop the preliminary comprehensive mapping of our traceability systems, which will include both the procedural and informational aspects. In addition, we will be able to provide our preliminary recommendations concerning the installation of sensors, taking into account our discoveries in relation to the identification of points where information is lost.

This deliverable will be updated on a regular basis throughout the entirety of the project in order to reflect any changes or updates that are made as a result of newly acquired information. The subsequent versions of this deliverable, version 2 and the final version, will be available after the completion of the 24th month (v2) and the 48th month (final version), respectively.

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6. References

[1] "A Digital value chain Integration Traceability framework for process industries for Circularity and low Emissions by waste reduction and use of secondary raw materials (proposal)." [Online]. Available: https://www.digintrace.eu/

[2] X. Zhang and L. Ling, "A Review of Blockchain Solutions in Supply Chain Traceability," *Tsinghua Sci Technol*, 2023, doi: 10.26599/TST.2022.9010030.

[3] S. Ni, X. Bai, Y. Liang, Z. Pang, and L. Li, "Blockchain-based traceability system for supply chain: potentials, gaps, applicability and adoption game," *Enterp Inf Syst*, vol. 16, no. 12, 2022, doi: 10.1080/17517575.2022.2086021.

[4] T. C. Du, V. S. Lai, W. Cheung, and X. Cui, "Willingness to share information in a supply chain: A partnership-data- process perspective," *Information and Management*, vol. 49, no. 2, 2012, doi: 10.1016/j.im.2011.10.003.

[5] M. E. Porter, *Competitive advantage : creating and sustaining superior performance*. New York : London: Free Press ; Collier Macmillan, 1985.

[6] C. Coursaris, K. Hassanein, and M. Head, "Mobile technology and the value chain: Participants, activities and value creation," *Journal of Business Science and Applied Management*, vol. 3, 2008, [Online]. Available: https://www.researchgate.net/publication/26518923

[7] S. K. Dubey, R. Singh, S. Singh, A. Mishra, and N. Singh, "A Brief Study of Value Chain and Supply Chain," *A Brief Study of Value Chain and Supply Chain*, no. September, 2020.

[8] T. Craig, "SUPPLY CHAIN GRANULARITY." Accessed: Oct. 04, 2023. [Online]. Available: https://supplychainminded.com/supply-chain-granularity/

[9] S. Santana and A. Ribeiro, "Traceability Models and Traceability Systems to Accelerate the Transition to a Circular Economy: A Systematic Review," *Sustainability (Switzerland)*, vol. 14, no. 9. MDPI, May 01, 2022. doi: 10.3390/su14095469.

[10] "BS EN ISO 9000-2015 - TC."

[11] Keyence, "What is Traceability?" Accessed: Sep. 29, 2023. [Online]. Available: https://www.keyence.com/ss/products/marking/traceability/basic_about.jsp

[12] M. Laskowski and H. Kim, "Uses of Blockchain in Supply Chain Traceability (slides)." [Online]. Available: http://blockchain.lab.yorku.ca

[13] P. Olsen, "Food traceability in theory and in practise," 2017.

[14] P. Olsen and M. Aschan, "Reference method for analyzing material flow, information flow and information loss in food supply chains," *Trends in Food Science and Technology*, vol. 21, no. 6. 2010. doi: 10.1016/j.tifs.2010.03.002.

[15] T. van Norden, "Identifying critical traceability points and elements of organisation and technology for the traceability system The case of breeders and feed companies of the Dutch pork supply chain," 2018.

[16] P. Olsen and M. Borit, "The components of a food traceability system," *Trends in Food Science and Technology*, vol. 77. Elsevier Ltd, pp. 143–149, Jul. 01, 2018. doi: 10.1016/j.tifs.2018.05.004.

[17] K. Demestichas, N. Peppes, T. Alexakis, and E. Adamopoulou, "Blockchain in agriculture traceability systems: A review," *Applied Sciences (Switzerland)*, vol. 10, no. 12, pp. 1–22, Jun. 2020, doi: 10.3390/APP10124113.

[18] S. Haber and W. S. Stornetta, "How to time-stamp a digital document," *Journal of Cryptology*, vol. 3, no. 2, 1991, doi: 10.1007/BF00196791.

[19] S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," 2008. [Online]. Available: www.bitcoin.org

[20] J. M. Song, J. Sung, and T. Park, "Applications of Blockchain to Improve Supply Chain Traceability," in *Procedia Computer Science*, Elsevier B.V., 2019, pp. 119–122. doi: 10.1016/j.procs.2019.11.266.

[21] J. Sunny, N. Undralla, and V. Madhusudanan Pillai, "Supply chain transparency through blockchain-based traceability: An overview with demonstration," *Comput Ind Eng*, vol. 150, Dec. 2020, doi: 10.1016/j.cie.2020.106895.

[22] F. Tian, "An agri-food supply chain traceability system for China based on RFID & blockchain technology," in *2016 13th International Conference on Service Systems and Service Management, ICSSSM 2016*, 2016. doi: 10.1109/ICSSSM.2016.7538424.

[23] J. Lin, A. Zhang, Z. Shen, and Y. Chai, "Blockchain and IoT based food traceability for smart agriculture," in *ACM International Conference Proceeding Series*, 2018. doi: 10.1145/3126973.3126980.

[24] M. P. Caro, M. S. Ali, M. Vecchio, and R. Giaffreda, "Blockchain-based traceability in Agri-Food supply chain management: A practical implementation," in *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany, IOT Tuscany 2018*, 2018. doi: 10.1109/IOT-TUSCANY.2018.8373021.

[25] K. Salah, N. Nizamuddin, R. Jayaraman, and M. Omar, "Blockchain-Based Soybean Traceability in Agricultural Supply Chain," *IEEE Access*, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2918000.

[26] R. Kamath, "Food Traceability on Blockchain: Walmart's Pork and Mango Pilots with IBM," *The Journal of the British Blockchain Association*, vol. 1, no. 1, 2018, doi: 10.31585/jbba-1-1-(10)2018.

[27] S. Figorilli *et al.*, "A blockchain implementation prototype for the electronic open source traceability of wood along the whole supply chain," *Sensors (Switzerland)*, vol. 18, no. 9, 2018, doi: 10.3390/s18093133.

[28] H. Hasan, E. AlHadhrami, A. AlDhaheri, K. Salah, and R. Jayaraman, "Smart contract-based approach for efficient shipment management," *Comput Ind Eng*, vol. 136, 2019, doi: 10.1016/j.cie.2019.07.022.

[29] J. H. Tseng, Y. C. Liao, B. Chong, and S. W. Liao, "Governance on the drug supply chain via gcoin blockchain," *Int J Environ Res Public Health*, vol. 15, no. 6, 2018, doi: 10.3390/ijerph15061055.

[30] I. Haq and O. Muselemu, "Blockchain Technology in Pharmaceutical Industry to Prevent Counterfeit Drugs," *Int J Comput Appl*, vol. 180, no. 25, 2018, doi: 10.5120/ijca2018916579.

[31] Archa, B. Alangot, and K. Achuthan, "Trace and track: Enhanced pharma supply chain infrastructure to prevent fraud," in *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST*, 2018. doi: 10.1007/978-3-319-73423-1_17.

[32] T. Bocek, B. B. Rodrigues, T. Strasser, and B. Stiller, "Blockchains everywhere - A use-case of blockchains in the pharma supply-chain," in *Proceedings of the IM 2017 - 2017 IFIP/IEEE International Symposium on Integrated Network and Service Management*, 2017. doi: 10.23919/INM.2017.7987376.

[33] S. S. Kamble, A. Gunasekaran, and R. Sharma, "Modeling the blockchain enabled traceability in agriculture supply chain," *Int J Inf Manage*, vol. 52, Jun. 2020, doi: 10.1016/j.ijinfomgt.2019.05.023.

[34] S. Yousefi and B. Mohamadpour Tosarkani, "An analytical approach for evaluating the impact of blockchain technology on sustainable supply chain performance," *Int J Prod Econ*, vol. 246, Apr. 2022, doi: 10.1016/j.ijpe.2022.108429.

[35] P. Dutta, T. M. Choi, S. Somani, and R. Butala, "Blockchain technology in supply chain operations: Applications, challenges and research opportunities," *Transp Res E Logist Transp Rev*, vol. 142, Oct. 2020, doi: 10.1016/j.tre.2020.102067.

[36] S. Kamble, A. Gunasekaran, and H. Arha, "Understanding the Blockchain technology adoption in supply chains-Indian context," *Int J Prod Res*, vol. 57, no. 7, 2019, doi: 10.1080/00207543.2018.1518610.

[37] European Commission, "Legal and regulatory framework for blockchain." Accessed: Oct. 25, 2023. [Online]. Available: https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-blockchain

[38] P. Michelman, "Seeing beyond the blockchain hype," *MIT Sloan Manag Rev*, vol. 58, no. 4, 2017.

[39] J. L. Zhao, S. Fan, and J. Yan, "Overview of business innovations and research opportunities in blockchain and introduction to the special issue," *Financial Innovation*, vol. 2, no. 1. 2016. doi: 10.1186/s40854-016-0049-2.

[40] A. Castor, "A (Short) Guide to Blockchain Consensus Protocols." Accessed: Oct. 02, 2023. [Online]. Available: https://www.coindesk.com/markets/2017/03/04/a-short-guide-to-blockchain-consensus-protocols/

[41] Coinbase, "What is 'proof of work' or 'proof of stake'?" Accessed: Oct. 02, 2023. [Online]. Available: https://www.coinbase.com/learn/crypto-basics/what-is-proof-of-work-or-proof-of-stake

[42] IBM, "What are smart contracts on blockchain?" Accessed: Oct. 02, 2023. [Online]. Available: https://www.ibm.com/topics/smart-contracts#:~:text=Next%20Steps-,Smart%20contracts%20defined,intermediary's%20involvement%20or%20time%20loss.

[43] L. Li *et al.*, "A Blockchain-Based Product Traceability System with Off-Chain EPCIS and IoT Device Authentication," *Sensors*, vol. 22, no. 22, Nov. 2022, doi: 10.3390/s22228680.

[44] M. M. Aung and Y. S. Chang, "Traceability in a food supply chain: Safety and quality perspectives," *Food Control*, vol. 39, no. 1. Elsevier BV, pp. 172–184, 2014. doi: 10.1016/j.foodcont.2013.11.007.

[45] T. Kelepouris, K. Pramatari, and G. Doukidis, "RFID-enabled traceability in the food supply chain," *Industrial Management and Data Systems*, vol. 107, no. 2, pp. 183–200, 2007, doi: 10.1108/02635570710723804.

[46] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," *Future Generation Computer Systems*, vol. 29, no. 7, pp. 1645–1660, 2013, doi: 10.1016/j.future.2013.01.010.

[47] N. G. Markatos and A. Mousavi, "Manufacturing quality assessment in the industry 4.0 era: a review," *Total Quality Management and Business Excellence*, vol. 34, no. 13–14. Routledge, pp. 1655–1681, 2023. doi: 10.1080/14783363.2023.2194524.

[48] J. Qian, B. Fan, X. Wu, S. Han, S. Liu, and X. Yang, “Comprehensive and quantifiable granularity: A novel model to measure agro-food traceability,” *Food Control*, vol. 74, 2017, doi: 10.1016/j.foodcont.2016.11.034.

[49] A. F. Bollen, C. P. Riden, and N. R. Cox, “Agricultural supply system traceability, Part I: Role of packing procedures and effects of fruit mixing,” *Biosyst Eng*, vol. 98, no. 4, pp. 391–400, Dec. 2007, doi: 10.1016/j.biosystemseng.2007.07.011.

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Annexes

Annex I (Ethics Approval)

Brunel University London

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

28 September 2023

<u>LETTER OF APPROVAL</u>

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 16/10/2023 AND 25/09/2024

Applicant (s): Dr Nikolaos Grigorios Markatos Dr Kyriakos Kandris

Project Title: DigInTraCE (Horizon Europe)

Reference: 44842-LR-Sep/2023- 47248-2

Dear Dr Nikolaos Grigorios Markatos

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- **The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.**
- **Please ensure that you monitor and adhere to all up-to-date local and national Government health advice for the duration of your project.**

<u>Please note that:</u>

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to any conditions that may appear above.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- If your project has been approved to run for a duration longer than 12 months, you will be required to submit an annual progress report to the Research Ethics Committee. You will be contacted about submission of this report before it becomes due.

Simon Taylor

Professor Simon Taylor

Chair of the College of Engineering, Design and Physical Sciences Research Ethics Committee

Brunel University London

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Annex II (Participant Information Sheet)

PARTICIPANT INFORMATION SHEET

Brunel University London

<u>Study title</u>

DigInTraCE Questionnaire

<u>Invitation Paragraph</u>

You are being asked to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me/us if there is anything that is not clear or if you would like more information.

Take time to decide whether or not you wish to take part. Thank you for reading this.

<u>What is the purpose of the study?</u>

The study is conducted as part of the "WP2, Task 2.1 : Methodologies for digital tracing across value chains" of the HORIZON Europe project DigInTraCE. The purpose of the study is to understand the demo cases of the DigInTraCE project and map them with more detail.

<u>Why have I been invited to participate?</u>

You were selected to be invited to this study because you are affiliated with the DigInTraCE project and are involved in the studied demo cases of the project. Your expertise and involvement in this sector make your input valuable to our research.

<u>Inclusion Criteria:</u>

Participants must be employees or representatives of companies that are actively involved in the DigInTraCE project.

Participants must be at least 18 years old.

<u>Exclusion Criteria:</u>

Companies or individuals that are not involved in the DigInTraCE project or do not possess relevant information about the demo cases of the project.

Participants below the age of 18.

<u>Do I have to take part?</u>

As participation is entirely voluntary, it is up to you to decide whether or not to take part. If you do decide to take part, this information sheet and the consent form will be part of the relevant questionnaire. If you decide to take part you are still free to withdraw at any time up until 25/09/2024 and without having to give a reason.

<u>What will happen to me if I take part?</u>

Your participation in this research project involves completing an online survey, and it is entirely remote, requiring no visits to any physical locations like university premises, laboratories, hospitals, or schools. The study will span from October 16th , 2023, to September 25th , 2024. During this period, your sole responsibility is to provide accurate and honest responses to the survey questions. There are no traveling expenses associated with your participation, as it is entirely online. Your input in this survey is essential accurately mapping the value chains of DigInTraCE project, and we expect you to dedicate the estimated time required to complete the survey thoughtfully and thoroughly. Your participation is voluntary, and you can withdraw from the study at any time without providing a reason.

<u>Are there any lifestyle restrictions?</u>

No

<u>What are the possible disadvantages and risks of taking part?</u>

Participating in this research study primarily involves completing an online survey, which carries minimal risks and disadvantages. However, it's important to note that as with any online activity, there may be some potential privacy and security risks associated with sharing information over the internet. To mitigate these risks, we take data security seriously and have implemented measures to protect your information. Your responses will be treated with the utmost confidentiality, and your personal data will not be disclosed or published. Additionally, participation in this study is entirely voluntary, and you have the right to withdraw at any time. If you have any concerns about privacy or data security, please feel free to contact us, and we will address your questions and concerns promptly.

<u>What are the possible benefits of taking part?</u>

Beyond contributing to the accurate and advanced digital tracing across value chains, your organization can also gain from the forthcoming results. If you wish, we can share aggregated results with you for use in the development of your business strategy, research and development (R&D) purposes, or any other applications you may find suitable.

<u>What if something goes wrong?</u>

In the unlikely event that something goes wrong during your participation in this research study, please rest assured that there are measures in place to address any issues or concerns:

Data Security: Your data is treated with the utmost confidentiality and is stored securely. If you have concerns about data security, please contact us immediately, and we will address your questions and investigate any issues promptly.

Withdrawal: You have the right to withdraw from the study at any time without providing a reason. If you choose to withdraw, your data will be removed from the study's dataset. The deadline for data withdrawal is September 25th , 2024. Please contact Nikolaos Markatos (Nikolaos.markatos@brunel.ac.uk) or Kyriakos Kandris (Kyriakos.kandris@brunel.ac.uk) to request data withdrawal.

Privacy Concerns: If you have privacy concerns or believe your personal information has been mishandled in any way, please contact us, and we will investigate and rectify the situation to the best of our ability.

Ethical Oversight: This research study is conducted following ethical guidelines and regulations. If you have concerns about ethical matters, you can reach out to the research ethics committee or relevant authorities.

Your well-being and data security are of paramount importance to us. If you encounter any issues or have concerns during your participation, please do not hesitate to contact us, and we will take appropriate actions to address them. Your feedback is highly valued, and we are committed to ensuring a safe and ethical research environment.

Will my taking part in this study be kept confidential?

We take the required actions to assure all the participants information and collected data provided for DigInTraCE will be kept secure based on Data Protection Act 2018 and the EU General Data Protection Regulation (GDPR), and will only be accessible to the project consortium. Results from this research will be published for academic purposes and the project deliverables only and will be referred to anonymously, i.e. it will not be possible to trace back your organization or exclusive contribution.

All information which is collected about you during the course of the research will be kept strictly confidential. Any information about you which leaves the University will have all your identifying information removed. With your permission, anonymised data will be stored and may be used in future research – you can indicate whether or not you give permission for this by way of the Consent Form.

Will I be recorded, and how will the recording be used?

No.

What will happen to the results of the research study?

The results of the study will be included in the DigInTraCE deliverables. Also, aggregated results from this research might be published for academic purposes, as part of a journal/conference manuscript. The results will be referred to anonymously, i.e. it will not be possible to trace back your organization or exclusive contribution.

Who is organising and funding the research?

The project has received funding from the European Union's Horizon Europe research and innovation programme.

What are the indemnity arrangements?

Brunel University London provides appropriate insurance cover for research which has received ethical approval.

Who has reviewed the study?

This study has been reviewed by Brunel University Research Ethics Committee.

Research Integrity

Brunel University London is committed to compliance with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from the researchers during the course of this research

Contact for further information and complaints

Researcher name and details: Nikolaos Grigorios Markatos (Nikolaos.Markatos@brunel.ac.uk) and Kyriakos Kandris (Kyriakos.Kandris@brunel.ac.uk)

For complaints, Chair of the Research Ethics Committee: Prof Simon Taylor (simon.taylor@brunel.ac.uk)

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Annex III (Questionnaire)

Raw Material composition

Category	Question	Answer	Example
Primary Raw Materials	What are the primary raw materials used in the manufacturing process of the product? Please list them.		
	Please provide a brief description of the composition of each primary material (e.g., wood species, metal types, plastic polymers).		

	Are any of these materials certified as sustainably sourced (especially biological materials) or environmentally friendly? If yes, please specify the certification(s) and criteria.		
Recycled or Secondary Materials	Do you incorporate any recycled or secondary materials into production? If yes, which materials, in what percentage (if known) and what is the source?		
	How do you ensure the quality and safety of recycled materials used in your products?		
Corporate sustainability	Do you ask your suppliers for certtification or other business standards before purchasing from them?		

<u>**Transportation of Materials**</u>

Category	Question	Answer	Example
Transportation Mode	What transportation modes are used to bring raw materials to your manufacturing facility? Please, specify for each raw material separately.		*e.g., Truck, vessel, airplane, post, courier, etc.*
	What type of delivery is it?		*(Distribution terminal or directly from supplier, either)*

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Transportation distance	What is the average distance between your manufacturing facility and the primary sources of raw materials?		
	Do you source any materials from international suppliers? If yes, what is the average transportation distance for these materials?		
Transportation frequency	How often do you receive shipments for each of the identified raw materials?		*(e.g., daily, weekly, monthly)*
	Are there seasonal variations in transportation frequency due to factors like demand or availability of materials?		
Packaging and handling	How are the raw materials packaged for transportation?		*(e.g., bulk, pallets, containers)*
	Are there any special handling requirements during		

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	transportation to ensure material integrity and reduce waste?		

Storage and Handling

Category	Question	Answer	Example
Unpacking and handling	Are there any specific protocols for the safe handling of raw material upon their arrival at your facility?		
	Do you use any specialized equipment for handling and storing raw materials?		*(e.g., forklifts, pallet jacks)*
	How are raw materials inspected upon arrival for quality, damage, or discrepancies? Are there any guidelines or criteria followed? How are quality control checks recorded?		
Storage conditions	Where are raw materials typically stored within your facility?		
	Please describe the storage conditions for different types of raw materials. Are there any temperature, humidity, or light requirements?		
	Do you have systems in place to monitor the quantity and condition of stored materials in real-time?		
Packaging waste management	What types of packaging materials are typically used for each shipment?		*(e.g., cardboard, plastic, wood)*
	Are there any waste streams generated during the unpacking and storage process? How are they managed or disposed of?		

	Do you monitor those waste streams? If yes, how are data being recorded?		
	Do you have aqcuired certifications for safe waste management and disposal?		

Manufacturing process

Category	Question	Answer	Example
General overview	Please provide a breakdown of the key manufacturing and assembly steps involved in your production.		
	Are there any standards in place covering any aspect of the manufacturing process?		
Water management	Describe water management practices, including any water treatment or recycling systems used to minimize consumption.		
Energy sources	Are there specific energy sources powering your manufacturing process?		
	Are renewable energy sources (solar, wind, etc.) integrated into your manufacturing process?		
	Could you provide an estimate of the percentage breakdown of your energy consumption (including renewables)?		
Waste generation and management	Please mention the types of waste generated at each manufacturing step.		
	What percentage of generated waste is sent for recycling, reuse, or appropriate disposal?		
	Do you have aqcuired certifications for safe waste management and disposal?		
Monitoring	Do you monitor water consumption, energy consumption, and waste generation? If yes, how are these data being recorded?		
Reporting and Transparency	How do you communicate your energy, water, and waste management efforts to stakeholders? Are there any published reports or metrics?		

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	Is there any compliance documentation and information required under Union law applicable to the product, such as the declaration of conformity, technical documentation or conformity certificates?		
	Is there currently a need to report any specific parameters/specification and if yes based on which regulations.		
Occupational health and safety (H&S)	Do you have aqcuired H&S certifications?		

Post-production

Category	Question	Answer	Example
Storage After Manufacturing	How do you store finished products after the manufacturing process is complete? Are there specific storage conditions or facilities?		
	What type of transport from process to packaging is used?		*(Not needed / Flow line / Fork-lift / By hand / etc.)*
Labeling	Is a label used, if so, what type?		*Clear text, barcode / Radio Frequency Identification number (RFID) / none / etc.*
	What information is included on product labels? Do you provide relevant environmental or sustainability information to customers?		
	Do your products carry any labeling certifications, such as eco-labels, indicating environmental attributes? If yes, which ones?		

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Packaging	What types of packaging materials are used to protect finished products during storage and transportation?		
	Do you implement reusable or returnable packaging solutions to reduce the environmental impact of packaging waste?		
End-of-life management	Do you offer options for customers to return packaging materials for recycling or reuse after purchasing products?		
	How do you facilitate the end-of-life phase for your products? Are there take-back programs, recycling initiatives, or partnerships in place?		
	Do you provide repair services for your products? How do you encourage customers to repair rather than replace?		

<u>Transportation of finished goods</u>

Category	Question	Answer	Example
Transportation of finished goods	How do you typically distribute your finished products to the next node in the value chain?		*(e.g., wholesalers, retailers, customers)*
	What modes of transportation do you use to move products from		

	your manufacturing facility to distribution centers or retailers?		
	How is the vehicle identified?		*(e.g., Registration number of vehicle or name and address. Etc.)*
	How is the shipment identified?		*(e.g. SSCC, transporter code, delivery code, freight code, etc.)*
	What is the average distance between your manufacturing facility and distribution centers or retailers?		
	If international transportation is involved, what is the average distance for these shipments?		

Internal Traceability

Category	Question	Answer	Example
Collection of raw materials	From whom are shipments of raw materials received?		*(Name and address for each raw material)*

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	How is each shipment identified?		*(SSCC, transporter code, delivery code, freight code, etc.)*
	If the received shipment is divided into logistic units (LUs), how is each LU identified? What type of code and media is used? Is this identifier discarded or recorded and kept?		
	What parameters are linked to each LU? How are they transmitted (on Label, Paper, Electronically, Other)? Are they recorded at reception?		
	If LUs are divided into trade units (TUs), how is each TU identified? What type of code and media is used? Is this identifier discarded or recorded and kept?		
	Can the producer link the LU-ID from the TU-ID?		
	What parameters are linked to each TU? How are they transmitted (on Label, Paper, Electronically,		

	Other)? Are they recorded at reception?		
	How is this raw material identified as it enters production?		
Application of ingredients and raw materials	Can the producer trace the ID of lot/batch from the identification of ingredients and raw materials? If the answer is yes, how is it linked?		*(No/Yes indirectly/Yes directly (ingredients and raw materials ID recorded under production)*
	Are the TUs of raw materials split up, joined together or kept as one during production?		
	What parameters are recorded to document the application of each raw material? How are they recorded?		*(on paper, punched into computer system, automated data collection, other)*
During production	How are the batches separated during production? 1 batch only or many in parallel? If many, are they ever mixed? Are these batches identified during production?		

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	Is this identifier retained or referred to after production?		
End of production	What type of lot/batch is used for finished product?		*(Daily, weekly, etc.)*
	How is the lot/batch identified?		
	What parameters are recorded for the finished production batch? How are they recorded; on paper, punched into computer system, automated data gathering?		
	Is the finished lot/batch split up, joined together or kept as one?		(Split up / joined together/kept as one)
Transportation of finished goods	What parameters are linked to a shipment of LUs? How are they transmitted (on Label, Paper, Electronically, Other)? Are they kept for own use only, given to the transporter, sent directly to the buyer, or sent to the buyer via the transporter?		

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	If collected amount is divided into LUs, how is each LU identified? What type of code and media?		*(Trip number / SSCC /none / etc. - Structured Barcode / RFID / Direct reference (label) / Indirect reference, etc.)*
	If LU is divided into TUs, how is each TU identified? What type of code and media?		*(Trip number / SSCC /none / etc. - Structured Barcode / RFID / Direct reference (label) / Indirect reference, etc.)*
	Can the producer trace the LU-ID from the TU-ID? If the answer is yes, how are LUs and TUs linked?		*Yes, LU-ID on each TU label*
	What parameters are linked to each TU? How are they transmitted (on Label, Paper, Electronically, Other)? Are they kept for own use only, given to the transporter, sent directly to the buyer, or sent to the buyer via the transporter?		